CLIMATIC SUITABILITY, INDOOR COMFORT AND HOUSEHOLD ENERGY CONSUMPTION : A STUDY OF SUBURBAN HOUSES IN ADELAIDE, SOUTH AUSTRALIA

by

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Thesis submitted for the degree of Doctor of Philosophy at the University of Adelaide.

Awarded June 1980

September, 1979.

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SUMMARY

This study of suburban houses in Adelaide endeavours to analyse their climatic suitability and provision of indoor comfort, relative to the energy consumption of the household. It was prompted by an apparent neglect of climatic considerations in domestic design, planning and construction and the consequent need to achieve indoor comfort only by considerable use of energy for heating and cooling and/or alterations and modifications to the house. Although Adelaide enjoys a "Mediterranean" type climate, it is subject to greater extremes in some respects, than any other capital city in Australia. While most urban development has taken place during an era of cheap, readily available fuel there was no need for house-designers, builders and occupants to consider or concentrate on "energy efficiency". The onset of the "energy-crisis" of the (late) 1970's, with its rising fuel prices and possible fuel shortages is, however, likely to change attitudes. This study attempts to provide data on which such behavioural and attitudinal changes could be based.

House facade photographs, an interview/questionnaire schedule of 452 houses and a small temperature survey were used to collect data on the nature of the house and its occupants, priorities in its purchase, existing methods of achieving comfort, past and anticipated house modification, the householder's evaluation of its comfort and general attitude to, and knowledge of, climatic design principles. Data on the seasonal and annual consumption of electricity, gas and heating oil for the sampled householders were obtained from the South Australian energy supply authorities.

In addition, interviews and discussions with architects, building-designer and house-construction firms, real estate agents and business firms dealing

in such products as domestic air conditioning and ceiling insulation were completed. Information from such sources was integrated in order to evaluate the relative importance of the "climate factor" in the design, construction, sale, occupation and modification of Adelaide's houses. Other methods of evaluation included the development of an index of climatic suitability (the combined effect of several attributes of design and structure contributing to thermal performance), the analysis of householders' three-fold evaluations of the comfort of their homes, and the use of stepwise regression procedures to develop operational models of household energy consumption.

It was thus shown that, both for houses of the past and in houses being built in the mid 1970's, low priority had been given to climatic suitability and indoor comfort in the processes of design and construction and in house sales or purchases. Consequently there was a relatively high level of weather-induced discomfort, householder dissatisfaction and house modification to ameliorate conditions. This was particularly evident in the recently-constructed houses of the sample (in which, for example, 50 per cent of householders were dissatisfied with room temperatures in summer, and, within five years of moving into the house, ceiling insulation, outside awnings and air conditioning had been added to 50, 31 and 28 per cent of houses, respectively). The degree to which annual energy consumption was shown to be related to the size of the house, the number and nature of occupants, the major appliances and amenities of the houses and the household income is also shown. Rather than consider climatic suitability and potential comfort during design, construction and purchase of a house, most householders preferred to rely on relatively costly rectification procedures and/or energy consuming appliances in order to achieve the desired level of indoor comfort. Among builders and salesmen, the importance of such factors as costs, tradition, sales appeal, room layout and appearance were stressed.

Given the desirability of improved thermal comfort and the necessity of conserving finite energy resources, methods of effecting change in Adelaide's housing and some of the practical difficulties and implications are discussed. It is concluded that energy-conservation measures in existing houses may be best achieved by the individual householder, but the acceptability of climatically-suited, comfortable and energy-efficient new dwellings depends on the efforts of the designers, planners and builders on the one hand and the real estate agents, lending authorities and house-buying public on the other.

DECLARATION

Except where otherwise acknowledged in the text, this thesis represents the original research of the author.

Jill Susan Kerby.

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to the numerous individuals and organizations who have advised, assisted and encouraged me in this project. It was begun in 1974 under the guidance of Mr Bruce Mason of the Department of Geography. After his retirement in 1975 and my twelve months' leave during 1976, the supervisory role was taken over by Dr Blair Badcock (Department of Geography) and Dr Ian Halkett (at first with the Department of Architecture, now with the South Australian Housing Trust). I am especially indebted to Ian, for his ready co-operation in the sorting out of practical and academic problems, his thoroughness with, and critical appraisal of numerous drafts and, above all, his friendly professionalism. Blair's advice on statistical and methodological problems was much appreciated, as were his assessments of earlier drafts. Mrs Ann Marshall, though not willing to act as supervisor, encouraged me from the outset and was always willing to discuss ideas and comment on written material. Dr Sandy Taylor was also generous with her time and advice.

Various organizations of Adelaide willingly provided data or assistance, without which the project would have foundered or have been incomplete. Mr Alan Hickinbotham commented on a draft of the Building Firm Questionnaire, provided addresses of his company's house-building activity from which part of the household sample was drawn, and continued to show an interest in the project. The Electricity Trust of South Australia, the South Australian Gas Company and the South Australian offices of five heating oil companies made data available on the energy consumed by individual households. I am particularly grateful to Mr John Hoepner (Electricity Trust) and Mr Kevin Boyle (S.A. Gas Company) who were so generous with their time. Valuable assistance was received from Mr John Moreland-Mitchell, of the Real Estate Institute of South Australia who organized the mailing of a questionnaire to real estate agents.

At various stages I profited from correspondence and discussion with Mr E.R. Ballantyne (CSIRO Division of Building Research, Melbourne), Mr A.B. and Mrs E. Coldicutt (Department of Architecture and Building, University of Melbourne), Mr D.J. Crossley (School of Australian Environmental Studies, Griffith University), Mr J.W. Drysdale (Experimental Building Station, Sydney) and Mr T. Wheeler (School of Environmental Design, Canberra College of Advanced Education). Many Adelaide architects and representatives of building and business firms, too numerous to name individually, also rendered assistance. To all these people, I express my thanks.

I am indebted to the members of the ancillary staff of the Geography Department. Mrs Anke Johnsen, Sandra Stevenson, Meng Stain and Miss Rebecca Duckworth assisted with typing. Chris Barrington, with help from Debbie Oakley, drafted and printed the figures and maps, and printed the large tables. Wence Sulda organised files, analysed the seasonal nature of household energy consumption and patiently helped me to disentangle the complexities of the computer. Robert Allan, a postgraduate student, extracted the data on household gas consumption from the S.A. Gas Company's microfilm records. Members of other University departments also assisted, namely Mrs Chris Klingner with computing, Stephen Duddy with architectural drawings and Phil Leppard with statistical procedures. The final typing was the combined efforts of Meng Stain, Anne Whicker, Jane Roberts and Joan Howe. The help of Anne and of Joan, supervisor of the computerized typesetting service, is gratefully acknowledged, particularly in the demanding last stages.

My gratitude is extended to Professor Graham Lawton, Professor Fay Gale and Mr Trevor Griffin, who, in their capacity as elected chairpersons of the Department of Geography made university research grant finance available, and permitted extensive postgraduate use of the facilities and expertise of the department. Additional financial support was provided by a Commonwealth Postgraduate Research Grant.

Finally, I wish to acknowledge the constant help and encouragement from my husband, Miles. He not only provided most of the financial support, but also assisted in many other ways, ranging from questionnaire design and proof-reading to housework and child-care. His patience and forebearance were remarkable, particularly as the project was interrupted by the births of Timothy and Pippa in March 1976 and November 1978, respectively. To our older boys, Richard and Nigel, I also express my thanks. Without the children the project may have been much easier, but far less meaningful.

Jill Kerby

Adelaide

September 1979.

CHAPTER 1

INTRODUCTION

Since earliest times, man has attempted to modify his environment. He has built artificial structures designed, on the whole, to provide protection from the elements and a degree of physical comfort often not available outdoors. Yet some of the dwellings of relatively primitive people were better suited to their local climate than many modern houses which rely more and more on technology to provide comfort.

Australia's climate, though generally not as severe as, for example, the Northern European winter, has sufficient variation, unpredictability, and periods of extreme heat or cold, wind or humidity to necessitate its consideration in building design and construction. But the typical suburban house of Australia shows little evidence of systematic response to climatic conditions, particularly in temperate areas. Most houses face the street, regardless of orientation, with little or no consideration given to the insulating value of building materials, to windows of sensible size and placement, to sun-shading devices, or to integrated outdoor living facilities and cross ventilation. Indoor comfort is achieved only by considerable use of energy for heating and cooling, or by alterations and modifications to the house.

This study aims, primarily, to determine the level of climatic suitability, indoor comfort and household energy consumption of Adelaide's suburban houses. Although many authors (such as Drysdale, 1959; Marshall, 1962; White, 1975; National Capital Development Commission, 1977; Jenkins and James, 1978) have discussed aspects of climate, comfort, energy and housing, no systematic data have been presented for Adelaide's housing. Adelaide, with its so-called "Mediterranean" climate, has particular requirements in that the winter months can be cold, wet and bleak, whereas heat waves are quite frequent during the summer[1]. This need for dwellings to cater for extremes of both heat and cold complicates the design problem, since there are both common points and conflicts between design principles for winter and summer comfort[2].

If it is assumed that the vast majority of Adelaide's houses, past and present, fail to adequately meet the basic criteria of suitability to the local climate and the indoor comfort of occupants, then it is necessary to find reasons for this neglect, clarify other, over-riding factors and discuss ramifications. Many of the reasons for neglect are related to the historical and cultural background of the Australian community. Australia is still basically a transplantation of European culture, and houses are usually no exception. They differ from European ones only by being larger in plan (an expression of affluence and the availability of space) and by being less well-insulated. Most house-styles in Adelaide[3], for example, originated from countries with quite different climates (such as villas from Europe and Tudor architecture from England) and even when modified for local use remained unsuited to their new environment. Even those styles originating from similar climates (such as the "bungalow" and "Mission" styles from California) struggled to retain their basic design and cohesion once built in Adelaide.

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1. Adelaide's climate is described in Chapter 2, pp. 21-22.
2. Climatic design principles are discussed in Chapter 6.
3. Adelaide's house-styles are described in Chapter 4.

It is also significant that Australia's development has taken place during the technological expansion of the 19th and 20th century. Increasing affluence (as a result of extensive natural resurces and a relatively small population) has encouraged an exploitive attitude to resource use, and the attitude that "more technology" is better. Australians have tended to accept (and prefer) technological solutions rather than "natural" ones (such as the use of energy for heating and cooling poorly designed buildings rather than the construction of improved designs). During the last two centuries the significance of domestic building has also changed, away from an original function and basic meaning as shelter, towards social acceptability, status and prestige[4], suggesting that any suitability of contemporary architectural fashion to the local climate could be little more than coincidental.

When these tendencies coincided with an era of cheap, readily available fuel there was no need for house - designers, builders and occupants to consider or concentrate on "energy efficiency". The onset of the "energy crisis" of the 1970's, with its rising fuel prices and possible fuel shortages is, however, likely to change attitudes. Although some energy savings can be achieved by such measures as more winter clothing (that is, accepting a lower indoor temperature), or more efficient thermal management of a house, Australians are not likely to be able (or willing) to reduce energy consumption solely by reducing their comfort standards or by radically changing their behaviour. Data on climatic suitability, indoor comfort and energy consumption, such as

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4. Cooper (1975,211) argues that in a hierarchy, extending from more basic needs to more specialised needs, from shelter, security, comfort, convenience through socialising, self expression and aesthetics, a more basic need must always take precedence over a more specialised one.

those presented in this study, are necessary in order to change current and future attitudes and practices of the many people concerned with "a house".

The research questions suggested by these notions are outlined in Figure 1.1 and illustrate the framework for this study. The underlying themes are three fold :

(i) Adelaide's housing fails to adequately meet the fundamental criteria of suitability to the local climate and the indoor comfort of occupants;

(ii) the importance of the "climate factor" varies according to the people and processes involved in the various stages of "a house" (the most common stages being choice of design, construction, sale, occupation and subsequent modification);

(iii) among architects, building designers, real estate agents, householders, air conditioning firms and others, knowledge[5] and understanding of the principles and practice of climatic design, comfort and energy efficiency is likely to be highly variable.

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5. Such information might include effective methods of keeping a house cooler during hot weather (interception of the sun's rays before they strike the house and/or reflecting them back, insulating the house to slow down the amount of heat that penetrates inside, and reducing the heat that does flow inside by some kind of cooling unit or by ventilation), the improvement in year-round climate control to be gained from a well-planned garden, or ways of improving the energy - efficiency of a household.

Figure 1.1 Framework of Systematic Investigation

MAJOR QUESTIONS	OTHER QUESTIONS	RESEARCH METHOD
How important is climate in the designing and building of houses in Adelaide?	Who designs and builds Adelaide housing? Where do the building ideas come from? What knowledge of local climate do builders have and use?	Architect, Building designer and Building Firm Interview Statistical and Media Information
How important is the climate aspect in selecting a house to buy?	What are the important considerations in house selection? cost? location? appearance? size? future comfort?	Householder's and Real Estate Questionnaires
How significant is climate once the house is being lived in? What level of energy consumption is necessary?	How satisfied are householders with the general level of comfort in their house? What action is taken to improve thermal comfort and to overcome deficiencies? How much energy is required for heating and cooling?	Householder's Questionnaire Business Firm Interview Energy data
Does the age, style, costs, design etc. of the house affect residents' a) behaviour and attitudes b) actual comfort?	How has house-building style changed in Adelaide over the years? How does this affect residents' actions, the internal temperature of the house, attitudes?	Photographic Record Analysis of Householder's Questionnaire Instrumentation
What is the general level of public knowledge regarding local climate and its relation to house comfort?	What methods are used to reduce discomfort in houses and for what reasons? What learning process from mistakes made? What feedback from clients to designers and builders? What public information is available on air conditioning, outside awnings, ceiling insulation and other products? Is improved education of the householder public desirable?	Parts of the Householder's Questionnaire and Building and Business Firm Interviews.

W H A T I S T H E B E S T H O U S E F O R A D E L A I D E ' S C L I M A T E ?

FIG. 1·1 FRAMEWORK OF SYSTEMATIC INVESTIGATION

After describing previous research on climatic suitability, indoor comfort and energy consumption (Chapter 2) and the methods employed in the collection and analysis of the data (Chapter 3), the role of climatic suitability and physical comfort in the processes of design and construction and in house sales or purchases are discussed in Chapters 4 and 5 respectively. A representative sample of occupied and householder - modified suburban houses are then evaluated for their climatic suitability (Chapter 6), indoor comfort (Chapter 7) and energy consumption of the household (Chapter 8). Data analysis from this household survey and information from planners, builders, salesmen and householders are then used in an attempt to identify the "best" house for Adelaide's climate and to generalise about the level of climatic suitability, indoor comfort and energy consumption in Adelaide (Chapter 9). Finally, the implications of attempts to improve climatic design of houses are considered (Chapter 10).

CHAPTER 2

PREVIOUS RESEARCH ON CLIMATIC SUITABILITY, INDOOR COMFORT AND HOUSEHOLD ENERGY CONSUMPTION

Any study which explores the relationships between climate, people and houses must draw on previous research from a variety of disciplines. In this study where the "climate factor" assumes a pivotal role, the interactions of climate with people and/or houses not only provide the main focus of attention, but also suggest an organizational framework for this chapter.

Aspects of the interaction between climate and people are discussed first. It is demonstrated that, despite comprehensive studies of thermal comfort and of "preferred temperature", and research into means of determining the level of discomfort in Australia and of presenting climatic data for use in building design, the nature of discomfort in South Australia, particularly in domestic buildings, is not well documented. Salient features of Adelaide's climate and the limited published studies of comfort in the home are used to indicate a possible frequency of conditions outside the "comfort zone" (below 19^{o}C or above 27^{o}C) on an average of 253 days per year in Adelaide's houses.

The second part of the chapter discusses aspects of the interaction between climate and houses. It is stressed that technical knowledge on the contribution of various attributes of house design and structure to thermal performance, indoor comfort and household energy consumption is readily available. Previous studies on energy costs and energy conservation in dwellings are also evaluated. The recent nature of these studies is emphasized, highlighting the many gaps still evident in Australian household energy data.

The interaction of climate, people and houses is discussed in terms of the emergence and practical application of climatic design and low-energy principles in Australian architectural and technical literature, followed by a discussion of the situation in South Australia, past and present. This historical perspective demonstrates that, although information on climatic design and energy- efficiency has been progressively accumulated and disseminated during the 20th century, practical application has (until recently) been relatively slow and limited. The "energy crisis" of the late 1970's is, however, prompting a revival of public interest in climatic design and the need to conserve energy.

The chapter ends with a description of empirical forerunners of the present study. They are divided into two types: studies which deal specifically with climatic suitability, indoor comfort or energy consumption of dwellings at various levels of applicability; and non-specific studies in which a consideration of these topics forms a part (usually small) of a larger study. It is shown that no previous empirical study has been completed in Australia which attempts to assess the climatic and comfort performance of dwellings, relative to their energy consumption.

Thermal Comfort and Climate

Since man is homeothermic, his body temperature must be maintained by physiological thermo - regulation (such as vasodilation, metabolic heat changes or evaporative regulation) and by behavioural thermo - regulation (such as the adjustment of clothing and the construction of dwellings). Research into thermal comfort has ranged from physiological studies (Court, 1948; Lee, 1956; Fanger, 1972) through subjective interpretations of physiological responses in order to define the "comfort range" (Bedford, 1950; Roberts, 1959; Griffiths, 1970; Auliciems, 1972), the study of the science of clothing (Newburg, 1949; Steadman, 1971; Nevins et al. , 1974), studies of acclimatisation and man's adjustment to thermal comfort (Irving, 1960; Edholm, 1966) to assessments of comfort in buildings (Bruce, 1960; Wyon, 1974). Most researchers agree that physical comfort differs markedly from one individual to another, depending on such factors as sex, age, metabolism, physique, clothing and rate of working (Macfarlane, 1958; Webb, 1959; Macpherson, 1965). In terms of human comfort, these differences between individuals are more marked than geographic ones.

Studies on Preferred Temperature

Although there are many examples of British and North American studies aiming to define the "comfort range" of temperature[1] (see Table 2.01)

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1. In recognition of the variability of human reactions to environmental conditions the American Society for Heating, Refrigeration and Airconditioning Engineers (ASHRAE) defines the comfort zone as a range of conditions in which at least fifty per cent of people will feel comfortable. An alternative "comfort range" preferred by some workers is $t_{w/tw} - t_{tc/c}$
where $t_{w/tw}$ is the transition temperature from "warm" to "too warm"
$t_{tc/c}$ is the transition temperature from "too cool" to "cool"
on the seven-point thermal sensation scale
much too cool
too cool
cool
neutral
warm
too warm
much too warm

there have been relatively few comfort studies in Australia, and most have been based on findings from a small group of subjects. For example, the first systematic enquiries into preferred temperature, undertaken by Drysdale (in association with Macfarlane, a physiologist) in Sydney, during 1947 to 1950, were physiological studies based mainly on three groups of five or six subjects under laboratory conditions at the Commonwealth Experimental Building Station (Drysdale, 1950a; Macfarlane, 1958)[2]. Nevertheless, results from these studies were subsequently used for several recommendations, such as the suggested optima of 18.5°C (65°F) dry bulb temperature for winter and 24.5°C (75°F) for summer which appears in the Experimental Building Station's definitive bulletin "Designing Houses for Australian Climates" (Drysdale, 1959, 33)[3]. Similarly, the study undertaken by Hindmarsh and Macpherson (1962) using daily-comfort "votes" for a twelve-month period was based on a sample of fourteen people seated in a Sydney tea-break room. Analysis of over 2,000 votes suggests the most generally preferred temperature to be 23°C (73°F) with a 2°C (3°F) seasonal difference. The value was largely independent of humidity. Wong (1967) reports similar results from his study of office workers in Sydney, but there is insufficient detail on subjects and methodology to permit critical appraisal.

The comprehensive nature of comfort-studies in non-temperate parts of Australia has varied: Wyndham's (1963) data for Weipa was based on a

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2. Even the original field survey (Drysdale, 1948a) in which office staff at Broken Hill, Townsville and Sydney kept personal records of the number of layers of clothing being worn and any changes made, and when perspiration dampened skin about the waist or thighs, was based on 12 to 20 subjects in each location: the limited data indicated that most people expressed discomfort at a dry bulb temperature of 85° to 86°F.

3. The third edition of this bulletin was published in 1975.

sample of sixteen males; surveys of daytime thermal preferences of the acclimatised white population of Batchelor, near Darwin (Macpherson, 1961) and their sleep disturbances from excessive warmth (Macpherson and Muncey, 1962) were described as "large scale", but there were less than fifty participants over one period of three months; Auliciems (1975) surveyed 600 Brisbane school children under classroom conditions in winter. In Port Moresby, Ballantyne et al. (1967) obtained assessments of thermal sensations from 34 subjects within the living rooms of their homes. The results of these studies are summarized in Table 2.01.

The best comparative study of non-tropical comfort in Australia, designed specifically to investigate thermal requirements in diverse geographic locations representing major population areas, appears to be that of Auliciems (1977), one of the few geographers actively engaged in human comfort research. Using the "comfort vote" technique, thermal preferences of students at six tertiary institutions of temperate Australia were obtained during the winter months of June to September (1975). Regression analysis led Auliciems to suggest that, for coastal locations, preferred temperatures were associated with neutrality changes of at least 1°C for every five degrees latitude. Thus suitable indoor design temperature (for winter) appeared to be 23°C for Brisbane (latitude 27°), 22°C for Perth (latitude 33°), 21°C for Adelaide (latitude 34°) and 20.5°C for Melbourne (latitude 38°).

Such relatively scant studies do, however, reinforce the inherent danger of applying the results of findings from small samples, or those obtained in other climates and locations, to a country's population or to different regions. Australian comfort data prior to 1963 were all obtained in Sydney. Although only one degree apart in latitude, the contrasting coastal locations of Sydney and Adelaide result in considerable differences in humidity. The South Australian climate is relatively dry: even though there is an average annual total of 39 days in Adelaide when the maximum temperature is at or near 30°C (86°F)[4], the average relative humidity in summer at the time of maximum temperature is 34 per cent (compared to 56 per cent in Sydney). Many studies have shown that "preferred temperatures" are largely independent of humidity (Bedford, 1948; Koch, 1963; Morse and Kowalczewski, 1968). Only above 25°C (77°F), a temperature higher than all but one of the preferred optimum temperatures of the studies shown in Table 2.01, does the effect of humidity on the feeling of warmth become noticeable. Thus, in the relatively "dry" climate of Adelaide, Drysdale's (1950a, 18) contention that dry bulb temperature alone can be used as an indicator of comfort if the humidity lies between 20 and 60 per cent at the hot time of the day, is far more acceptable. Dry bulb temperature is the simplest of instrumental measurements, in direct contrast to the complexities of the recommendations of Olgyay's bioclimatic chart (Olgyay, 1963), or the stringent recommendations of air conditioning manuals.

The only extensive research on ascertaining comfort temperatures in South Australia is the largely unpublished work of the Department of Architecture, University of Adelaide. For five years (1961 to 1965 inclusive) data on thermal environment preferences were collected from male architectural students during lecture weeks. A total of 6,300

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4. Drysdale (1950a, 19) suggests 86-88°F dry bulb as a threshold for discomfort (for persons seated at rest, or performing light tasks).

TABLE 2.01

EMPIRICAL STUDIES OF PREFERRED TEMPERATURES FOR HUMAN COMFORT

(OVERSEAS AND AUSTRALIAN)

Place	Subjects	Comfort Range	Optimum	Author
U.S.A.	Sedentary, clothed adults	Winter 60-74°F ET Summer 64-79°F ET	66°F ET 71°F ET	Houghten and Yagloglou (1923a, 1923b) Yagloglou and Drinker (1928)
Britain	Light industrial workers	58-68°F DB 57-63°F ET	65°F DB 61°F ET	Bedford (1936, 1948)
Britain	Office workers	64-72°F DB		Black (1954)
Britain	Light industrial workers		67°F DB 63°F ET	Hickish (1955)
Britain	Sedentary, multi-racial audiences		70°F DB 65°F ET	Angus and Brown (1957)
U.S.A.	Office workers		Summer 71°F ET Winter 68°F ET	A.S.H.V.E. (1959)
S.Africa		70-76°F DB		Wyndham (1957)
Singapore	Europeans	74-84°F DB	76°F ET	Ellis (1953)
England	Secondary school-children		59-63°F DB	Auliciems (1972)
Sydney	Indoor workers (laboratory study)	72-82°F DB	72-74°F DB	Drysdale (1948a, 1950a), Macfarlane (1958)
Sydney	Office workers		73°F DB	Hindmarsh and Macpherson (1962)
Batchelor, N.T.	Acclimatized white population		Daytime 77°F DB Night 76°F DB	Macpherson (1961) Macpherson and Muncey (1962)
Wiepa, N.T.	Canteen workers		77°F DB	Wyndham (1963)
Port Moresby, TPNG	Acclimatised Caucasian subjects		78°F DB	Ballantyne et al. (1967)
Sydney	Office workers		Winter 70-72°F DB Summer 73-74°F DB	Wong (1967)
Brisbane Perth Adelaide Melbourne	University students		23°C DB 22°C DB (70°F) 21°C DB 20.5°C DB	Auliciems (1977)
Adelaide	Architecture students		18°C ET 17-22°C DB (68-72°F)	Baranikova, unpub. (1974) Bryzgalin and Logethetis, unpub. (1977)

Note: Temperatures are quoted in the same scale as used in the original research. Conversion from the Fahrenheit to Celsius scales by the Commonwealth Bureau of Meteorology occurred on September 1st, 1977.

valid "comfort-vote" forms were analysed[5]. The two main findings were, first, preferred dry bulb temperatures ranged from 17.3°C (the average "vote" during third term, 1963) to 22.3°C (the average during first term, 1960 and 1962); second, there was about a two-month delay in the time from the peaks and depressions of the average monthly temperatures to the peaks and depressions of the average preferred temperatures. During the winter terms, the average preferred temperature ranged from 17.8°C to 19.7°C, approximately one to two degrees lower than the 20.6°C neutrality suggested by Auliciems (1977, 87) from his analysis of thermal preferences of university students in Adelaide.

Human Comfort Indices and Maps

The "comfort vote" technique relies, for effectiveness, on large-scale samples, controlling at least some of the intervening variables (such as age, sex, metabolism, previous activity or clothing level). Thus, in the last half century a large number of human thermal exchange indices[6] have emerged which attempt a quantitative assessment of heat or cold stress. Macpherson (1962) reviews well over 70 publications (dealing with assessment of the thermal environment) and shows that the more important indices conform to a restricted number of types. Although all indices suffer from certain limitations (such as neglecting one or more of the human thermal exchange processes or lacking strict applicability to any one individual), Tuller (1974, 4) points out that

5. Comfort votes were rejected from female, sick or overseas born students: data collection, analysis and interpretation are contained in two reports held by the Department of Architecture (Baranikova, 1974; Bryzgalin and Logethetis, 1977).

6. Human thermal exchange takes place via the processes of radiation, convective (sensible) heat flux, evaporative (latent) heat flux and conduction.

one of their main advantages for geographers is their ability to provide a convenient method of evaluating and comparing the climatic differences from place to place.

Until the late 1960's Australia has not been part of the trend towards man-oriented climatic classifications and the development of bioclimatic maps (Maunder, 1970,200). Despite some early attempts (see Table 2.02) mapping of human comfort in Australia is well behind that of other countries such as Germany (Byrnes, 1973, 3) and New Zealand (Maunder, 1962; Tuller, 1977). Thus the various areas covered by studies in the last decade, namely Morse and Kowalczewski (1968), Hounam (1970) and Auliciems and Kalma (1979) for the whole of Australia, Gentilli (1978) for the state of Western Australia, and Auliciems (1976) for the Moreton region of Queensland are all important contributors to the discussion of climate and comfort factors on different types of human activity. Since there is no comparative study on Adelaide and South Australia, the data on the possible level of discomfort must be extrapolated from the few Australia-wide studies listed in Table 2.02. In the earlier studies of heat discomfort (prior to 1960) Adelaide falls outside the "uncomfortable zone" of central and northern Australia. Later studies suggest a period of between nine and twenty nine "uncomfortably hot" days in an Adelaide summer. Most calculations have tended to ignore or underrate the effect of particular building design on indoor thermal performance: Marshall's (1972) is the only study (in Australia)[7] which

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7. Ballantyne et al. (1967) also obtained thermal comfort data from subjects inside the living room of their homes in Port Moresby; four different types of construction were examined (asbestos - cement, weatherboard, aluminium and concrete - block) which significantly affected the preferred and transition temperatures of the occupants.

TABLE 2.02

INDICES AND ZONES OF HEAT DISCOMFORT IN AUSTRALIA

Author	Method of Calculation/Zonation	Adelaide's value or position
Barkley (1934)	Each length of an inch of vapour pressure above or below the limits of comfort (.2 to .5 inch) in each month was reckoned as a unit of discomfort.	Below the zero-line, i.e. not experiencing (on the average) more than two consecutive weeks of uncomfortable weather.
Marshall (1957)	Brick houses (in Adelaide) likely to be uncomfortable if mean daily dry bulb temperature exceeds 82°F (indoors) and 80°F (outdoors).	Daily mean dry bulb temperature of 80°F or more likely to occur 20 times in the most usual Adelaide summer.
Gaffney (1959)	Mean monthly effective temperature (derived from mean monthly dry and wet bulb temperatures and wind speeds).	Not applicable (calculations for Perth and Kimberleys only: Perth only slightly uncomfortable during January and early February).
Venville (1959)	Used thermal strain equations and indexes developed by Lee (1947, 1956), based on air temperature, vapour pressure, air movement, rate of work and level of clothing.	Adelaide (with thermal strain of 3 at 9 a.m. in January, 4½ at 3 p.m. in January) in the relatively comfortable zone of southern Australia.
Wickham (1961)	Uncomfortable conditions likely to occur in a house during the greater part of the day when the Effective Temperature 80°F (at 3 p.m.) outside, and 78°F inside.	On average, nine days per year when the Effective Temperature is equal to or greater than 80°F (thus outside the "uncomfortable" region of Australia in which 80°F E.T. is exceeded on more than 25 days/year).
Morse and Kowalczewski (1968)	Formula, showing relationship between air temperature, heat production rate (activity), air velocity and clothing. Recommend temperature of 78 to 80°F as upper limit in offices (depending on clothing) between 8 a.m. and 6 p.m. Maximum recommended for night-time conditions is 75°F.	Adelaide offices need cooling for 6 to 8% of the day-time hours in an average year, and cooling for 7% of the night-time. Higher percentage for light factory work, or housework. Eight per cent of the year uncomfortable in Adelaide (a total of 29 days), thus cooling can be justified.
Hounam (1970)	If "Relative strain index" (a calculation incorporating air and wall temperature, wind movement, vapour pressure, metabolic rate and the effect of clothing) equal to 0.3 indoors at 3 p.m., then day is "uncomfortable".	Adelaide has RSI of 0.3 at 3 p.m. on eight days per year, thus in the zone of Australia where air conditioning can be considered optional.
Auliciems (1976)	Heat stress and cold stress, used to calculate net thermal stress (in kcal. hr^{-1}) using climatic data, metabolic rates, activity levels and clothing.	Not applicable: mapped for Moreton region (of Queensland).
Gentilli (1978)	Over forty indices used, ranging from "dry bulb temperature, January 900 hours" to "mean basic sweat rate at rest in shade at 900 hours," and "Main Climatic Stress Factors".	Not applicable: mapped for Western Australia only.

attempts directly to relate temperatures inside and outside the house to the level of comfort registered by the occupant.

Presentation of Climatic Data for Use in Building Design

Although the use of various indices of human thermal exchange does permit regional comparison, most indices require computation and interpretation bey nd the scope of the majority of building designers. When climatic data are considered for planning, the most usual source of information is the nearest office of the Bureau of Meteorology[8]. Such climatological and meteorological data, however, need interpretation so that the information can be readily applied to a particular site or type of building. The more notable attempts to present climatological data for use when designing buildings for Australia, are summarized in Table 2.03. Although there are many useful ways of estimating discomfort from heat, the best method of quantifying cold discomfort for a season is probably that of "degree days"[9]. O'Brien (1970) shows Adelaide to have

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8. Occasionally specific on-site meteorological / climatic data are obtained, such as for an Environmental Impact Statement (as for the proposed Redcliff Petrochemical Scheme, S.A.) or prior to the planning of a major regional centre (as for the proposed new town of Monarto, S.A.)

9. "Degree Days" are the accumulated departures of mean temperatures on successive days from some reference temperature (negative departures for space heating, sometimes called "heating degree days", and postive departures for air conditioning, sometimes called "cooling degree days"). Thus the advantage of the degree-day concept (over dry bulb temperature, for example) is that its value is proportional to the energy required to provide comfort. If the mean temperature for a winter day is 10°C and the reference value is 18.3°C (65°F), then 8.3 degree days are added to the previous total, usually summed for a year. The median number of heating degree days for American households is about 4,500 (Newman and Day, 1974).

TABLE 2.03

VARIOUS METHODS OF PRESENTING CLIMATOLOGICAL DATA FOR USE IN BUILDING DESIGN

Author	Method of Calculation/Presentation	Type of Information resulting
Keough (1951)	Bureau of Meteorology data (climatic averages, rainfall statistics etc) organised into usable form for 83 meteorological stations in Australia.	In Adelaide, the average number of days when the maximum equals or exceeds 100°F is 11 days, 95°F on 20 days, 90°F on 30 days, 85°F on 41 days.
Comm. of Australia, Dept of Works (1959)	Mean annual frequency charts (matrix) of dry bulb, wet bulb and effective temperatures for capital cities and selected major towns.	For Adelaide, on 16½ years of observation A dry-bulb temperature of 85°F or more occurs 36 times/year A wet-bulb temperature of 65°F or more occurs 33 times/year An effective temperature of 75°F is exceeded on 33 times per year.
Ashton (1964)	Frequencies, and durations (hourly, daily, monthly) of dry, wet bulb temperatures and effective temperatures for 18 representative meteorological stations.	In Adelaide, in January, a dry bulb temperature between 92.0 and 92.9°F occurs 10.1 per cent of the hours between 8 a.m. and 6 p.m.
Spencer (1965a, 1965b, 1965c)	Solar position and radiation tables for many Australian localities, providing angles and intensities of radiation on dates at monthly intervals for various surfaces.	At Adelaide (latitude 35°S) on December 22, vertical surface facing north receives 865 BTUs per square foot per day, of which 284 is direct and 581 BTUs diffuse radiation.
Phillips (1948, Revised 1963)	Principles involved in finding the extent and direction of sunlight and shadows on buildings (the use of solar charts and shadow-angle protractor) and a series of charts for different hours and seasons for the latitudes of Australasia.	In order to exclude direct sunlight from a window facing northwest (at latitude 35°S) at all hours up to 5 p.m. from November to January, a horizontal sun-screen needs to give an angle of 35°S from the bottom of the glass to the lower edge of the screen.
Brealey (1972a)	Matrix of temperature probabilities, for each month at 3-hourly periods of the day, based on 10, 50 and 90 per cent exceeded values. Thermal comfort isotherms superimposed.	For Melbourne, transition temperature from neutral to warm (76°F) is likely to be equalled or exceeded on 10% of occasions at 12 noon for 6 months (mid-October to mid-April)
O'Brien (1970)	Heating Degree days for some Australian cities (base temperature 65°F): monthly and annual totals (with percentage annual variation) calculated from data for 1956-1964 (inclusive).	Adelaide: average winter temperature 53.1°F; annual total 2,302 degree-days (with 8% variation); coldest months June (351 degree-days), July (436), August (390).
Coldicutt, Coldicutt and Curzon-Siggers (1977b)	Graphical Method by which the designer can determine the need for solar control and at the same time design the appropriate control: shows the effectiveness and dimensions of shading devices and how to find the shadows cast by objects such as trees and buildings.	At 12 noon, on February 22nd, at latitude 35°S under clear sky conditions, the heat gain due to incident direct and diffuse solar radiation through a 3 mm thick plain glass window in a vertical wall, N 20°W, is 574 W/m^2.
Ballantyne (1975a); Walsh (1976a)	Meteorological information (dry-bulb temperature, direct and diffuse solar irradiance on a horizontal surface, wind velocity and cloud cover) for hourly intervals, over a period of several years, ranked to find frequency levels, and thus the nature of "extreme" weather for use in predicting indoor temperatures, and heating and cooling loads.	Selection of "reference" year (for use in estimating annual heating and cooling load) and of "critical" fourteen day periods of extreme combinations of temperatures and solar radiation levels.

an average of 2,302 degree-days (base temperature 18.3°C). The number of degree-days is a useful indicator of the requirements for home-heating (Institution of Engineers, 1977, 218) and indicates that almost continuous heating is required on the Adelaide Plains during the three winter months (June, July and August) which may extend into April-May and September - October[10].

Comfort in the Home

Much of the above research relates primarily to the typical "office worker" in air conditioned premises, or has been obtained from laboratory or single room studies. Relatively few researchers have investigated the domestic situation in which there is usually a large variation in indoor environmental conditions and in the level of comfort tolerance. A house is subject to all kinds of disturbances: occupants raise and lower blinds, open and close windows, leave outside doors open and add heat by cooking and lighting. Unlike most office situations, however, there is relative freedom to move about, change activity or adjust the amount of clothing. Thus Williamson and Coldicutt (1974) argue that comfort can be achieved with any combination of humidity and environmental temperature that falls within the zone defined for various activities in summer and winter (see Figure 2.1). Despite the flexibility of the proposal (well suited to the domestic situation) the main disadvantage is its reliance on "environmental temperature", a combined effect of air temperature and the mean radiant temperature of

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10. Personal communication, J. Edwards, Shell Heating Oil, S.A., 24th May 1978. The concept of "heating degree days" is particularly useful in the heating oil industry to predict customer delivery requirements.

surrounding surfaces[11]. Williamson and Coldicutt suggest that the permissible frequency of occurrences of conditions outside these limits should, on the average, be no more than one per cent, or four days per annum outside the "warm" and "cold" limits respectively. Without actual measurements or further computer simulations of dwellings typical of Adelaide[12] it is extremely difficult to specify the frequency of conditions in Adelaide houses outside these limits. Yet, because it is an established criterion (Coldicutt and White, 1977,4) that thermal comfort is not possible where the air dry bulb temperature and the mean radiant temperature differ by more than 5°C, it may be acceptable to interpret "environmental temperature" as "dry bulb temperature" for the majority of conditions.

Housing and Comfort in Adelaide

Since this study relates to human comfort in the Adelaide region, some description of the salient features of the climate is necessary. Most of the state of South Australia has been classified as dry-summer subtropical or Mediterranean by Koppen, Thornwaite and other climatologists. Opinions of, and statements on the climate vary:

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11. Since the mean radiant temperature of surrounding surfaces is difficult to measure, National Capital Development Commission (1977, 8), which adopts Williamson and Coldicutt's recommendations, suggest that building designers can usually take account of the effect of radiant temperatures by considering the types of surfaces and the mass of building elements. A maximum summer comfort temperature of 27°C is utilised later in the Commission's report, though it is not really clear whether environmental or dry bulb temperature is meant.

12. Nearly all computer programs developed in Australia require simultaneous hourly values of such data as solar radiation, wind speed, dry bulb temperature, cloud cover and relative humidity. Climatic data in this form exist only for Melbourne and Hobart: in other places, data on solar radiation are insufficiently comprehensive (Coldicutt, 1978a, 116).

> ...Briefly, the basic features of the South Australian climate are hot, dry summers with relatively mild nights and cool, but not severe winters with most rainfall occurring during the months of May, June, July and August.
>
> (South Australian Year Book, 1967, 3)

> ...the Adelaide region is described as having a dry, warm temperate climate, but every summer has sufficiently hot to very hot days to make the majority of houses uncomfortably warm.
>
> (Twopenny, 1966, 78)

> ...to develop a South Australian "house type", the harsh climate of our State must be taken into account.
>
> (Hannaford, 1966, 66)

> Blessed with a mild climate, we are an outdoors - loving people and we need convenient outdoor spaces, adjacent to our houses, for everyday living and playing.
>
> (Architect's Advisory Service, 1970,12)

> S.A. has a natural advantage with its exceptionally dry climate which lends itself to evaporative air conditioning systems.
>
> (Chappel, 1973c, 9)

The best description of the climate features (relative to building) of the Adelaide region is, however, provided by Marshall (1973, 5-6):

> Winter
>
> (a) Temperatures never extremely low, but some form of heating needed most of the time from April to October.
>
> (b) Winds strong, especially from the westerly sector.
>
> (c) Rain often comes with strong winds, particularly from the west. This can be readily evaluated from a simple diagram[13] (Figure 2.2).
>
> (d) High percentage of winter sunshine, and low winter sun will penetrate into rooms from north windows.

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13. Marshall's diagram has been replaced by one for Adelaide, showing rainfall associated with different wind directions (Figure 2.2). It demonstrates that most rain falls when the wind is from south-west to north-east.

Summer

(a) A great deal of clear weather with moderate temperatures, in which indoor comfort depends on disciplining the amount of radiant energy coming in from the roof, walls and exposed glass.

(b) Occasional, unpredictable "heat waves" of great intensity but usually short duration. Reasonable comfort without positive means of cooling is helped by almost total exclusion of radiation. In a sense, these are emergencies and require emergency measures[14].

(c) Rapid fall of temperature with the arrival of the cold front, usually with a strong south or west wind. To cool the house down to normal, good through ventilation is necessary.

Figure 2.3 has been up-dated from Marshall's original diagram (Marshall, 1955, 14) using the same method of calculation and concept of "consecutive hot days" (namely those in which the running mean maximum temperature is above 35^{o}C (95^{o}F) for at least three days[15]) on the premise that such conditions will result in indoor discomfort in all houses and extreme discomfort in some. The graph shows that the summers prior to 1943 were, on average, more extreme than those over the last 36 years. Two reasons are possible: first, this period of relative coolness in Adelaide's climate may be reflecting a world-wide trend (particularly in the northern hemisphere) towards a cooler climatic regime since 1951 (Australian Academy of Science, 1976; Brinkman, 1976; Pittock et al., 1978) or second, the method of recording temperatures has changed in some way. In fact, on 1st August, 1947, at the Adelaide Bureau of Meteorology, the Greenwich stand for temperature recordings

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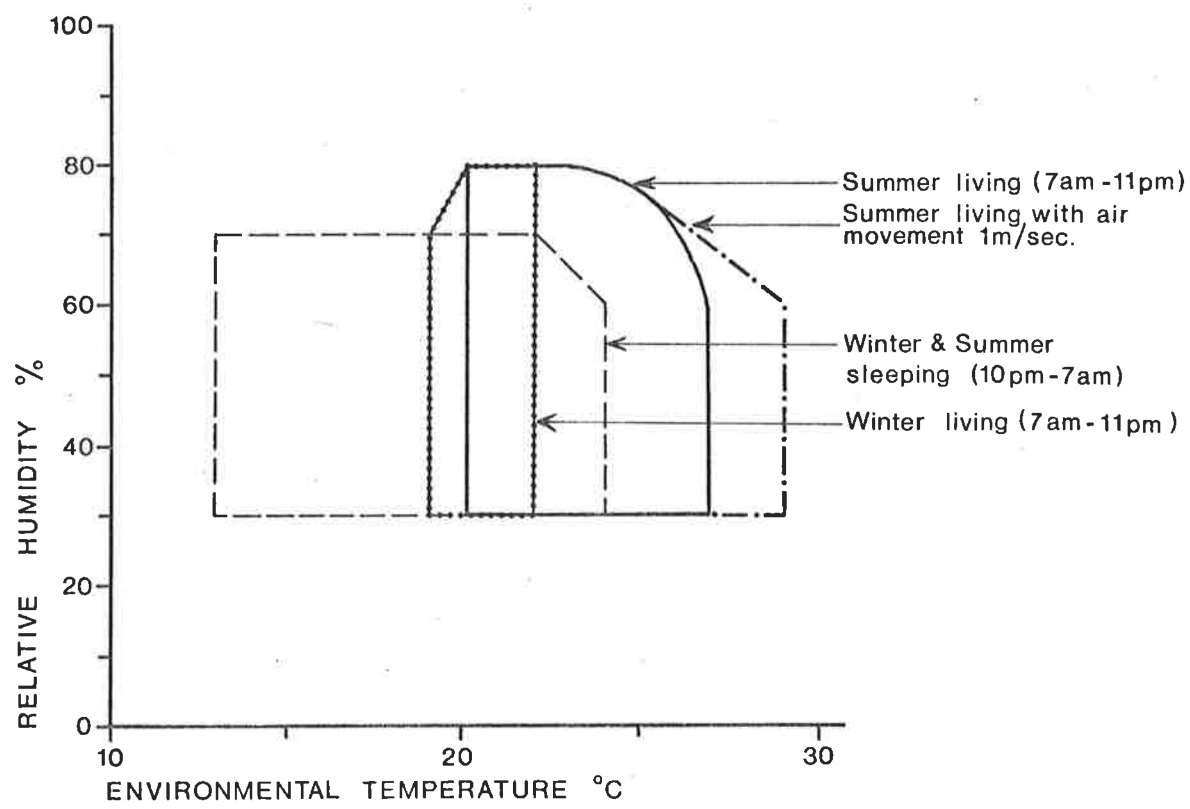
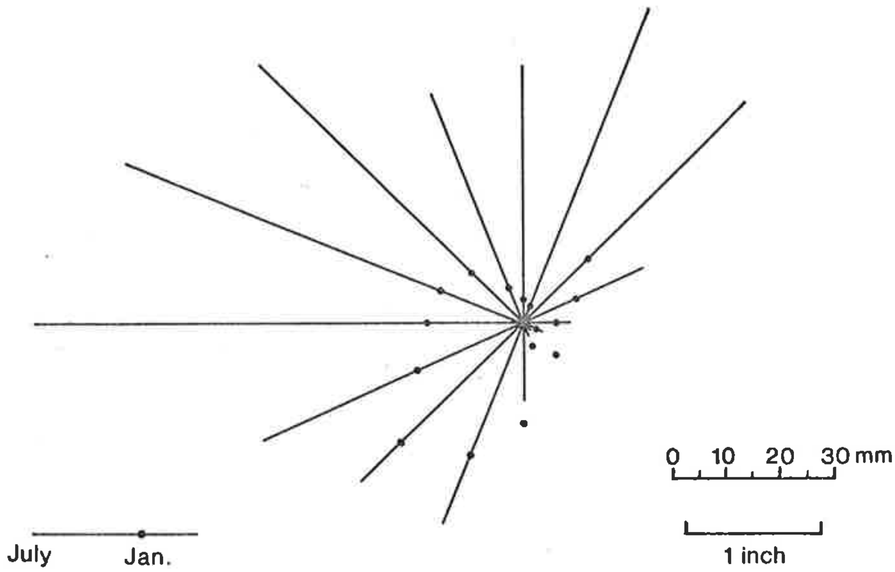
14. A reference to Figure 2 "Relative severity of summer heat. Adelaide 1921-1951" is omitted here because an up-dated version has been included in this study (see Figure 2.3).

15. Marshall (1955, 14) argues that more than one cool day is necessary to break a sequence of hot days, since one cool day in the middle of a hot spell is not sufficient to reduce house temperatures significantly.



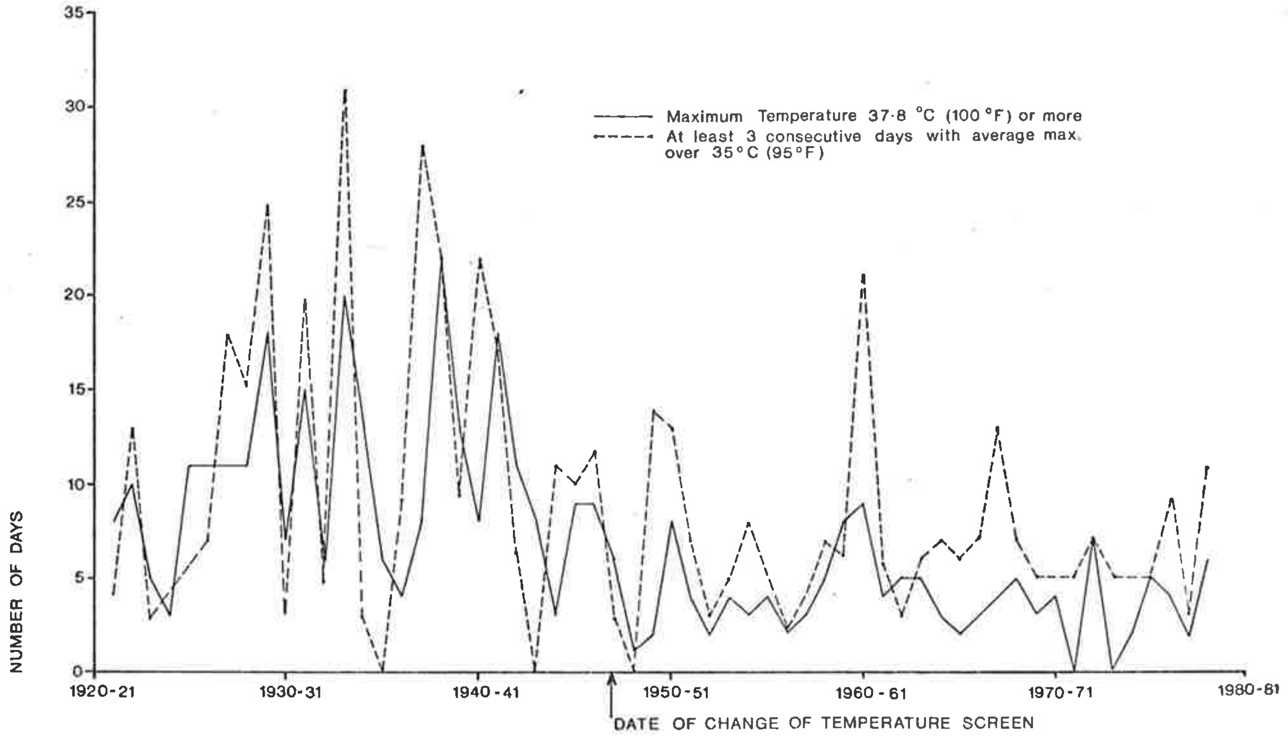
SOURCE: Williamson & Coldicutt (1974,3)

FIG. 2·1 DOMESTIC COMFORT ZONES



SOURCE : unpublished data, Bureau of Meteorology, Adelaide

FIG. 2·2 ANALYSIS OF RAINFALL ASSOCIATED WITH DIFFERENT WIND DIRECTIONS AT ADELAIDE (based on 1911-'60 incl.)



SOURCE: updated, from Marshall (1955, 4), using Bureau of Meteorology data

FIG. 2·3 RELATIVE SEVERITY OF SUMMER HEAT. ADELAIDE 1921-22 TO 1978-79 was replaced by the Stevenson Screen. Fortunately, maximum and minimum temperatures had been recorded in both instrumental shelters since 1887, and comparison revealed that, during the warmer months (October to April), the maxima recorded in the Stevenson Screen were approximately 2 to 2 1/2°F lower than the maxima recorded in the Greenwich stand[16]. Thus a more realistic picture might be obtained if each of the values on Figure 2.3 prior to 1947 was reduced by two.

Conclusion

In summary, research on "preferred temperatures" in Australia has shown that dry-bulb temperature can be used alone as an indicator of physical comfort. The optimum "preferred temperature" indoors for Adelaide appears to lie within the 19° - 21°C range (66° - 70°F) for winter and 20° - 22°C range (68° - 72°F) for summer. The transition from neutral to warm occurs at about 24°C (75°F) - lower if doing light work, such as housework - and the transition from neutral to cool occurs at about 19°C (66°F)[17]. The recommended night-time maximum is 24°C (75°F).

Various criteria and methods of calculation have been used in studies of the zonation of physical comfort in Australia. In many of these the effects of particular building designs on indoor thermal performance have

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16. The Greenwich stand, open at the back, and rotated to avoid direct sunlight provided less protection from indirect and ground radiation. Thus the minima were slightly higher in the Greenwich stand.

17. Ballantyne (1975b, 9) states that subjective assessments of thermal sensation are usually recorded on a seven-point scale, ranging from "much too cool" to "much too warm". The central three sensations (cool, neutral and warm) may be deemed to be acceptable conditions, whilst the two at each end of the scale are deemed unacceptable.

been ignored or underrated. This makes it difficult to apply the findings of published studies to studies of Adelaide housing. One possible exception is the research of National Capital Development Commission (hereafter NCDC, 1977, 9) which recommends an environmental temperature of 27°C as the upper level of comfort in summer (daytime) and 19°C as the lower limit in winter, and uses computer programs to predict indoor temperatures of typical detached houses of different types of construction and orientations of main glass areas. Such calculations (NCDC, 1977, 29-30) show the delayed relationship between outdoor and predicted indoor temperature: for example, if the outdoor temperature reaches 28°C, then all houses with unshaded glazing to the living area will also reach an internal temperature of 28°C. In Adelaide, the dry-bulb temperature at 3 p.m. is likely to equal or exceed 28°C (82°F) on an average of 42 days per year: thus the indoor temperature could exceed 27°C (the upper level of comfort) on 42 days. However, the actual indoor temperature reached, and the length of time during the afternoon and early evening that the house is uncomfortable (above 27°C) depends primarily on orientation of the main glass areas, shading of glazed areas, insulation, nature of floor and wall material and use of ventilation. In contrast, on an average of 211 days per year the outdoor temperature in Adelaide does not reach the lower level of comfort selected by NCDC (1977, 9) of 19°C (66°F). This suggests that supplementary heating may be required for a maximum period of seven to eight months (April to October - November). Once again, the level of heating required depends on the design and structure of the house.

Climatic Performance, Thermal Properties and Energy Consumption of Buildings

General Research

Comprehensive discussions of thermal properties and performance of buildings are presented by Billington (1952), Van Straaten (1967), and Chalkley and Cater (1968). The need for, and methods of, controlling the indoor environment by the materials and design of the building itself (thus improving thermal comfort, and reducing the need for supplementary heating and cooling) are well documented. This documentation has been in terms of general considerations (Weston, 1959; Muncey, 1964; Phillips, 1965; Burberry, 1970); solar radiation and sunlight (Hutchinson and Cotter, 1955; Langer, 1960; Phillips, 1960; Building Research Institute, 1963); sun protection (Editorial Staff of Sunset Books, 1961; Wilson, 1962; Danz, 1967); and daylighting (Paix, 1962; Brierley, 1971, 1972). From this research, indicators and standards regarding daylight and sunlight have been developed both in Great Britain (for example, Great Britain, Ministry of Housing and Local Government Bulletin No. 5, 1964) and in Australia (Phillips, 1948; Australian Department of Labour and Immigration Industrial Data Sheets A2, L2; and Coldicutt *et al.*, 1977b). Such publications permit designers to find the extent and direction of sunlight and shadows on buildings, calculate the availability of daylight outdoors and indoors, and to design the type of shades required. Surveys of a sociological nature (Walker, 1972; Longmore and Ne'eman, 1974) show that most people appreciate sunshine indoors, and may even tolerate thermal discomfort or lack of view in order to obtain the benefits from sunlight.

Thermal Behaviour of Buildings

The temperatures inside buildings have been investigated in many parts of the world (Billington, 1952; Givoni and Hoffman, 1966; Van Straaten, 1967; Loudon, 1968). Four case studies illustrate the genre. Dunham (1960) evaluated the temperature regulation ability of the courtyard house. Raychaudhuri et al. (1965) show that, of 32 occupied dwellings in New Delhi of similar plans and design specifications, but with eight different orientations, those facing southeast and south have a better indoor climate throughout the year. Richards (1954) investigated thermal conditions inside similar dwellings of different materials and forms of construction in South African climates. Ballantyne and Spencer (1972) show, for housing in Port Moresby, that while orientation does not make a great difference to average house temperature, it does to individual rooms, and that acceptable conditions can be achieved with effective ventilation and restriction of direct solar radiation.

These, and other studies, demonstrate the complex interaction between the design and structure of the whole building and the internal temperature regime. The earliest long-term investigation in Australia, aimed to disentangle some of these complexities in the thermal behaviour of dwellings was that of J.W. Drysdale of the Commonwealth Experimental Building Station (hereafter CEBS and now EBS), North Ryde, and published in a series of documents (Drysdale, 1947a, 1947b, 1947d, 1948b, 1948c, 1949, 1950b, 1950c). Field work started in January 1946 with temperature measurements inside and outside experimental huts in different climatic areas of Australia, and was later broadened to record temperatures that occurred in occupied houses: further hypotheses were tested at Ryde with the aid of thermal model stuctures. Thus the effect of weight of construction, pitch of roof, insulation of ceiling, ventilating the roof space, heating systems, nature of floor, size of windows and orientation could be investigated. A number of the important guidelines that emerged are summarized best in Drysdale (1959), "Designing Houses for Australian Climates", and in the Station's series of Notes on the Science of Building (NSB). However, recommendations from this and other research usually need to be interpreted for Adelaide conditions. In Chapter 6, each attribute of the house contributing to thermal performance (listed below) is discussed separately, the consequences for Adelaide design and construction outlined, and the climatic suitability of the sampled dwellings evaluated. The attributes contributing to thermal performance are

* orientation and siting (particularly of main glass areas)
* material and colour of outer walls
* material, pitch and colour of roof
* floor material
* height of ceiling and insulation
* window size, placement, protection
* self-shading, verandahs
* vegetation
* ventilation, infiltration

The use of artificial heating and cooling is discussed in Chapter 7, in which the physical comfort of the sampled dwellings is described and assessed. Research on the use of energy for domestic heating, cooling and other purposes is discussed in the following section of this chapter.

Energy Costs and Energy Conservation in Buildings

Most Australian homes were built in a time when the supply and price of energy were of little consequence. Events in the northern hemisphere over the last six years, particularly the Arab oil embargo of November 1973 and the subsequent rapid increase in oil prices set by the Oil Petroleum Exporting Countries (OPEC), have prompted increasing public awareness of energy issues, research activity into energy use in the built environment, efforts by many overseas governments to introduce measures aimed at reducing energy consumption, and a plethora of publications on energy - efficient buildings[18].

Since information on the thermal performance of buildings based on extensive monitoring is difficult and expensive to obtain, much Australian research has concentrated on the development of techniques, particularly mathematical models, to predict indoor temperatures, estimate heating and cooling loads and calculate annual energy costs. For reliable comparisons of alternatives the use of high speed, large capacity digital computers is necessary (Coldicutt, 1978a, 103). Various computer programs which have been developed are summarized, with examples of their use, in Table 2.04. Although limited in some way by lack of information or climatic data, or lack of long-term testing of the accuracy of the predictions against actual buildings, they are the only available tools for the comparison of the performances of buildings, and thus essential for progress in the reduction of energy use in buildings.

Energy Conservation Measures. Since the energy required to build a typical brick veneer dwelling in Australia has been shown to be only about five per cent of the service energy used in its lifetime, taken as

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18. A conference on "Energy Conservation in the Built Environment" organised by the Department of Environment, Housing and Community Development in Sydney in March 1978 attracted a wide range of papers on topics ranging from computer calculations of thermal performance of buildings to legal obstacles to solar energy use in buildings.

TABLE 2.04

COMPUTER CALCULATIONS OF THERMAL PERFORMANCE OF BUILDINGS: AUSTRALIAN PROGRAMS AND EXAMPLES

Name of Program	Organization	Description	Examples of Use
SUSTEP (modified from STEP)	CSIRO Division of Building Research, Melbourne (Calculation technique outlined by Muncey, 1953b; Muncey et al., 1970 and modified by Scanes, 1974)	Response factor method to calculate indoor temperatures (or heating and cooling loads and energy consumption) for any particular building using actual climatic data (takes account not only of the thermal resistance of the various parts of the structure, but also of their thermal capacity, so that thermal storage effects are allowed for).	1. to calculate effect of floor, wall material (and other factors) on the thermal performance, of panelized construction (Gupta and Spencer, 1970) 2. to evaluate role of incident solar energy in determining heating and cooling requirements of three typical Australian dwelling types (Walsh, 1976a, 1976b) 3. to calculate annual index of uncomfortably hot and uncomfortably cold conditions for various types of building envelope (Ballantyne, 1975a)
TEMPER	CSIRO Division of Mechanical Engineering, later used jointly with Dept of Construction, Canberra	Simulates the internal temperatures of any given building according to varying climatic conditions, internal loads and heating and cooling equipment: later adapted to indicate energy consumption.	1. to predict indoor temperatures of conventional detached house with unshaded living room glazing facing various orientations (NCDC, 1977)
TEMPAL	Department of Architecture and Building, University of Melbourne (developed by Coldicutt et al.)	For zones differing in requirements predicts environmental temperatures, heating and cooling loads and annual energy requirements of building based on hourly information of actual or modified climatic data.	1. cost-value analysis of an uninsulated conventional detached house compared to a solar improved version (in Melbourne) (Williamson and Coldicutt, 1974) 2. to compare ten variations of the elements of construction (and five variations for most of these, such as proportion of glazing) for a "solar house" in a typical Melbourne year (Coldicutt, 1978b)

forty years (Ballantyne, 1975b), there is obviously a great need for energy-conservation measures in the service energy area[19]. Research in the northern hemisphere has concentrated primarily on conservation of energy required for heating in terms of the shape of the building (Page, 1974), double glazing, insulation, and improvements in heating (and cooling) equipment (Berg, 1974; Shell, 1974; Rosenberg, 1975; Socolow, 1976). The possible saving in energy consumption of a cold-climate country by the "economic optimum" of insulation in all houses, and the use of double glazing has been estimated at fifty per cent (Hirst and Moyers, 1973; Anon, 1974). An energy conservation program implemented in a multi-storey building of New York (reduced lighting and changes in building operating hours and methods and thermostat settings) achieved a reduction of 54 per cent in energy consumption for the summer (Lammers et al., 1978). Grants and incentives made by overseas governments to encourage energy conservation in the built environment are most commonly for the installation of devices which assist energy conservation such as double glazing, draught prevention, insulation of walls, floors, roofs and ducts and heating system improvements (Mineral Wool Manufacturer's Association of Australia, 1976). Government initiatives include education and information (such as the "Save It" campaign of the British Government), technical measures (for example, the "Canadian Code for Energy Conservation in New Buildings"), subsidies and taxes (such as the New Zealand government's interest-free loan, over four years up to $400, for the purpose of retrofitting existing buildings with thermal insulation to improve thermal performance), and legal requirements (such as minimum levels of thermal insulation for new housing in some states of U.S.A.).

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19. Cole (1977, 405) points out that it is also important to realise that the architectural decisions of the building form and fabric establishes a pattern of energy consumption that is carried forward for decades.

In comparison, the Australian Government has no such schemes or promotion campaigns, and only recently have some State governments considered the introduction of mandatory insulation requirements for new housing, (particularly Government housing) and planners started to design new buildings with sunlight/shadow as a major consideration.

The problems of poularising energy conservation among Australians and the social consequences of energy policy decisions are comprehensively discussed by Crossley (1977b, 1979a, 1979b). In the past a home owner considering a heating or cooling installation would have approached a government instrumentality or a fuel supplier (who have a vested interest in energy consumption[20]) or a commercial firm (whose survival depends on sales of equipment). Such patterns are difficult to change.

Various non-Government organizations and statutory authorities have been responsible for research and publicity into energy-efficient dwellings for temperate Australia[21]. Most have been aware of the sometimes conflicting demands of the seasons. Although most energy is consumed for space-heating (rather than space cooling)[22] the temperate climate is

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20. There has, however, been a tendency for major oil companies in America and Australia to purchase interests in solar equipment manufacturing firms (Blazevic, 1979).

21. Particular examples include the National Capital Development Commission (Canberra), the Department of Architecture and Building (University of Melbourne), the Division of Building Research (CSIRO, Melbourne) and some energy authorities (such as the Electricity Trust of South Australia).

22. A report of the Institution of Engineers (1977) shows that the percentage of the annual household energy budget used for space heating is approximately 38 per cent of the total for warmer temperate cities (such as Perth) increasing to 60 per cent for colder cities (such as Canberra, Hobart).

such that summer comfort must also be considered and care taken to ensure that design measures which aid the penetration of solar heat in winter do not also contribute to heat gain in summer. Hence some kind of summer-winter compromise is usually necessary when designing and evaluating low-energy housing (Wheeler, 1977; Coldicutt and White, 1977). Material currently available (mid 1979) of a technical and non-technical nature for the householder, examples of which are the bulletin of NCDC (1977) and the publications of the Electricity Trust of South Australia (1978a, 1978b), are directed primarily at those about to build a new home.

Household Energy Use: Patterns and Attitudes. Relatively little is known about the ways in which Australians use energy in their homes. Overseas studies have included research into the American energy consumer by Newman and Day (1975), energy consumption in the typical American home (Maadah and Maddox, 1976) and in a residential community (Grot and Socolow, 1974), and the effect of intermittent occupation[23] of United Kingdom dwellings on domestic energy consumption (Desson, 1976). Comprehensive studies of electricity consumption in New Zealand housing have been undertaken (Blakeley and Cook, 1974; New Zealand Department of Statistics, 1976). There is no comparable comprehensive study of energy use in Australian dwellings to date (mid-1979), although some data are available on the percentage of energy used for space heating, water heating and other uses (Institution of Engineers, 1977), on energy use in Canberra detached houses (NCDC, 1977) and in Brisbane

23. Desson (1976, 2) specifies intermittent occupation as that resulting from part- or full-time working adults : non-working housewives (who spent an average of 19 hours a week from home) were assumed to represent a group of households with "continuous" space heating.

(Crossley, 1978) and on average household expenditure on fuel and power for the home (Australian Bureau of Statistics, 1977, 1978). The present study attempts to fill some of the large gaps evident in Australian household energy data.

Efforts to make householders more aware of the energy they consume and of the total impact that their personal actions make on the nation's energy resources have been widespread overseas (Crossley, 1977b) and in Australia (Smallternatives, 1977). Ballantyne (1977, 21) explains how to calculate one's "Personal Energy Quotient": namely the estimated consumption of purchased primary energy of a given household for a given calendar year divided by the number of members of that household. It is expressed in gigajoules (GJ) of primary energy equivalent. He suggests that the average Australian PEQ for 1975 was about 70 GJ (a figure similar to some European countries and about half that in U.S.A., whilst in India the average PEQ is about 3 GJ). Surveys of householders' attitudes to energy consumption and conservation have been carried out in the United Kingdom (Phillips and Nelson, 1976), in the United States (United States, Federal Energy Administation, 1976), in New Zealand (Phillips, 1976) and in Brisbane, Australia (Crossley, 1977a). These surveys demonstrate

* the relationship between the pattern of energy use and income
* the constraints by such factors as the type of house ownership, structural or mechanical features of the house, or lack of knowledge about alternative practices
* the wide range of individual attitudes about energy conservation issues
* the fact that people's attitudes on energy conservation do not necessarily carry through to their actions

Solar Energy in Housing. Many people perceive the only solution to the "energy crisis" to be a change from fossil fuels to renewable energy sources (such as sun, wind, waves). In discussing the use of solar energy, the distinction is usually made (by architects and others) between:

(a) "passive" systems[24] (the "back-to-roots" approach) which aims to reduce the house's energy budget by the subtleties of house orientation, insulation and fenestration, and to use solar energy for heating without the addition of special equipment; and

(b) "active" systems (the "plumbing" approach) in which solar collectors are installed to capture solar energy and this is conveyed by some means to the space to be conditioned or to an energy store. (In this type the heat-transfer fluid may be either air or water, the latter having the potential of being used for both heating and cooling).

Home-owners' manuals are available for both types of approach, such as the use of thermal insulation to reduce energy costs (Townsend and Colesby, 1975), "retrofitting" an existing house (Adams, 1975; Murphy, 1976), designing and building "solar" houses (Anderson, 1976; Watson, 1977) and low-cost energy-efficient ideas for dwellings (Eccli, 1975; Prenis, 1975, 1977). Increasing attention is being paid, in Australia, to solar space heating, cooling and water heating (Morse et al., 1974; O'Hannessian and Andrews, 1976; Sheridan, 1978), particularly the potential for domestic solar hot water systems (Andrews, 1976).

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24. Coldicutt (1978b, 13) prefers "interactive" (for "passive") since it describes the series of systems and applications adapted by designers and users, all relying on the other for effectiveness.

However, there is still criticism of the lack of Government spending on solar energy research (Calder, 1978, 14), and competition between solar energy equipment manufacturers, insulation makers and the fuel companies and energy authorities (Royal Australian Institute of Architects, 1977a, 70).

There are numerous overseas examples of "autonomous" houses - self-sufficient, closed-circuit, ecological houses which aim to use the natural elements of sun, wind and rain to heat, cook and, by recycling refuse, to grow food (Howden , 1974a, 1974b; Matheson, 1975; Townsend, 1975a). Britain's first solar-heated council house was opened in 1975 (Townsend, 1976a) and other solar-heated housing for elderly couples is being evaluated (Anon, 1975). Large-scale developments are also starting to appear (Gordon, 1974): three new State office buildings in Sacramento, California were described as an "unprecedented effort" and the first example of energy efficiency and successful social architecture in sizeable public office buildings (Temko, 1977).

In contrast, there are relatively few examples of buildings in Australia designed and built primarily for "energy efficiency". Some exceptions include

* the "Solair experimental home" for north Queensland towns (Juppenlatz, 1961; Sheridan and Juler, 1961)
* the Solarch Experimental House built at Fowler's Gap, New South Wales (Ballinger, 1977)
* the "autonomous house" built by Sydney University students (Friends of the Earth , 1976)
* various houses designed by one particular firm of architects in

Melbourne (Royal Australian Institute of Architects, 1977b, 73-77)

* the competition - winning "Low Energy House" opened at Albury - Wodonga in March, 1978 (The Age, 1978)
* a house with solar space heating and solar heated water, converted from a popular Jennings home design, and built at CSIRO's Highett site (CSIRO, 1978c)
* an insulated house, with solar air conditioning and water tank as a heat bank at Forest Range, South Australia (Boucher, 1978)
* a pair of houses built by the South Australian Housing Trust, both based on a standard Trust design, but one modified to use sun and natural ventilation for heating and cooling, and both to be fully monitored for two years after occupation by similar families (Spiers, 1978).

In addition, houses designed for Monarto, the proposed new city 57 km from Adelaide , would have utilized both "passive" and "active" systems to maximise the natural energy sources of wind, rain and sun (Kelton, 1976).

Despite the wide range of technical knowledge, expertise and "case studies" relating to household energy consumption, very few empirical studies have been completed, particularly of the spatial and behavioural patterns in Australia. Furthermore, whatever the technical knowledge available, its real merit emerges only during widespread application. The practical application of climatic design and low- energy principles in Australian domestic building, past and present, is discussed in the following section.

Practical Application of Climatic Design and Low-Energy Principles

The building research studies described in the previous section must be considered in the context of Australian (and South Australian) design and construction, and the various influences on domestic architecture. The emergence and practical application of "design-for-climate" and "low energy" principles is of particular interest.

The building of permanent houses in Australia dates from the first European settlements in the late 18th Century. Architectural histories such as those of Joedicke (1961) and Freeland (1968) provide background information for the Western world and Australia respectively. The development of house-types overseas, from which Australian housing has largely evolved is discussed by Rapoport (1969). He considers that dwellings are shaped by such forces as cultural factors, climate, construction, materials and technology. These modifying factors, prominent in primitive and vernacular buildings, are less dominant in modern Western culture with its great freedom of choice in housing, reduced physical constraints and increased value placed on fashion.

Emergence of Concepts of Climatic Design

The general principles of "design-for-climate" have been widely discussed especially in North American literature (Rowley, 1939; United States Housing and Home Finance Agency, 1954; Aronin, 1956; Conklin, 1958; Olgyay, 1963; and Givoni, 1969). A useful summary of the climate-man - architecture approach is provided by Mather (1974, 334), "The achievement of comfort in housing through harmony with nature should be the goal of a revitalized architectural climatology". A recent example is provided by the underground or earth-sheltered dwellings of the New England area (United State of America), described by Neal (1978, 4) as the "silent , green alternative to the asphalt society". Increased interest is being shown overseas in climatically - designed buildings as a result of the "energy crisis" situation since 1975 (Burberry, 1976a; Cole, 1977).

Most frequently, however, climatic aspects are ignored, neglected or underrated. Even in the design of individual houses in Australian suburbs the most rudimentary climate considerations have not been considered or incorporated in site planning, grouping of buildings, street orientation, or suitable landscaping (Kendrick, 1963). Suggested reasons for this neglect include the lack of basic climatic data for planning (Keough, 1951), the meagre treatment in architect - training (Quarry, 1965; Taylor 1973), and cost factors (Shellard, 1965)[25]. This study aims, to clarify reasons for the almost total neglect of climatic considerations in domestic design, planning and construction in Adelaide.

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25. In contrast, Drysdale (1968) considers that, in some circumstances (such as designing for tropical regions), the rigours of climate are sometimes exaggerated, and the availability of preferred materials, adequate trade labour and reasonable costs erroneously assumed.

An Historical Perspective of "Design for Climate" in Australia

Since Australia has a range of climates (from hot-humid to cold-temperate) many different housing styles should have evolved. Although the principles of hot weather housing are largely understood (Macpherson, 1960, 1) and an extensive literature on Tropical architecture[26] has developed (such as Lee, 1953; Littlemore, 1958; Oakley, 1961; Fry and Drew, 1964; Holshausen, 1966; Saini, 1970; Koenigsberger *et al.* , 1974), house design in non-tropical parts of Australia has been less adequately discussed and often appears incidentally in the literature. (The only three publications dealing solely with house design suited to southern Australia are Drysdale's (1959) "Designing Houses for Australian Climates" NCDC's (1977) "Low Energy House Design for Temperate Climates" and Jenkins and James (1978) *The Wise House. Adapting Your Home to the Australian Climate*).

The first Australian houses were erected with wattle - and - daub or timber-slab mud-plastered walls, and thatched roofs, but all had brick fireplaces and chimneys (Freeland, 1968, 17). On later dwellings (particularly in the country districts of New South Wales in the early 1800's) verandahs were frequently added - first at the front, and later on all four sides of the house. Freeland, (1968, 45) describes the verandah as perhaps the first "architectural answer" to the Australian climate. Both Paynter (1965) and Young (1968) attribute its' origins to the influence of settlers from India or the West Indies ; they describe

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26. Tropical regions include hot dry areas in which design principles emphasize sun control, roof shading, thermal insulation, and the use of mechanical aids (see Saini, 1961, 1963, 1973) and hot humid zones where air movement and cross ventilation need to be combined with reduced solar radiation heat load (Dalton, 1963).

its function as a source of sun and rain protection to poorly constructed walls, and as a means of access or outdoor corridor. Despite some disadvantages (such as darkening adjoining rooms) the house with all-round verandah remained popular for decades, particularly in country districts[27]. Many early country houses were built one room thick to maximise cross - ventilation (and minimise construction costs); in others the roof-line was extended to carry rainwater beyond the walls, thus the fore-runner of the modern wide-eaves (Freeland, 1968, 48).

Proper orientation of buildings, however, was generally a factor made subordinate to the demands of style and fashion (Boyd, 1952). In 1902, an architect Walter Butler, in a paper to the Health Society in Melbourne, advocated the principle of "solar planning" for houses. He proposed a northern exposure for all rooms and explained how to exploit the difference in the sun's altitude in summer and in winter, by utilising an eave of calculated width which would shade the glass only in summer. These suggestions were revolutionary. Generations of builders of Victorian and Edwardian houses had avoided north orientation for their main rooms and the best windows. However, Boyd shows (1968, 105) how these ideas began to become accepted in later years, as the "accent moved to warmth". During the 1930's the northern aspect was used for living rooms (with wide eaves), bedrooms moved to the north or east, and sunrooms and sundecks made their appearance.

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27. The popularity of the all-round verandah was aided by periodic revivals; see Martin and King (1965), Watson (1965), and Chappel (1973a).

Nevertheless these changes occurred in only a small percentage of houses (Freeland, 1968, 260). Part of the reason was that nearly all housing styles were imported from elsewhere and were quite unsuited to local conditions, even when modified or adapted. Both the Californian Bungalow (introduced prior to the first World War) and the Spanish Mission style (introduced in the 1930's) had their potential climatic suitability negated by disappointing translation from architect planning to ordinary houses (Hayes and Hersey, 1970, 21) and replacement of desirable features by " a veneer of trivial ornament" (Marshall, 1973, 8).

During the second World War "solar planning" almost became a catch-phrase. Moore (1944) discusses past mistakes in domestic architecture (such as insufficient attention to aspect, rigidity of planning, and over-emphasis on the front of the house) and outlines suitable designs for the future (such as a pise, courtyard house for hot arid areas of Australia). Homes in the Sun is the apt title of Bunning's (1945) book in which several "Suntrap" houses are featured. Other architects (Jenkins, 1946) and writers (Langer, 1944) tried to resolve the problems of house design of subtropical and temperate areas of Australia. In the early 1950's two local - area conferences on "Building for the Climate" were held for residents of rural areas (Gentilli, 1954; Tully, 1955). When old houses were remodelled, verandahs were removed, and fire-places were disappearing from all but the main room of most houses (Douglas, 1974). However, the paucity of relevant research data for Australia, the inability to directly interpret overseas data, and the volume of enquiries concerning climate and house design promoted the establishment, in 1944, of a Commonwealth Experimental Building Station at North Ryde, Sydney. The outcome of seven years of research was published as a series of bulletins and technical papers by Drysdale and provides fundamental data on climate, comfort and house design in Australia.

Despite this wave of publicity for "solar planning" most post-1950 architecture continued to ignore climate in favour of other demands, so that Australia could be described as

> ... the great suburb; a nation of "fibro" box dwellers ... Single-fronted, double-fronted, triple-fronted bungalows, each one facing the street regardless of orientation; each spaced equally from its neighbours in accordance with Council regulations; and the closed, tight form of each huddled under the pitched roof, proclaiming its origin in less favourable climates;
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> (Taylor, 1972, 11)

Some architects and individuals (such as Seidler, 1959a; 1960; Macpherson, 1960) attempted to popularise the use of courtyards, maximum glass to the north with sufficient horizontal overhang and exterior sun-protection, minimum glass to east and west, provision for cross-ventilation, and wall and roof insulation. Nevertheless, Seidler (1959b, xii) argues that most standard domestic buildings continued to provide neither physically comfortable nor aesthetically desirable surroundings. Unlike in California, (Baylis and Parry, 1956) there was no successful attempt in Australia to build houses suited to their local setting.

During the 1960's the major changes in Australian housing occurred in marketing methods rather than in design, quality or consideration of local climate. A. Howard (1966, 277) classifies the house market of the mid 1960's into four types; : the few architect-designed, the slightly higher number of owner-designed and/or owner-built, the many builder-designed homes which followed a stereotyped pattern in order to achieve a sale, and the standard-type homes marketed by large-scale project builders with an eye to economy. The last two, the so-called "speculative home" and "project home" were responsible for an estimated 80 to 90 per cent of the market for new (non-Government) homes at the time (Australian Women's Weekly, 1965; McCredie, 1969). The effect on the quality of design has been two-fold. First, increasing use of "standard-built" homes, package deals, and exhibition (or display homes) has led to the greater inclusion of ego-lifting items in the home which have no functional or architectural value (Woolley, 1967) and the likelihood that superficial stylism will be more rapid than in the past (Nielson, 1972; Thorne et al. , 1972). Second, there has been, for the first time, widespread public acceptance of architect-designed project houses, particularly those built by Pettit and Sevitt (in Sydney) and by Merchant Builders (Melbourne). It is in this latter group of houses, especially those built by smaller firms, that the quality of design has been improved and some consideration given to local climate (Architects Advisory Service, 1970; Boyd, 1970). However, there has also been a changed attitude to domestic space heating and to manufactured insulation (and more recently to air conditioning), so that sensible design for climate has again been neglected in favour of providing comfort by the use of energy for heating and cooling. Only an energy crisis of the chronic type (Burberry 1976a, 35) with its high energy costs is likely to result in universal building designs which are thermally efficient and use a minimum of scarce energy resources.

Climatic Design and Low-Energy Principles in South Australia

Having outlined the treatment of "design for climate" in the general architectural history of south-eastern Australia, some consideration needs to be given to South Australia, with its hotter, drier climate and different influences on building design. Some of the more outstanding differences are mentioned.

Williams (1974) provides a comprehensive dscussion of the forces which shaped the landscape of South Australia, rural and urban, and an explanation of the patterns of growth and internal change in Adelaide. Some influences on the design, structure and style of building were similar to those operating in Melbourne or Sydney; others were distinctively different. For example, house building styles which became popular in Australia had their origins overseas and tended to be first introduced to Melbourne or Sydney. In being transferred into South Australia from the Eastern States, further modification (and then rejection or assimilation) occurred. One major factor in this process was the availability of local building materials in South Australia, particularly stone, brick and slate. As a consequence,South Australia has a distinctive range of house-styles, and the highest state ratio of houses with stone or brick exterior walls.

The smaller size of the capital city and the different economic and financial structure, has meant that fewer large-scale developers were involved in house construction in Adelaide in the past, and fewer project home builders have been involved during the last decade[28]. The largest single builder has been the South Australian Housing Trust, which began operation in 1936. By 1978 almost 84,000 dwellings had been completed (Annual Report, 1978), of which 74 per cent had been built in urban Adelaide (1976 Census Boundary). Many Housing Trust homes were built in the northern and outer northern suburbs, with smaller groups elsewhere : however, the largest single concentration is that at Elizabeth, a satellite city 27 kilometres (17 miles) north of Adelaide,

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28. For example, Pettit and Sevitt entered the South Australian house building market in November, 1975.

where building started in 1955 and the area reached an (estimated) population of 54,000 by 1976 (Ramsay, 1956; McKnight, 1965; Stretton, 1974). The large number of public-sector houses in South Australia (and in other States) has obvious implications for design standards, including those concerned with local climate and energy costs.

As in the eastern States, exponents and practical application of principles of climatic design were rare in South Australia. John Chappel, architectural correspondent for The Advertiser from 1962 to 1975, often stressed the fundamental principles in his weekly articles, and also provided designs for an Adelaide project home builder for several years. For country residents in particular, Broinowski (1962a, 1962b, 1963, 1964, 1966, 1967) discusses ways of improving an old house, various aspects of summer and winter comfort and "solar planning" principles. However, the main research in South Australia was undertaken by Marshall, who examined the evolution of house types in a small country town in terms of architectural fashion and local climate (Marshall, 1954, 1955), measured indoor temperatures and householder discomfort in newly constructed houses at Elizabeth (Marshall, 1957), evaluated the climatic relevance of Adelaide building styles since 1842 (Marshall, 1963a), measured indoor temperatures, over three summers, in a large University building (Marshall, 1963b) and conducted a survey of indoor comfort among householders in four country towns (Marshall, 1966). The underlying theme throughout this research, perhaps best presented in a later symposium paper (Marshall, 1973), is that the primary function of building for living and working environments is to provide shelter and maximum indoor comfort, without wasteful use of energy for heating and cooling.

After a relatively quiet decade (coinciding with increased use of domestic space heating, insulation and air conditioning, and low energy costs) there has been a revival of public interest, since 1975, in climatic design, and the need to conserve energy in houses. Various ideas have been put forward, in the popular press and elsewhere, as the "solutions" for South Australia: these include

* adoption of practices from a dry climate such as Spain (Jervis, 1977, 23)
* a return to building styles and materials of the past, particularly the verandah (Chappel, 1973a, 16; 1974a, 14), the traditional Australian homestead design (Anon 1977, 20) or log cabins (Townsend, 1975b, 46)
* a greater relationship with outdoors, particularly the use of courtyard and patio designs
* emphasis on functional design to suit the South Australian climate and varying lifestyles (Townsend 1977a, 1977b).

Commencing late in 1977, books or pamphlets on correct orientation, siting and energy efficient design were published by a State government department, and by electricity and gas authorities[29]. The Electricity Trust of South Australia displayed a model of a "low energy house" during the 1978 Royal Adelaide Show. Energy conservation was the theme for courses and seminars organized in South Australia during 1977 and 1978.

In addition there has been an almost continuous series of articles in the popular press on topics such as house management during hot and cold

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29. These were South Australia State Planning Authority (1978) Residential Design Guide for South Australia; South Australia, Department of Housing, Urban and Regional Affairs (1978) Sunlight and Privacy in Your Home and Electricity Trust of South Australia (1978a) Energy Efficient Dwellings.

weather, the value of insulation, the merits of various types of mechanical and heating equipment, and suggestions for reducing household energy use[30]. As in the Eastern States, energy conservation in houses appears to have become a dominant issue, in terms of both research and its practical application.

Empirical Studies of Climate, Comfort, Energy Consumption and Housing

Empirical forerunners of the present study are relatively few and limited in scope. The few studies presenting systematic data can be grouped into broad categories: those initiated for the specific purpose of examining aspects of climatic suitability, indoor comfort or energy consumption and studies that have yielded data on these subjects as part of a larger undertaking. The two principal genres in the latter category are behavioural studies and studies of the quality of the urban environment.

Specific Studies

Housing studies initiated for the specific purpose of examining aspects of climatic suitability, indoor comfort or energy consumption examine these topics at various scales: some investigate these topics in a range of housing types, others examine only a particular aspect.

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30. For example, a course was run by the Department of Further Education (Education Department) on "Designing Your Home" during 1977 and a seminar organized by the Department of Continuing Education (The University of Adelaide) on "Energy Conservation in Housing" during September 1978.

Examples of the first approach (a range of housing types) are provided by Marshall's (1966) investigations of the relationship between climate, comfort and housing in South Australia, and by Crossley's (1977a) studies of the environmental implications of different patterns of household energy use. During the summer of 1963-64, Marshall conducted a survey of hot-weather comfort in houses of four country towns of South Australia (Clare, Kadina, Tailem Bend and Naracoorte). Approximately 150 householders rated the daily comfort-level of their own houses for three months and completed a questionnaire on the climate-related design and structural features of the house, their management of the house during hot weather, and their perception of local climate. Analysis of the comfort charts highlighted the expected differences between houses of heavy-weight (brick and stone) and light-weight (timber and asbestos) construction, and revealed some unexpectedly large regional differences, with the residents of the hotter towns of Kadina and Tailem Bend far more heat tolerant that those of Naracoorte and Clare (cooler locations). The survey enabled a prediction of the number of uncomfortable days to be expected in an average summer for each district. This information was later used by Broinowski (1967) in an article for country people entitled "Are air conditioners really necessary?". Many of the remaining data in the "indoor climate survey" (the householder's questionnaire) have not been analysed, and remain unpublished[31].

No general survey of household energy use has been completed in Australia of the nature of Newman and Day's (1976) study of The American Energy Consumer, or of Blakeley and Cook's (1974) analysis of household

31. Personal communication, Ann Marshall, Department of Geography, The University of Adelaide, 15th December, 1975.

electricity consumption in New Zealand. The only substantial survey in Australia is Crossley's (1977a) study of householders' attitudes to household energy use and various associated behavioural factors[32]. Preliminary analysis of data from 512 Brisbane households has demonstrated the importance of such factors as household size, number of rooms in the house, household income, educational level and occupational status of the household head on energy-related behaviour (Crossley, 1978). No data on the nature of the house design or structure were collected by Crossley and no attempt has been made to relate the energy consumption of the household to the climatic suitability or indoor comfort of the house.

A larger number of studies into climatic suitability, comfort and energy consumption have been concerned with particular housing types or restricted locations. Marshall (1954, 1955), for example, discusses the evolution of house-types in Meadows, a small South Australian country town, and shows that the influence of fashionable styles from the suburbs was stronger than the natural evolution of desirable design features to suit local climate, especially in the absence of architectural advice or information on modern building research. During the summer of 1957-58, Marshall (1957) investigated indoor temperature and levels of discomfort in newly constructed brick and timber frame houses in the South Australian Housing Trust town of Elizabeth. Simple monitoring (thermographs in two houses, maximum-minimum thermometers in

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32. Crossley's study is incomplete, at the time of writing. (Personal Communication, D.J. Crossley, Energy Authority of N.S.W., 20th August, 1979).

thirty houses) and a "house comfort" chart completed by the householder were used to establish relationships between indoor and outdoor temperatures and the householder's subjective rating of the comfort-level of the house. Despite individual differences (the onset of discomfort ranged 10^{o}F from the most to the least heat-tolerant resident), the effect of householder management methods on indoor temperatures (identical houses varied 10^{o}F or more on the same hot day) and the poor correlation between maximum temperature indoors and the level of comfort recorded, Marshall was able to show that the "most usual" resident will find the house uncomfortable when the mean indoor temperature reaches 82^{o}F (28^{o}C) in brick houses and 80^{o}F (27^{o}C) in timber frame houses[33]. Since this indoor temperature results from an outdoor mean temperature of 80^{o}F, Marshall concludes that indoor discomfort in houses of this type is likely to occur 20 times in an Adelaide summer.

A survey with a different emphasis was carried out by Sumner (1975a, 1975b, Sumner and Oliver, 1978) who investigated the development of the distinctive characteristics of houses in tropical north Queensland from the viewpoint of the environmental influences to which the first settlers and home builders were exposed. Examination of early designs and building techniques, plus instrumental measurements in several tropical houses built between 1861 and 1921, demonstrated little recognition of the requirements of the tropical climate. Sumner concludes that the dwellings of the earliest settlers, who were primarily concerned with meeting the basic needs for their new life,

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33. In order to simplify analysis the mean temperature (the average of daily maximum and minimum) was used as an indicator of the temperature regime during 24 hours: a reasonable correlation occurred between comfort level and mean daily temperatures.

were more strongly influenced by social and economic factors (such as their immigrant origins, the limited availability of building materials, or the problems of distance) than by the climatic environment. Only in the slow evolvement of the bungalow style, with its encircling verandahs, additional shading devices, steep roofs, high ceilings, ventilation, elevation above the ground and"balloon frame" construction, did the climate exert some influence. As in Marshall's study of Meadows, climatic considerations were found to have been given lower priority than other factors.

Other research data on climate and comfort were obtained from surveys in dwellings . The Commonwealth Experimental Building Station, for example, used houses of various constructions and locations to provide thermal performance data to compare with results from huts and model structures (Drysdale, 1947a, 1947b, 1947c, 1948c). Ballantyne and Spencer (1972) assessed the thermal comfort preferences of acclimatised Caucasian subjects in Port Moresby by obtaining their thermal sensations within the living room of their homes. Of the four different types of construction, subjects in concrete block houses showed the highest transition temperatures (neutral to warm) and those in the aluminium houses the lowest (probably associated with high ceiling temperatures causing a greater radiation load on the subjects). The high value for the concrete block houses may have been due to lower wall temperatures than in other houses. Temperatures in the houses were recorded on bi-metallic strip thermographs (which avoided the need for non-technical respondents to have to read a thermometer consistently and correctly). Studies of household energy use in particular housing types have been completed in Canberra (NCDC, 1977) and in Twin Rivers, New Jersey (Grot and Socolow, 1974). In Canberra twelve typical detached Government houses were monitored for two winter seasons by attaching kilowatt-hour meters to the various electrical circuits of the house. Data on the household's use of heating oil were supplied by several oil companies, so that the actual and proportional amounts of energy used for space heating, water heating, cooking, lighting, refrigeration and other uses could be calculated (NCDC, 1977, 7)[34]. On a smaller scale, limited monitoring of actual dwellings in Melbourne and Hobart has been recently undertaken in order to test the accuracy of the thermal and energy predictions of the TEMPAL computer package developed at the Department of Architecture and Building, University of Melbourne (A. Coldicutt, 1978a; S. Coldicutt, 1979). In North America the Twin Rivers' survey obtained electricity and gas consumption of 400 townhouses by monthly meter readings, meteorological data from the nearest weather station, structural details of the units from architectural drawings, sales records and observation during construction, and limited demographic information from some households. This permitted correlation of energy-consumption with climatic data (particularly degree days) and enabled an attempt to identify the factors that account for the variations in gas and electric consumption in similar units. Future plans in the Twin Rivers' survey include the erection of an on-site automatic weather station and detailed monitoring of several units. These plans indicate the expense and methodological problems when undertaking comprehensive studies of household energy use.

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34. The survey was jointly organized by the Australian Capital Territory Electricity Authority (ACTEA) and the Department of Construction, Canberra (Personal Communication, Tone Wheeler, School of Environmental Design, Canberra College of Advanced Education, 15th May, 1978).

Particular aspects of climatic suitability, comfort or energy - consumption of houses have been studied in a variety of disciplines. CSIRO Division of Building Research scientists investigated the performance of conventional space heaters in living rooms (CSIRO, 1977, 1978b). The Australian Consumers' Association conducted several surveys on comfort - related appliances such as oil heating, and homeheating and insulation (Australian Consumers' Association, 1973, 1978a). The Electricity Trust of South Australia has completed periodic surveys of randomly - selected domestic electricity consumers, primarily to collect data on the type and usage of household electric appliances owned. Such surveys provide valuable comparative data on the ownership and attitude towards energy - consuming and energy - saving household appliances.

Non-specific Studies

Behavioural Studies. Halkett (1975, 14) describes behavioural studies in geography and other social sciences as a loose-knit group of research approaches which attempt to describe the behaviour of individuals or groups and the motivations or attitudes that underlie patterns of behaviour, and then to formulate statements about the behaviour of groups and individuals. He argues that the behavioural approach in geography is distinguished, at least nominally, from that of other disciplines by the emphasis geographers place on spatial behaviour and on the spatial implications of particular types of behaviour. Golledge, Brown and Williamson (1972), in a review of behavioural approaches in geography, identify five major types of study: decision making and choice behaviour, the diffusion of information, search and learning, political behaviour, and perception. They conclude that one of the approaches which stands out as giving the most immediate and obvious returns to research efforts is work on decision making, including, for example, residential site selection.

Examination of the many decision-making studies of residential location gives little indication that home-seekers consider either climatic suitability or potential indoor comfort in selecting a house, or the climatic implications of a home site. Examples of such studies, overseas and Australian, in which climate-related features are rarely mentioned, are discussed in Chapter 5.

Quality of the Urban Environment Studies. Like the behavioural studies, most studies of the perception and evaluation of environmental quality have not included attempts to systematically describe housing in terms of its climatic suitability or comfort. This occurs partly because many studies concentrate on evaluation of the quality of the local environment (such as Michelson, 1966; Lansing and Marans, 1969; Pryor, 1969; Headey, 1972; Wearing and Wearing, 1973) rather than the quality of the housing . It is only in those studies which attempt to measure the householders' satisfaction with their own dwellings that evaluation of climate and comfort-related aspects is likely to occur. A method frequently used in such studies is to ask residents to rate various attributes on a scale, or to rank them in order of importance. In many North American and United Kingdom surveys of this type, some appraisal of heating systems, ventilation, or indoor temperature has been included (National Co-operative Highway Research Program, 1959; University of Edinburgh, 1966; Product Planning Ltd., 1966). An American study of low income family dwellings (Sanoff, 1972) found that highest on the list of ideal dwelling attributes was "comfortable temperature", followed by size of rooms, outside appearance of house, backyard, frontyard and large kitchen with eating areas: cross - ventilation and morning sunlight appeared lower down the list. The three most important "unsatisfactory" items in the respondents' present dwellings were "comfort", "size" and "appearance".

Despite the prominence given to physiological comfort in such overseas studies, most Australian studies of housing satisfaction have presented few systematic data on climatic suitability or householder assessments of the comfort of the house. Presumably researchers either consider climatic and comfort considerations unimportant, or make the assumption that householders include them in their general assessment of the "quality of the current dwelling" (Stimson, 1973; NCDC, 1975). Three studies demonstrate the lack of systematic data on climate and comfort. The Australian Home Journal (1972) ran an Australia - wide survey entitled "Help Yourself to Better Housing" (prepared by the School of Architecture, University of Sydney) but results of replies on climate and comfort - related questions were never published. Similarly, the 350 replies to an open-ended survey of the building block and house-design preferences of Adelaide housewives administered in 1973 by the Master Builders Association (South Australia) were considered too difficult to categorize[35]. Perusal of the unpublished report showed that many respondents did consider climate and comfort aspects in their "ideal house", including such topics as orientation, ventilation, heating and cooling equipment, indoor temperatures, outdoor living areas, and the value of verandahs. McCredie (1971) evaluated Housing Commission, speculative and project housing in the outer suburbs of Sydney in terms of social and psychological factors, overall estate

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35. Personal Communication, K.C. West, the Master Builder's Association (South Australia), 11th March 1975.

development, and design and construction of the individual dwellings. Included in a short chapter on design standards is the conclusion that climate considerations, whether in terms of summer-sun protection, cross - ventilation, outdoor areas or methods of heating, were not considered in most of the houses studied.

Despite the lack of systematic data on assessment of climate and comfort considerations, the few studies concerned with the evaluation of housing quality do highlight some of the difficulties in this type of survey: these include such aspects as

* the majority of people tend to be satisfied or highly satisfied with their home
* satisfaction increases the longer people stay in one place
* non - satisfaction is more frequently expressed by the young, the highly educated and by householders who are renting
* people find difficulty in distinguishing those features which do or do not satisfy them
* a large proportion of people do not know what they want, or at least find articulation difficult.

The Present Study

The present study is designed to contribute to an understanding of the house, in terms of its suitability to the local climate, its provision of physical comfort, and the energy required to maintain or achieve this level of comfort. The foregoing review of studies shows that the precedents for the present study are limited. No previous empirical study has been completed in Australia which attempts to assess the climatic and comfort performance of dwellings, relative to their energy consumption.

This study differs from previous related studies in a number of other ways. In all previous behavioural and housing evaluation studies of a general nature, climate and thermal comfort have played a minor role (such as McCredie, 1971; Australian Home Journal, 1972) or an incidental role (such as Brealey, 1972b or the survey run by the Master Builder's Association). Only in Sanoff's (1972) study, which was concerned with levels of satisfaction in neighbourhood and dwelling, did climate ("comfortable temperature") rank the highest desirable dwelling attribute. Each of the few climate - housing studies of which the writer is aware, differs from the present investigation in that they are concerned either with a particular type of housing (such as Marshall, 1957; Sumner, 1975a), or a particular small town (Marshall, 1954, 1966), or rely largely on physical measurement, plus some interview and questionnaire techniques.

Methodologically, the present study is different in that it attempts to integrate information from a number of sources on each of the design, construction, purchase, occupation and modification stages of a house. In the decisions leading to house purchase, for example, information is used from the designer/builder, the householder and real estate agents, and responses to similar types of questions asked of each group are compared. This wider viewpoint enables the climate factor to be assessed with greater confidence. Most previous studies rely on one information source, usually the householder (for example Ward, 1970; Australian Department of Housing and Construction, 1974), some on two types (for example Troy, 1971, 1973; Brealey, 1972b; University of Edinburgh, 1966; Halkett, 1976) or on one particular aspect (for example Rossi, 1955; Gibbings, 1973).

The interview and questionnaire schedules used are more comprehensive than those used in previous climate - housing studies, and in the case of the Householder's Questionnaire[36], are supplemented by facade and aerial photographic evidence. Unlike previous studies, relatively little physical measurement or computer modelling is used. Although other surveys of household energy use are currently under way, this appears to be the first in Australia to use energy consumption data provided by the energy-supply authorities for such a large number of households; previous empirical studies of energy consumption (such as Crossley, 1977a; Ballantyne, 1977) have relied on data supplied by the householder. Finally, no previous studies have related the patterns of energy use to the design, structure and comfort of the house.

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36. The Householder's Questionnaire appears in Appendix I, pp. 397-403.

CHAPTER 3

SAMPLING PROCEDURES AND THE COLLECTION AND ANALYSIS OF THE DATA

The evaluation of climatic suitability and indoor comfort of dwellings relative to their energy consumption required integration of information from a number of sources. In this study, consideration of the climate factor in the design, construction and sale of housing was obtained from architects, home designers, building firms and real estate agents. Information on the climatic suitability and indoor comfort of occupied dwellings, however, was provided by householders, supplemented by data on the physical structure of the dwelling, monitoring the thermal environment, and information on the equipment and energy required to maintain comfortable conditions. Energy consumption was considered both for individual households and as part of the general trend indicated by manufacturers and retailers of domestic "energy - consuming" and "energy - saving" equipment. These wide-ranging sources were then used to determine the relative importance of the climate factor in Adelaide's housing, and to identify the "best" house for Adelaide's climate[1].

Thus the study is based principally on social surveys (Moser, 1958; Scott, 1961; Burton and Cherry, 1970). Previous studies provide useful examples of methodology and techniques, such as questionnaire and interview schedules (University of Edinburgh, 1966; Sanoff, 1972; Gibbings, 1973), facade and aerial photographs (Rickert, 1967; Halkett, 1976), physical measurement (Marshall, 1957; Noble and Ash, 1966) and

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1. The organization of these notions and questions into a framework of systematic investigation is shown in Figure 1.1, p.5.

integration of information from dual sources (Troy, 1971, 1972; Brealey, 1972b). In this study information from households included a householder's questionnaire, house facade photographs and observations, energy consumption data and a small temperature survey. Additional information was obtained from interviews with architects, building designers and building firms, a short questionnaire to members of the Real Estate Institute of South Australia, and discussions with a selection of firms dealing with house modification (such as heating, cooling or air conditioning systems, thermal insulation or window treatment). Sampling procedures and the collection and analysis of the data from each of these sources are described below.

The Households

Sampling Procedure

The first requirement was to determine a survey population in order to frame the sample. Only detached housing was considered on the assumption that ownership (and thus possible house - modification) is predominant in this type of private dwelling. In the 1971 Census, 74.6 per cent (173,905) of houses in the Adelaide Statistical Division were owner - occupied, 10.1 per cent (23,477) had tenants of the South Australian Housing Trust, and 12.6 per cent (29,278) housed other tenants. Sampling occurred in two stages; selecting the areas and selection of households within the area. Two areas were selected - southwestern suburbs and Salisbury East - in order to obtain a suitable sample.

Selection of Area. The areas were selected with emphasis on the following considerations: comparability of climate, especially in terms of gully and sea breezes; including all house-types as identified initially by Chappel in 1958[2]; including houses constructed by private building firms and by the South Australian Housing Trust; incorporating households with a range of socio-economic statuses, but predominantly middle level; and other (spatial) considerations. Each of these considerations was incorporated, as far as possible, in the selection of the sample areas (see Figure 3.1) in the following way:

(i) Climate requirements: Annual rainfall records (Australia, Bureau of Meteorology, 1966) and the Bureau of Meteorology's (1971) "Climatic Survey - Adelaide" were consulted in order to obtain the rainfall, temperature, humidity and cloud pattern over the Adelaide Plains and adjacent areas. In view of the quite different climate in the Mount Lofty Ranges, it was decided to concentrate on the Adelaide Plains only. With gully breezes prevalent in the foothills and adjacent eastern and south-eastern suburbs and sea breezes prevalent along the coast and the western suburbs, an area of the south-western suburbs was considered, parallel to Anzac Highway, roughly equidistant from the scarp (and its gully breezes) and extending to Brighton Road, one kilometre from the coast (see Figure 3.2). This area has a rainfall of approximately 508 mm (20 inches) per annum with slightly lower temperatures than in the northern suburbs (due to more frequent cloud cover over the southern suburbs, and a partial effect of gully and sea breezes).

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2. His five articles (Chappel 1958a, 1958b, 1958c, 1958d, 1958e) are hereafter referred to as Chappel (1958).

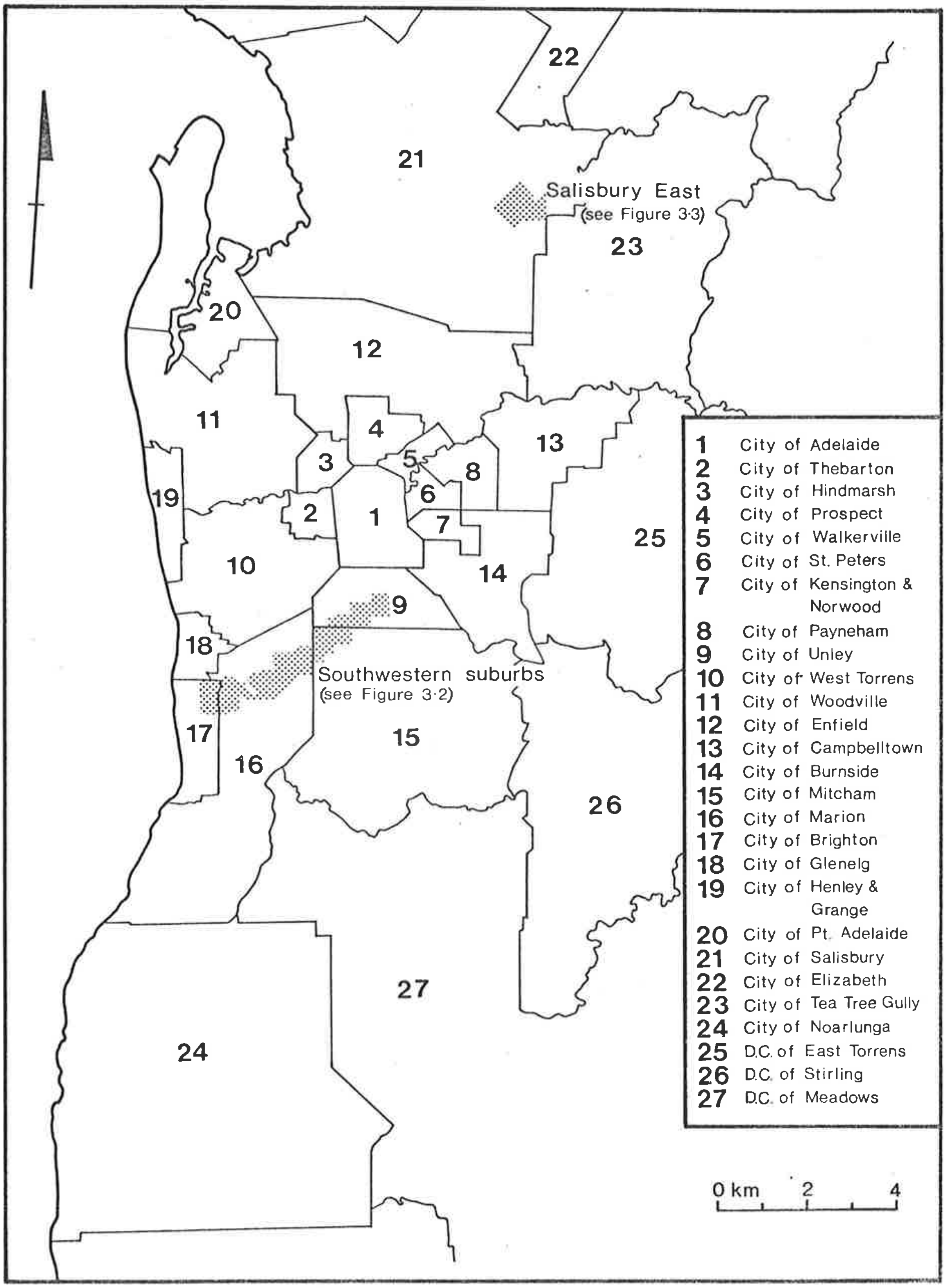

FIG. 3·1 METROPOLITAN ADELAIDE SHOWING THE LOCATION OF THE TWO SAMPLE AREAS

The Salisbury East sample area, located 16 kilometres (10 miles) north-north-east of Adelaide and 10 kilometres (6 miles) from the coast experiences summer maxima 1 to 2^{o}F higher, and has an annual rainfall approximately 51 mm (two inches) lower than that received in the southwestern suburbs sample area[3].

(ii) House-types: In the absence of a detailed catalogue or growth map based on age of housing for Adelaide, Marshall (1961, 67) compiled a subdivision map for the Adelaide Plains, based on sources such as early maps, documents and auctioneers' subdivision plans. The map indicates that the sample area of the southwestern suburbs between Goodwood and King William Roads (parts of Unley, Millswood and Hyde Park) was subdivided prior to 1900; much of the central section between Goodwood and South Roads (parts of Clarence Park, Clarence Gardens, Edwardstown and Ascot Park) between 1900 and 1926, and the section between South and Brighton Roads (Parkholme, Glengowrie, Somerton Park) after 1937[4]. Thus it seemed likely that theses suburbs contained housing of various ages (and thus styles). As described in more detail in Chapter 4, three main references for house-styles in Adelaide (Chappel, 1958, 1972; Real Estate Institute of South Australia, c.1968; Williams, 1974) were used in developing a classification for use in this study. The sixteen house-styles , mentioned by each of the three sources, were represented in the south-western suburbs, except for the latest "Spanish" or

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3. In the southwestern suburbs, Brighton's average annual rainfall is 514mm (2022 points), Unley Post Office 589 (2320); in the Salisbury area, Parafield Aerodrome averages 471mm (1854 points) and Salisbury 468 (1841). See footnote 2 on page 223 for description of temperature differences. No other detailed climatic data are available, although it is likely that there are differences in cloud cover and local wind patterns.

4. These suburb and street names are shown in Figure 3.2.

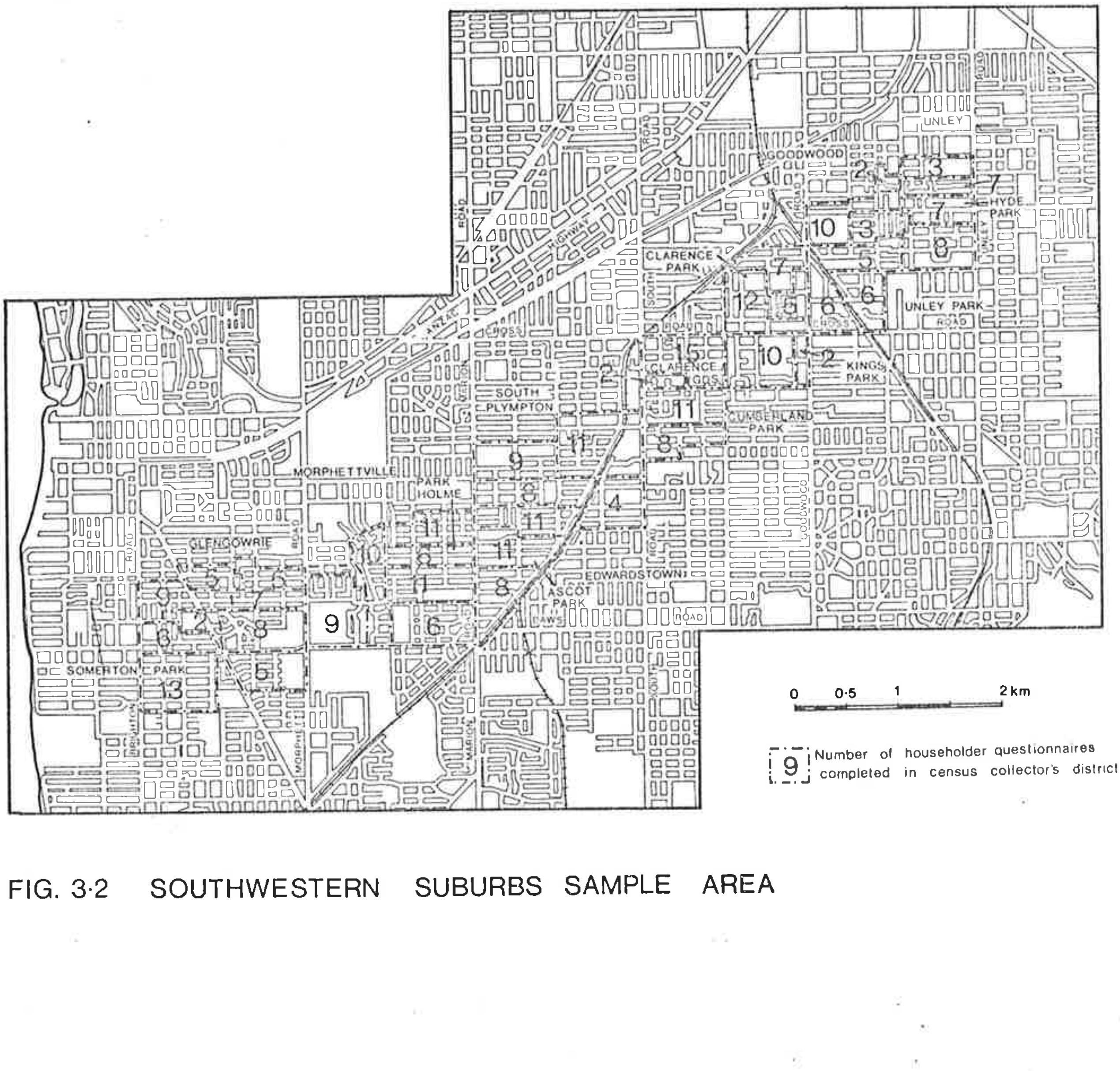

FIG. 3·2 SOUTHWESTERN SUBURBS SAMPLE AREA

"Mediterranean". Table 3.01 shows that some styles appeared in small numbers, such as the Bay Window Villa and "Spanish Mission". All house-styles which have made a major contribution to the present suburban landscape (especially Villas, Bungalows, Austerity, L-shape and other post-war houses) were well represented in the sample. Since there is no classification of all Adelaide housing by style, and limited evidence on age-distribution, the numerical growth of Adelaide housing had to be estimated from other sources. Census Data from various Householder's Schedules (Commonwealth Bureau of Census and Statistics, 1947, 1954, 1961, 1966, 1971) indicated that approximately 30 per cent of the 1971 total of private houses in Adelaide were built prior to 1933, 60 per cent built prior to 1961, and the remaining 40 per cent between 1961 and 1971[5]. Table 3.02 shows the date of construction of the sampled houses in the southwestern suburbs, as stated by the householder or estimated by the interviewer. The age distribution shows an adequate ratio of housing built before 1933, and between 1934 and 1961, but too few dwellings built since 1962. Consequently, an additional area of new housing was considered necessary in order that the sample be numerically, and spatially, representative. Approximately 7,000 houses have been constructed annually in Adelaide between 1971 and 1975. Several locations and housing estates, mainly in the outer suburbs, were considered. Alan Hickinbotham Pty. Ltd., one of the largest private builders in South Australia in the 1970's, co-operated by providing lists of all "Hickinbotham Homes" constructed since January 1970. Most house-building activity by the Company during the 1965 to

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5. Some cross-checking was provided by records compiled by Elder Smith & Co., (1954). The aerial growth of Adelaide's housing is also shown in maps of the Town Planning Committee Report (1962, 30-31) and of Williams (1974, 419) - maps based on early Military Surveys and aerial photographs taken after 1950.

TABLE 3.01

HOUSE STYLE AND AGE OF SAMPLED HOUSES IN THE SOUTHWESTERN SUBURBS

Period	Style	Number in sample	Percentage of sampled dwellings
1850-189	Single and double (or symmetrical) front	15	4.9
1870-1915	Villas - bay window	2	0.7
	- plain	14	4.6
	- return verandah	4	1.3
1905-1918	Louvred roof villa; Queen Anne/Art nouveau	18	5.9
1916-1935	Bungalow	39	12.7
1938-1938	Tudor	10	3.2
1929-1945	Spanish Mission	2	0.7
1946-1952	Austerity - S.A.H.T.	25	8.2
	- other	41	13.4
1950-1972	Contemporary	4	1.3
1952-1965	Conventional - L-shape	29	9.5
	- triple front	14	4.6
	- S.A.H.T.	32	10.4
	- other	38	12.4
1952-1972	Ranch or Colonial	9	2.9
1966-1974	New	10	3.2
1970-	Spanish or Mediterranean	-	-
Total		306	100.0

Source: House Details Form, see Appendix I, pp.404-405.

TABLE 3.02

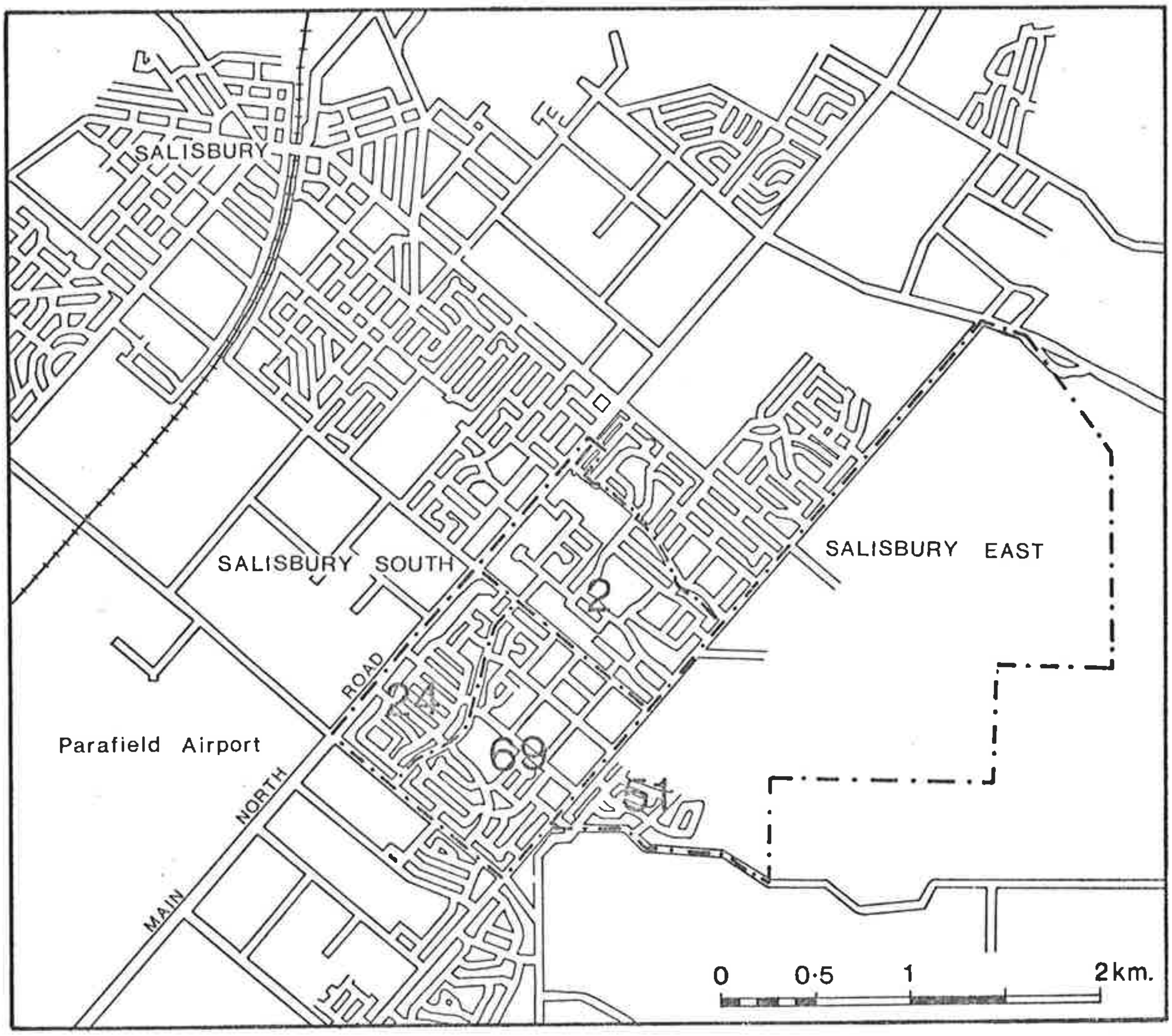
DATE OF CONSTRUCTION OF SAMPLED HOUSES COMPARED WITH ADELAIDE'S PRIVATE HOUSES BUILT BEFORE 1971

Date of construction (years)	Sampled Houses: Southwestern suburbs[a]		Sampled Houses: Salisbury East		Sampled Houses: Combined sample		Adelaide's private houses built before 1971[b]	
	number	percentage	number	percentage	number	percentage	number (approximate)	percentage
before 1922	62	20	-	-	62	14	42,000	18
1922-1932	34	11	-	-	34	8	26,000	11
1933-1946	34	11	-	-	34	8	19,000	8
1947-1960	142	46	-	-	142	31	54,000	23
1961-1971	34	11	146	100	180	40	92,000	39
Total	306	100	146	100	452	100	233,000	100

Chi-square (original data, combined sample and Adelaide) = 22.924, df = 4, s = .001

Source: a. Householder's Questionnaire (Question 3) or estimated by interviewer.

b. Compiled from Elder Smith & Co (1954) and Commonwealth Bureau of Census and Statistics, Census of Population and Housing, 1947, 1954, 1961, 1966, 1971.



9 Number of householder questionnaires completed in census collector's district

FIG. 3·3 SALISBURY EAST SAMPLE AREA

1975 period was concentrated in three estates in the north-eastern outer suburbs ("speculative" and "contract" houses), plus scattered contract homes in most other suburbs. The Manor Farm, Manor Heights estate at Salisbury East, the earliest and largest of the three, was selected for administering the Householder's Questionnaire. The location of this housing estate, between the Main North Road and the foothills of the Mount Lofty Ranges, and north-east of the Parafield Aerodrome, is shown in Figures 3.1 and 3.3.

(iii) Source of construction, private and public sector building: The South Australian Housing Trust was responsible for approximately 13 per cent of the houses built in Adelaide to 1971. Of the 306 sampled houses of the south-western suburbs, 57 (19 per cent) were Housing Trust homes, mainly in the Parkholme and Morphettville area. All the Salisbury East sampled houses were built by a private contractor. The designers and builders of the sampled houses (as stated by the present householders) are shown in Tables 3.03 and 3.04 respectively.

(iv) Socio-economic status: Initially, Stimson's (1971, 3) generalised map of socio-economic status for Adelaide suburbs was used to assess the socio-economic status of the sample areas. Stimson used factor analysis of 111 variables to evolve "constructs" of socio-economic status, "familism" and ethnicity. The socio-economic factor was found to account for the greatest proportion of variance (24 per cent), followed by measures of household composition. Mapping showed socio-economic status highest in eastern, southern, hills and seaside suburbs, lowest in the old inner city areas, industrial areas along the city-Port Adelaide axis, and in areas with a high concentration of public sector housing.

TABLE 3.03

DESIGNER OF SAMPLED HOUSES

Type of designer	Percentage of sampled houses: Southwestern Suburbs	Percentage of sampled houses: Salisbury East
Owner or previous owner	13	2
Architect	1	-
South Australian Housing Trust[a]	18	-
Building firm	17	95
Other or combination	1	3
Not known	50	-
Total	100 N = 306	100 N = 146

Source: Householder's Questionnaire (Question 3)

a. The South Australian Housing Trust, a semi-government authority, has a large architectural section which designs houses and flats for rental and houses for sale. Construction is undertaken by private contractors.

TABLE 3.04

BUILDER OF SAMPLED HOUSES

Builder	Percentage of sampled houses: Southwestern Suburbs	Percentage of sampled houses: Salisbury East
Owner or previous owner	4	1
Subcontract	3	-
South Australian Housing Trust	18	-
Building firm	29	97
Not known	48	1
Total[a]	100 N = 306	100 N = 146

Source: Householder's Questionnaire (Question 3)

a. Since percentages are rounded, a total of 100 may not always be obtained.

The detailed publication A Socio-Economic Atlas of Adelaide (Stimson and Cleland, 1975) appeared only after the household sample used in this study had been drawn. According to Stimson and Cleland's (1975, 214) mapping of socio-economic status, approximately half of the sampled houses of the southwestern suburbs had medium status, approximately a quarter medium - to - high status, and the remainder either low - to - medium or highest socio-economic status[6]. Houses in the Salisbury East sample area were mapped as low - to - medium in status. Thus most of the sampled households occurred in areas of low - to - medium , medium or medium - to - high socio-economic status in the 1971 Census[7].

(v) Other spatial considerations: The area selected in the southwestern suburbs was approximately one and a half kilometres (one mile) wide, parallel to Anzac Highway but one kilometre south of it. It extended from Unley Road in the east to Brighton Road in the west (see Figure 3.2). Other main roads (King William, Goodwood, South, Marion and Morphett) ran obliquely through the area, minimising the concentration of associated commercial and industrial development. The area generally had a medium to low percentage of rental housing (Stimson and Cleland, 1975, 66-67). The Salisbury East sample area was wholly contained between main roads (see Figure 3.3) and had a very low percentage of rental housing.

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6. Full details of Stimson and Cleland's ranking of L.G.A. - Parts appears in Appendix V, pp. 428-429.

7. A corresponding range of household incomes was assumed. Other attributes of possible influence, such as age, ethnicity, acclimatization or personality were not included in the sample selection procedure.

Selection of Households. In the southwestern suburbs contiguity (to enable interviewing by one person) was achieved by taking all Census Collector's Districts (hereafter CCD's) totally enclosed in the "radial strip" previously described. Forty-one CCD's contained a 1971 Census population of 6,399 detached and 666 semi-detached dwellings. A 5 per cent random sample was selected, using the latest available 1:25,000 orthophoto and topographic maps . Every 20th house in each CCD (counting clockwise around the block, from a random start) was selected[8]. Flats, home units and obvious shared houses were not included. This yielded a sample of street addresses of 356 houses, of which field checks eliminated ten; four were semi-detached dwellings, two commercial premises, and four were empty dwellings (being renovated or for sale).

In the Salisbury East area it was considered that the houses needed to have been occupied for at least a year, to enable the householder to have experienced summer and winter conditions. The personal interviewing of householders in the southwestern suburbs had exhausted the financial and physical resources of the author so that an alternative method of administering the Householder's Questionnaire was necessary in Salisbury East. Self completion (mail out, mail back) was therefore selected. A sample size of 300 was considered optimum due to the expected lower response-rate by mail questionnaire. The house locations[9] were obtained from the company records of Alan Hickinbotham Pty. Ltd., in which 243 "specs" (houses sold after or during construction) and 104 "contracts" (houses sold before construction) had

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8. Street addresses were obtained from the listing in Sands and McDougall's Directory of S.A., 1973

9. The lot number locations recorded by Alan Hickinbotham Pty. Ltd. were converted to street addresses by Salisbury City Council.

been built in Salisbury East between July 1970 and December 1973 (a minimum of 16 months prior to the intended survey). A questionnaire was mailed to the first 300 households on this list.

The Householder's Sample

The extent to which the questionnaire sample is representative of age and style of housing, private and public sector construction, and of socio-economic status in the Adelaide Metropolitan Area has been discussed above. To further test the reliability of the sample, various attributes of the sampled houses and households were compared with the equivalent data (1971 Census) for the population of the Local Government Areas (hereafter LGA's) which contain the CCD's from which the samples were drawn and for the whole of Adelaide (Adelaide Statistical Division). Although some differences in the compared distributions do occur, most can be explained[10].

Information from Households and Householders

An interview - questionnaire schedule for householders in the two sample areas was the main source of data. This was supplemented by a House Details Form and facade photographs (both by interviewer) and a small temperature survey (records kept by householders). Energy consumption data for each sampled dwelling were obtained after the household survey had been completed.

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10. See Appendix IV, pp. 416-421.

The Householder's Questionnaire. The questionnaire was designed to obtain data describing

* the house, its immediate environment and its occupants
* priorities in its purchase
* past and anticipated modification
* the existing methods of heating, cooling and related aspects
* levels of satisfaction with thermal comfort
* attitudes to air conditioning
* general attitudes to, and knowledge of, "design for climate" in Adelaide housing[11].

The schedule was pre-tested in both personal interview and self-administration situations, and some minor changes made. Interviewing in the southwestern suburbs was completed between September 1st and November 30th 1974, by one interviewer (the author). Thus first calls in the southwestern suburbs were completed during the three months of spring[12]. Each interview took a minimum of 15 minutes; most were 30 minutes or longer. If, after two calls to the house, no contact was made, the questionnaire was left under the front door, with an explanatory note and reply-paid envelope. The original sample contained 356 addresses, of which ten were immediately rejected on the first field check. This left 346 addresses, of which 154 questionnaires (44.5 per

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11. The Householder's Questionnaire is presented in Appendix I, pp. 397-403.

12. Since the interview schedule sought information from the householder on the summer and winter comfort of the house, it was important that the householder was not over-influenced by a period of weather extremes (heat wave or intense cold and rain). Thus the three hottest months in Adelaide (December, January and February) and the three coldest months (June, July, August) were not used for interviewing of householders.

cent) were completed by personal interview and 152 questionnaires (43.9 per cent) completed by the householders. There were 40 non-completions (12 per cent), the reasons for which are given in Table 3.05. The House Details Form was completed and a facade photograph taken for each of these 40 houses, but no substitutions of new households were made for the purpose of completing an interview - questionnaire. Although 14 per cent of the heads of households (south-western suburbs) were born in non English-speaking countries, few language problems were encountered, and verbal difficulties were the main reason for only three non-completions.

Interviewing was mainly carried out in the hours between 9.30 a.m. and 4.30 p.m., on the premise that the person (usually the wife) at home during these hours is the household member most frequently in the dwelling, and able to assess its day-to-day "comfort". Questionnaires left for self-administration were completed by any (adult) household member.

The Salisbury East questionnaires were mailed to "The Householder" on April 30th, 1975. A reminder note was sent to the non-returns on May 29th, 1975. Since the target of 50 per cent response was reached by early July, no further reminders were sent.

Possible bias may have been introduced by the dual method of administration of the Householder's Questionnaire. Evidence of significant methodological bias, where the distributions of answers to questions vary according to the method used, is discussed in Appendix IV (pp. 422-425).

TABLE 3.05

SUMMARY OF HOUSEHOLDER'S QUESTIONNAIRE COMPLETIONS AND REASONS FOR NON-COMPLETIONS

	Southwestern Suburbs			Salisbury East		
Reason for non-completion	No. of respondents	Percentage of non-completions	Percentage of sample	No. of respondents	Percentage of non-completions	Percentage of sample
No contact made with household or questionnaire not returned	8	20.0	2.3	151	98.1	50.3
Questionnaire returned blank or no reason given	9	22.5	2.6	1	0.6	0.3
Respondent (or spouse) "not wishing to participate"	6	15.0	1.7	2	1.3	0.7
Age, health, language reasons	6	15.0	1.7	-	-	-
Respondent "too busy"	6	15.0	1.7	-	-	-
Questionnaire an "invasion of privacy"	3	7.5	0.9	-	-	-
Recent death in family	2	5.0	0.6	-	-	-
Total non-completions	40	100.0	11.6	154	100.0	51.3
Interviews completed	154		44.5	-		-
Questionnaires completed by householder	152		43.9	146		48.7
Total	346		100.0	300		100.0

Source: House Details Form.

The House Details form and Facade Photographs. From the street, each house and garden was classified according to a number of categories, and a facade photograph taken[13]. Aerial photographs also assisted in identifying some of the features beside and behind the dwellings[14]. The structural and environmental data recorded on the House Details Form are shown in Table 3.06.

Some details provided by the householder in the questionnaire could be compared with similar specifications in the House Details Form. The householders often provided information on features not readily visible from the street (such as a back verandah, outside awnings, or the presence of large trees). Correspondences between the House Details Form, the aerial photographs and responses to the questionnaire are good, except on one item - Question 12(g):

> "shrubs, trees, vines etc., providing substantial shade to parts of the house (including from neighbouring properties)."

Table 3.07 compares the questionnaire responses to this question with data from aerial photographic and street observations and shows that there was a discrepancy of 16 per cent in the southwestern suburbs. Forty-one householders under-estimated and seven householders over-estimated the amount of shade received from vegetation in their own or adjacent properties. The error probably stems from the wording of the question, particularly interpretation of "substantial" and "parts of the house". Similarly, when asked to state the type of vegetation

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13. The House Details Form appears in Appendix I, pp. 404-405. Some facade photographs appear in Chapters 4 and 6.

14. Examples of aerial photographs appear in Figures 6.1 and 6.2 in Chapter 6.

TABLE 3.06

LIST OF ITEMS RECORDED ON HOUSE DETAILS FORM

(1) House style and age
(2) General description of house
(3) Nature of garden and trees
(4) House orientation (front of house)
(5) House type (e.g. one storey/split level)
(6) Size of house (floor space)
(7) Floor plan (e.g. square, elongated)
(8) Roof material
(9) Roof pitch
(10) Colours - roof, walls
(11) Ratio of window to wall
(12) Shading - eaves
(13) Shading effectiveness - vegetation
(14) Shading - verandah, porch, other features
(15) Local environment
(16) Effort by occupant to modify climate aspects - house, garden
(17) Method of questionnaire completion
(18) Reason for non-completion

providing the shade, approximately ten per cent of householders made an incorrect judgement, possibly due to lack of understanding of the terms "deciduous" and "evergreen", or because they were describing all the vegetation of their gardens, not just that part providing "substantial shade" (Table 3.08). Since most of these discrepancies occurred in questionnaires that were completed by the householder (when the

TABLE 3.07

QUESTIONNAIRE RESPONSES ON QUANTITY OF SHADE PROVIDED BY VEGETATION BY OTHER EVIDENCE ON HOUSE-SHADING (Southwestern Suburbs)

Photographic and observational evidence	Questionnaire responses (percentage)	
	House has substantial shade	House has no substantial shade
House has substantial shade from shrubs, trees, vines etc.	96	32
House has no substantial shade from shrubs, trees, vines etc.	4	68
Total	100 n = 172	100 n = 128

Source: Householder's Questionnaire (Question 12(g)), House Details Form, aerial and facade photographs.

TABLE 3.08

QUESTIONNAIRE RESPONSES ON TYPE OF VEGETATION PROVIDING SHADE BY OTHER EVIDENCE OF TYPE OF VEGETATION (Southwestern Suburbs)

Photographic and Observational evidence	Questionnaire responses (percentage)		
	Mainly deciduous	Mainly evergreen	Both
Mainly deciduous	60	7	2
Mainly evergreen	25	88	11
Both	15	4	67
Total	100 n = 48	100 n = 67	100 n = 89

Source: Householder's Questionnaire (Question 12(g)) and photographic and observational evidence.

Chi-square (original data) = 201.58, df = 4, s = .0000

interviewer was not present to assist) it would seem that the wording of the question was the main cause. This deficiency was not revealed in pre-testing of the schedule.

The Household Temperature Survey. In order to test the hypothesis that the physical structure of the dwellings affects the internal temperature pattern, seven houses representing predominant house-styles were chosen for temperature surveys of a simple nature. A U-type maximum - minimum thermometer was installed in one or two locations in each of the seven sampled houses in the southwestern suburbs, and the daily maximum and minimum temperature (dry bulb) recorded on a chart by the householder during March and April, 1975. Table 3.09 shows the nature of the houses and the thermometer locations.

Household Energy Consumption. Although the interview/questionnaire schedule provided information on the design and structural and mechanical methods of achieving physically comfortable conditions indoors, no data were requested from the householder on energy consumption and costs. Approaches were made subsequently to the supply authorities of electricity, gas and heating oil in Adelaide in order to obtain data on energy use in the sampled houses. A time period of two years was chosen, 1974-75, to coincide with the administration of the householder schedule. This also reduced the possibility of an atypical period of consumption, without allowing the data collection to exceed manageable limits.

Quarterly consumption data (on two tariffs) for two years were provided for 452 households by the Electricity Trust of South Australia, and two-monthly data for two years collected for 334 households from the

TABLE 3.09

LOCATION OF THERMOMETERS USED IN HOUSEHOLD TEMPERATURE SURVEY

House	House-style & year built	Wall & roof feature	Location of thermometer(s)
A	Villa front c.1900	Bluestone & free-stone walls, galvanised iron roof (new)	Kitchen, (facing south)
B	Bungalow, c.1920	Red brick walls, freestone front, galvanised iron roof	1. Kitchen (south-(east) 2. Sunroom (on north-west corner)
C	Bungalow, c.1927	Red brick walls, freestone front, white-tiled roof	Central passage
D	Tudor, c.1936	Sandstone & brick walls (painted cream)	Living room (facing south)
E	Austerity, 1950	Limestone walls (painted light green), galvanised iron roof	Kitchen (centre of house)
F	Conventional Triple-front 1959	Dark cream brick walls, light grey tiled roof	1. Kitchen (facing north) 2. Lounge (facing south)
G	Ranch, 1969	Cream brick walls, light red tiled roof	1. Living room (with wall air conditioner) 2. Playroom (facing north)

Source: Temperature Survey.

Note: Room layouts of houses B, C, F, are shown in Figure 7.2.

micro-film records of the South Australian Gas Company[15]. The collection of data on heating oil consumption was more difficult, since it was not known which of the six companies serviced the householder's tank. The address list of 53 householders known to use heating oil was

15. The co-operation of the Electricity Trust of South Australia and of the South Australian Gas Company is gratefully acknowledged.

sent to each company, with a request for consumption data on any of the company's customers listed. This eventually yielded data on 33 households[16] so that, for the purposes of data analysis (see Chapter 8), the remaining 20 households were assumed to use heating oil at the "average" rate (the mean consumption for the 33 households in which consumption was known)[17].

The Non-Household Component

Sampling Procedure

The study was designed to integrate information obtained from householders with information obtained from architects and building designers, building firms, real estate personnel and commercial firms dealing in products such as air conditioning and thermal insulation. Before sampling of these groups could be undertaken, the "population" of each had to be defined. This was more difficult than for householders, where Census Data could be used.

Building Firms. There were 963 "Builders and Contractors" listed in the business section of the 1974 Adelaide Telephone Directory. This necessitated a classification into groups, on the basis of size, type of operation,

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16. One company did not reply, another claimed none of the listed customers; one householder was "claimed" by two companies. The co-operation of the South Australian offices of five oil companies is gratefully acknowledged.

17. Subsequent analysis revealed considerable differences in energy consumption from one household to another, thus reducing the validity of assuming average consumption.

price-range of house, sales and marketing methods. Some information (on size and type of operation) was obtained from the Master Builders Association (Chapter 4, p. 106) and from real estate sections in the daily newspapers. All large firms operating in 1975 were included, since they make a major contribution to design and building trends: some smaller firms were included as representatives of their type; others were distinctively different[18]. Of a total of twenty-two building firms contacted, nineteen were interviewed. The reason for non-completion was either lack of interest, or that the firm was "too busy". The interview was based on the questions contained in the building firm questionnaire which was mailed in advance to the General Manager, with a covering letter[19]. Information on the general nature and size of the firm's building operation, the design, building and marketing methods, and details of "design for climate" aspects were included. Each interview took 45 minutes or longer and was conducted in the May, June, July months of 1975. Further information on the building firms was obtained from personal inspection of houses built by the interviewed builders[20] and by monitoring the real estate and home building sections of the local newspapers.

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18. Characteristics of the interviewed building firms are shown in Table 4.12.

19. The Building Firm Questionnaire appears in Appendix II, pp. 408-410.

20. Occasionally builders' houses were inspected as part of the interview, but more frequently by a later visit to exhibition homes and display villages.

Architects and Building Designers. Obtaining a representative sample of designers presented a similar problems. The business section of the 1974 Adelaide Telephone Directory listed 168 architects. However, relatively few are engaged primarily in domestic architecture, and the President of the Royal Australian Institute of Architects (South Australian Chapter) was able to recommend a "short list" of such members, to which were added two "building designers". A semi-structured interview was devised to elicit similar information to that obtained from the building firms as well as additional comment on the design of housing in Adelaide and elsewhere. A total of ten architects and building designers were interviewed at various times during 1974 and 1975.

Real Estate Agents. Various selection procedures were considered, using as a basis the lengthy listing of "Real Estate Agents" in the Telephone Directory. However, the Real Estate Institute of South Australia offered to mail a questionnaire, with a covering letter from the President, to all Ordinary Members of the Institute. In May 1975, membership was approximately 650. To restrict the length and time taken for reply, the questionnaire was restricted to four questions; two of which were "borrowed" from the Householder's Questionnaire[21]. Mailing took place on May 5th, 1975, with a reply-paid envelope for its return. By June 30th, 158 completed and three blank questionnaires had been returned (a response rate of 24 per cent). The location of the suburban offices from which usable replies were received is shown in Figure 3.4. The only reminder was an article in May/June (1975) issue of the Real

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21. The Real Estate Institute Questionnaire appears in Appendix III, pp. 411-413.

Estate Institute Bulletin (see Appendix III, p. 414) which published and commented on the survey results received from real estate members before the middle of June, 1975.

Manufacturers and Retailers. To improve summer or winter comfort, or both, the householder can modify his house by using such products as a heating or cooling system, ceiling insulation or outside awnings. Using the business section of the 1974 Telephone Directory, and other sources, firms dealing with such products were grouped on the basis of type and size of operation and products sold. Fifteen firms were selected, so that all major manufacturers and retailers of air conditioners , heaters, thermal insulation and window treatments in South Australia were included (Table 3.10). The Electricity Trust of South Australia and the South Australian Gas Company were also consulted. A semi-structured interview was used to obtain information on the nature, type and market trends of the products sold, and to assess the general awareness of "design - for - climate" principles among sales staff and purchasers of the firm's products. Interviewing occurred in the first few months of 1975.

The Analysis, Presentation and Interpretation of the Data

The data sources and collection methods used in this study are summarized in Table 3.11. This final section of the chapter explains how these data were analysed, presented and interpreted.

The levels of measurement employed in the collection of the data relating to the house structure and its occupants were primarily nominal and ordinal, which both preclude arithmetic operations and all parametric statistical tests (Siegel, 1956, 22-26). The statistical

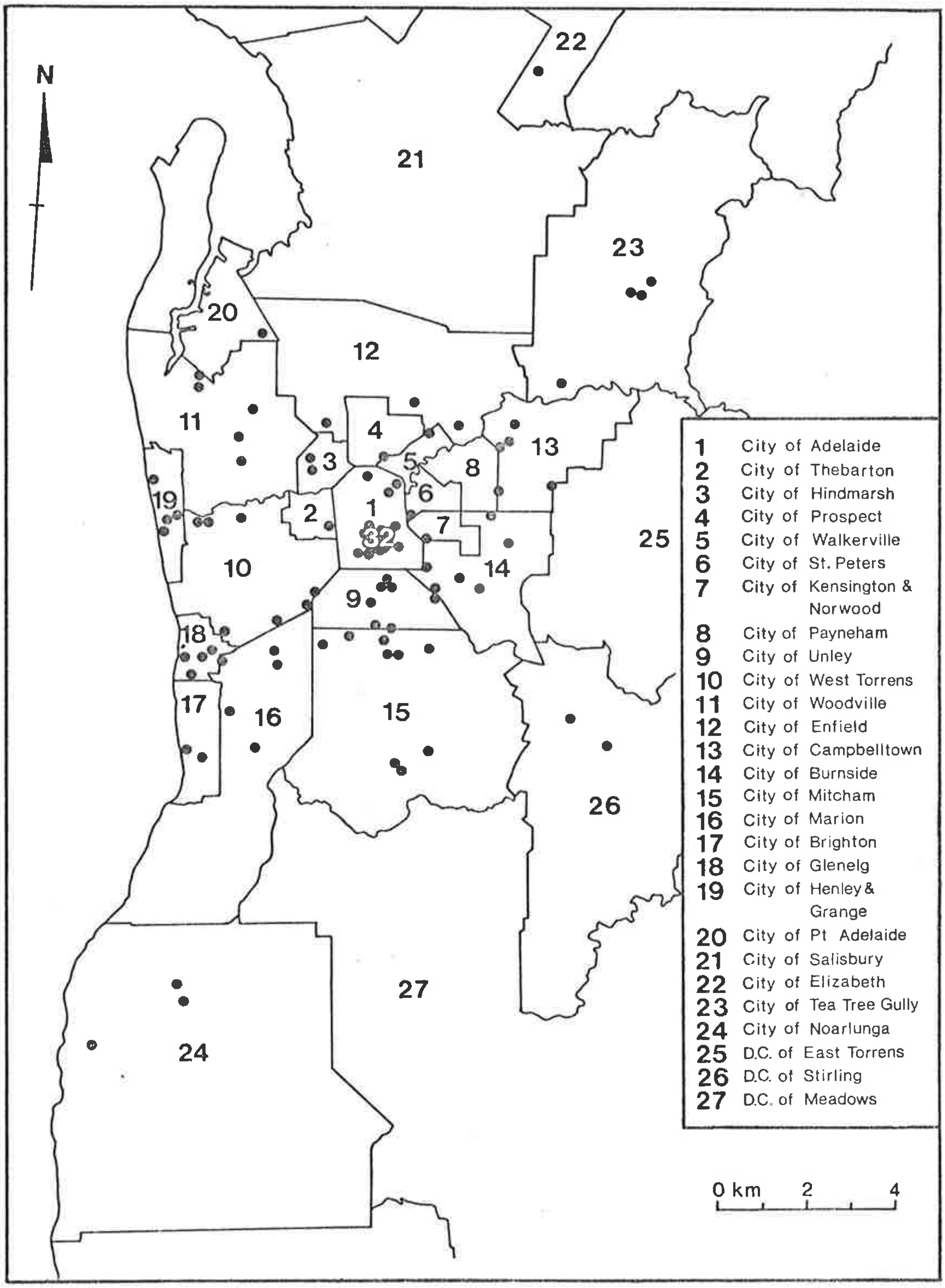

FIG. 3·4 SUBURBAN OFFICE LOCATIONS OF RESPONDENTS TO REAL ESTATE INSTITUTE QUESTIONNAIRE

TABLE 3.10

CHARACTERISTICS OF MANUFACTURING AND RETAILING FIRMS INTERVIEWED

Type of Operation	Products
Manufacturer/Distributor	Oil and gas space heaters, slow combustion heater, electric radiators, central heating system.
Manufacturer/Distributor	Room air conditioners. Mobile, split and ducted systems. (Refrigerated cooling, reverse-cycle heating).
Manufacturer/Distributor	Room and multi-room air conditioners. Split and ducted systems. (Refrigerated cooling, reverse-cycle heating).
Manufacturer/Distributor	Room and multi-room air conditioners. Split and ducted systems. Central heating systems. Kerosene heaters.
Manufacturer/Distributor	Portable and ducted evaporative cooling. Oil heaters. Combined gas space heating/evaporative cooling.
Contractor	Packaged units, split systems. Refrigerated, reverse-cycle, evaporative cooling, oil and gas heating.
Manufacturer/Distributor Contractor	Oil space heaters. Refrigerated, reverse-cycle, evaporative cooling. Oil and gas heating.
Installer/Retailer	Split and ducted refrigerated and reverse-cycle air conditioning units.
Manufacturer/Distributor	Mineral wool and fibreglass insulation.
Manufacturer/Distributor	Cellulose (loose-fill) insulation.
Manufacturer/Distributor	Reflective (aluminium) insulation. Window insulation.
Installer/Retailer	All types of ceiling insulation, blinds and awnings.
Installer/Retainler	Reflective window treatment.
Manufacturer/Distributor	Blinds, awnings, curtains, screen doors, etc. Mineral wool ceiling insulation.
Manufacturer/Distributor Installer	Blinds, awnings, curtains, etc.

TABLE 3.11

SUMMARY OF DATA SOURCES AND METHODS USED

SELECTION PROCEDURE	SAMPLE SIZE	COMPLETIONS	DATA-COLLECTION METHODS
HOUSEHOLD COMPONENT			
Householders			
(1) Southwestern suburbs: every 20th house from aerial photographs, in a sector of C.C.D.s in the southwestern suburbs, from Unley to Somerton Park	346	306	A. Householder's Questionnaire (householders of southwestern suburbs interviewed personally, Sept-Nov, 1974; sent by mail to householders of Salisbury East, March-May, 1975)
(2) Salisbury East: all houses completed by one large commercial builder, between June, 1970 and December, 1973	300	146	B. House Details Form and Facade Photographs (completed by interviewer)
Total	646	452	C. Survey of Household Energy Consumption (two years' data of electricity, gas, heating oil consumption, obtained from energy supply authorities)
Total	7	7	D. Household Temperature Survey (representative house styles: daily maximum-minimum temperatures recorded by householder)
NON-HOUSEHOLD COMPONENT			
(1) Building firms: representative house-building firms of Adelaide, in terms of size, type of operation, price-range of house, sales and marketing methods	22	19	A. Building Firm Interview (representative personally interviewed, May-June, 1975) B. Personall inspection of typical houses
(2) Architects and Home Designers: representative selection of those primarily engaged in domestic design	10	10	Personal interview, during 1974 or 1975
(3) Real estate personnel: all Ordinary members of the Real Estate Institute of South Australia	675	161	Real Estate Institute Questionnaire (short questionnaire mailed out by R.E.I., April, 1975)
(4) Manufacturers and Retailers: a representative selection of air conditioning firms, heating/cooling, thermal insulation, window treatment etc.	15	15	Semi-structured interview, 1975
(5) Energy-Supply Authorities (ETSA, S.A. Gas Company, Shell Co. etc.)	4	4	Discussion with various representatives, 1974-1978

tests employed in much of the analysis were limited, therefore, to non-parametric techniques. Some examination of relationships between the two variables was carried out by collapsing raw values into suitable categories, and then producing two-way contingency tables[22]. Statistics used were chi-square for associations in which the lowest level of measurement was nominal and Kendall's tau_c for associations in which the lowest level was ordinal (Nie et al., 1975, 4-5).

The data are presented in tables which are either simple frequency distributions for single variables, or percentage contingency tables for pairs of variables. Where appropriate the value, degrees of freedom and significance of the chi-square test, and the value and significance of Kendall's tau are presented at the ends of the tables. The chi-square test was used extensively throughout the analysis to determine the significance of differences between categories of responses to questions in the questionnaires or attributes of housing identified by observation. A large chi-square value, with a probability level of .001 or less, represents the likelihood that the observed frequencies are not in close agreement with the expected frequencies and that there is a significant difference in the categories of attributes. However, the actual nature of the relationship can be inferred only from the structure of the contingency table (Siegel, 1956, 42-45, 104-111).

Kendall's rank correlation coefficient, tau_c , yields a value of +1 for perfect correlation and the significance of the coefficient can be calculated. The value and significance of Kendall's tau_c are given in a few tables which present the results of correlating the householders'

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22. The CROSSTABS subprogram of the Statistical Package for the Social Sciences (SPSS) was used (Nie et al. , 1975, 320-367).

evaluations of the comfort of their house with ordinally - measured variables describing the house or household (such as the number of verandahs or the size of the household). A level of significance of ".001" not only represents the probability that the variables are related, but also indicates the degree to which the relative ordering on the first variable is the same as the relative ordering on the second variable (concordant) or if the ordering is reversed (discordant). Thus the nature and strength of relationships are measurable. The results of chi-square tests or Kendall's tau_c calculations with levels of significance of .20 or higher have been regarded as "not significant" in the present study.

Since the level of measurement of data on household energy consumption was on a ratio scale, all arithmetic operations and parametric statistical tests could be used. The Pearson correlation coefficient (Pearson's r) was used to measure the strength (and direction) of the linear relationships between seasonal energy use for each household and seven meteorological variables. The level of significance (p) chosen was 0.05. This permitted the seasonal nature of energy consumption to be examined for each household individually and for the entire group of sampled households.

The technique used to analyse the relationship between the dependent or criterion variable (Annual Household Energy Consumption) and a set of independent or predictor variables was multiple regression. The use of stepwise regression procedures to develop operational models of household energy consumption in the sample areas of the southwestern suburbs and Salisbury East is explained in Chapter 8.

Halkett (1975, 63) points out that the non-parametric levels of measurement such as those employed in his study of the use and design of residential gardens present a fundamental problem inherent to social science and behavioural studies of this genre; to what extent can the relationships observed in a plethora of non-parametric data be assumed to occur in the population from which the sample was drawn? Halkett argues that the answer lies in the reliability of the sample: the sample must be a good representation of the population, but that this cannot be rigorously tested in a new field of inquiry where the data are non-parametric, and judgement must be intuitive. However, he suggests, three basic procedures can be observed. First, the sample data can be compared with other data of known reliability. In the present study data which describe some of the characteristics of the sampled households are compared with Census data and it is possible to account for most of the differences between the two. Second, the data can be examined for unaccountable internal inconsistencies. Such inconsistencies do occur between the street observation data and the questionnaire data, and within the questionnaire data, but in most cases it is possible to account for the observed differences and where it is not possible, variables are eliminated from the analysis. Third, the sample data must be judged on the basis of whether the observed phenomena conform with the expectations of informed observers, even in the absence of comprehensive and comparable empirical precedents: few of the data presented in this study will be regarded as extraordinary by observers familiar with the suburban environment of Adelaide.

CHAPTER 4

THE IMPORTANCE OF CLIMATIC SUITABILITY AND COMFORT IN THE DESIGN AND CONSTRUCTION OF HOUSES IN ADELAIDE

The process of design and construction is a major factor in determining the climatic suitability and indoor comfort of a dwelling, and the energy required to maintain it. The decisions of the architect, builder, building-design firm or owner-designer on such matters as the siting of a house, the type of floor, wall and roof materials, the room layout, size and placement of windows and the nature of roof overhangs will always affect the life-style of its occupants. Even with later structural modifications (such as changing the roof material, increasing the size of window, or adding thermal insulation) the original house structure remains dominant.

The general pattern of design and construction of housing in Adelaide is complex, and reflects both the influence of overseas and interstate ideas, and the availability of local building materials and skills. The result has been a range of distinctive house-styles with varying degrees of suitability to the local climate. In this chapter, a brief historical perspective of house design and construction in Adelaide is followed by a description of present-day processes of design and construction, and an analysis of the efforts made by designers and builders to incorporate design-for-climate principles in the design and construction of their houses being built in Adelaide during the 1970's.

The House Styles of Adelaide

The residential fabric of Adelaide has been strongly influenced by the gridiron pattern (Van Zyl, 1963b), by the method of subdivision and street layout (Williams, 1974) and particularly by the repetitious building of several, distinctive house styles. Identification of house styles is aided by the use of features of the house facade, a method used by Rickert (1967) and Lewis (1975) in the United State of America, by Rubin (1977) in Los Angeles, by Middleton (1964) in Auckland, and by McCabe (1965) in his chronological classification of Brisbane house types.

For Adelaide Chappel (1958, 1972a, 1972b) has identified eight periods and dominant styles of housing, while the Real Estate Institute of South Australia (c.1968) published a booklet for its members, in which eighteen styles are identifed, compiled from a collection of over 500 photographic examples of period design. Williams (1974, 42) bases his "impressionistic sketch" primarily on visual observation. Details of these three classifications and the one used in this study are shown in Figure 4.1.

Plates 4.01 to 4.14 illustrate the dominant housing styles in Adelaide since the 1840's: Table 4.01 outlines the general architectural nature of each style, certain climate-related features and the probable outcome on indoor comfort. Much of the "climatic relevance" material is based on the work of Marshall (1963a) who points out that most housing styles originated from countries with different climates, and, even when modified for local use, remained climatically unsuitable. Over 140 years of house-building in Adelaide has resulted in a geographical pattern of older stone, iron-roofed houses with verandahs in the inner suburbs, extending to post-war private and public-sector housing in the outer suburbs, built of cavity brick or brick-veneer, with tiled roofs, larger windows and wide eaves.

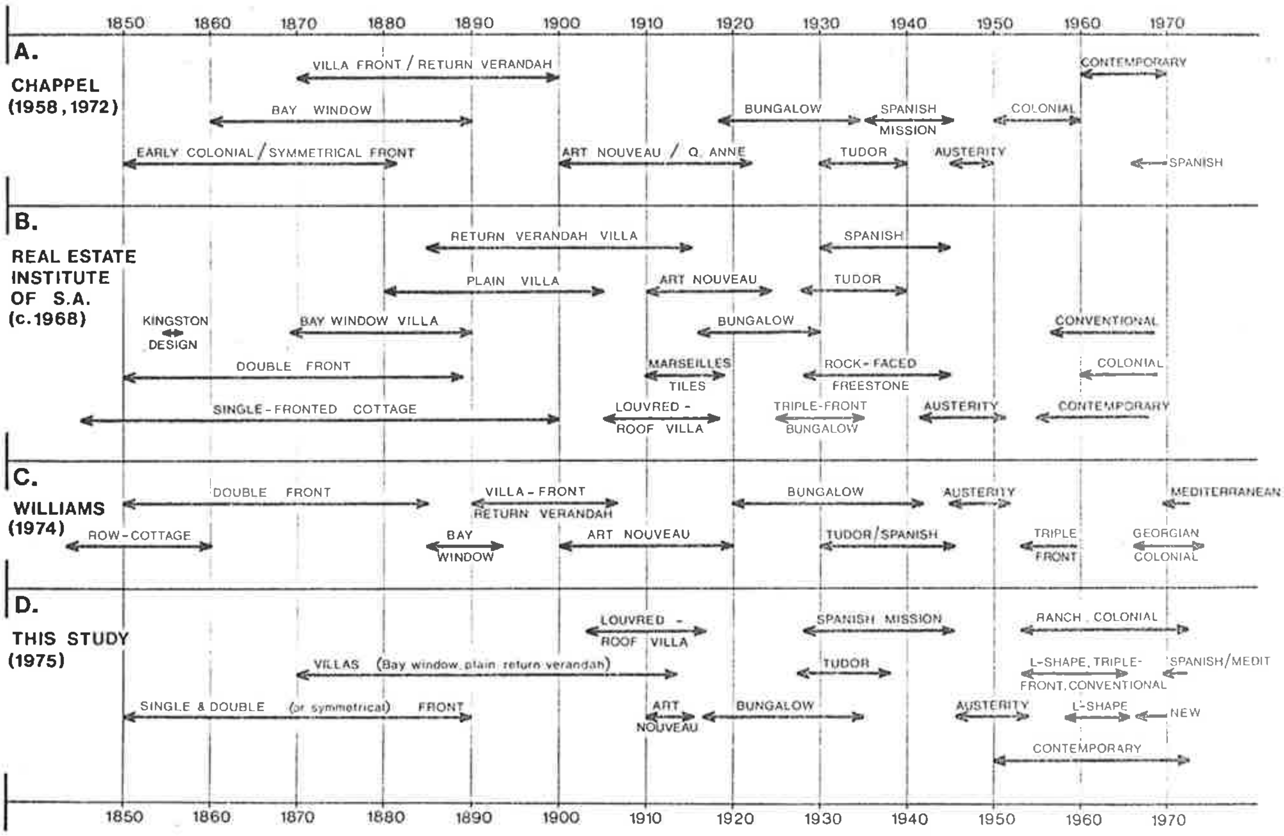

FIG. 4·1 HOUSE-STYLE CLASSIFICATIONS FOR ADELAIDE HOUSING

TABLE 4.01

HOUSE STYLES IN ADELAIDE SINCE 1842: GENERAL AND CLIMATE-RELATED FEATURES

GENERAL ARCHITECTURAL FEATURES	CLIMATE-RELATED ASPECTS
(1) Single and Double (or Symmetrical) Front: c1850-1890 (see Plate 4.01)	
Simple design, built usually of coursed or random bluestone, sandstone or limestone with galvanised iron roof and front verandah. Double-front designs featured a central passage with rooms opening off each side: additional 'lean-to' rooms often added to rear.	Stone walls served to keep house cool for the first few days or week of hot weather: cold in winter. Iron roof waterproof, but box gutters often overflowed. Unlined verandah always at front regardless of direction, and of limited value with regard to shading, room temperature or outdoor living: served to keep porous walls dry.
(2) Villas: c1870-1916 (see Plates 4.02, 4.03, 4.04)	
Usually built on bluestone footings, with bluestone walls, and iron 'well-type' roof, (which sloped inwards to a box gutter) reduced-length iron verandah of various contours (e.g. bullnose). Variations included bay window, plain villa, return verandah, louvred roof, with varying degrees of ornamentation. Asymmetrical appearance achieved by pushing 'front parlour' forward: rooms still opened off central passage.	Thick stone walls (plus high ceilings and small windows) kept house cooler in summer: also difficult to heat in winter. Projecting front window (from shortened verandah) usually fitted with fixed wooden awning or moveable shutters. Louvred roof originally functional to overcome the problem of the leaking 'well' roof and to allow air to flow through: louvres became ornament later. Central passage main source of ventilation.
(3) Queen Anne/Art Nouveau: c1910-1916 (see Plate 4.05)	
Developed from louvre-roofed, return-verandah villas: had more complicated roof-line, further asymmetry and over-ornamentation. Introduction of tiled roof ("Marseilles" tiles popular 1910-1918, followed by local terracotta), concrete footings, timber fretworks, leadlights and casement windows.	More complex room layout may have reduced cross-ventilation. Tiled roof (instead of iron) may have reduced roof and ceiling temperatures slightly.
(4) Bungalow: c1916-1935 (see Plate 4.06)	
Specialized meaning in South Australia: rectangular shape, with stone-faced front and brick back, made to look more impressive by the addition of a lower-roof pitch, gabled wide verandah, and sometimes a pergola. Later (1925-1935) style featured a triple-front of brick or rockfaced freestone, massive piers to the lightweight verandah, varying roof designs, and cement or tiled floor to the front verandah (¾ full width of house).	Lower pitch to iron or tiled roof has marginal effect on ceiling temperature. Verandah still at front, regardless of direction: even if on north side, greater width excluded sun from windows during summer - and in winter when not needed. Pergola ornamental rather than functional.
(5) Tudor: c1928-1938 (see Plate 4.07)	
Still a bungalow-style house with a steeply pitched roof of galvanised iron or tiles, plus a few pseudo-Tudor trimmings, such as ornamental gables, half-timbering and leadlight windows.	60 degrees slopes originated in climates of heavy rain or snow and quite unnecessary, and unsuitable for Adelaide: if dark coloured, major area for absorption of solar radiation and excessively high roof temperatures attained.
(6) Spanish Mission: c1929-1945 (see Plate 4.08)	
First used in upper price-bracket houses: later adapted to brighten up otherwise very plain small villas with a few decorative Cordova tiles, 'barley sugar' pillars, stucco walls and applied arches.	Genuine features (massive walls, reduced window size, white-washed surfaces, shaded outdoor living area) well-suited to Adelaide's (summer) climate: used more frequently as ornament rather than functional value.
(7) Austerity: c1946-1952 (see Plate 4.09)	
War-time shortages and post-war economics meant that a plain type of dwelling was all that could be built - with a lower roof, minimum eaves, and a tiny front porch (often a slab of concrete) the only ornament: poor quality bricks were frequently cement-rendered with a stucco finish.	Start of post-war trend towards lower roof pitch and height of ceilings (plus minimum eaves and no verandahs of immediate post-war period) changed thermal performance of house (reflects outdoor temperatures more quickly).
(8) Contemporary: c1950-1972 (see Plate 4.10)	
Typified by low-pitched roof lines, extensive use of glass and of stained timber. Appeared as early as 1940, but in the luxury class, or a foothills location: extends into the 1970s with the 'Natural' style used in the Hills areas, where the shape and colouring of the house are designed to blend with the bushland.	First low-pitched or flat roofs, needing careful insulation. Large picture windows (floor-to-ceiling glass) nearly always at the front of the house, regardless of orientation, a special problem in summer: thus extensive use of outside awnings and inside Venetian blinds to reduce internal temperature. Major problem in foothills suburbs, where view is to the west: airconditioning not optimum solution due to large areas of glass.
(9) Conventional: c1952-1965 (see Plates 4.11, 4.12)	
From mid-1950s cream bricks frequently used, followed by tuck-pointed sawn stone: wide eaves, big windows and later garages or carports under the main roof, grey or black tiles popular. Variety from a number of shapes - triple-front, stepped front, L-shape, T-shape.	Large windows still needed sun protection, when on east or west, and usually on north side also, even with wide eaves. S.A.H.T. used glass to restricted extent and were generally more careful about orientation. Reflective value of black tiles virtually nil. Cross-ventilation aided by some of these plan-shapes.
(10) Colonial: c1952-1972 (see Plate 4.13)	
Characterised by small Georgian window panes, with functional or decorative shutters, and sometimes bay windows. Intended to make a plain, economically built dwelling look attractive, and to add a touch of distinction to the more luxurious house.	Smaller window-size (and shutters, if functional) reduced summer heat load.
(11) Spanish/Mediterranean: c1970- (see Plate 4.14)	
Conventional room layout with addition of few Spanish-style archways, covered porchways, wrought-iron gate and so on, onto the facade: often painted white, with orange-red roof tiles. Common in 'speculative' houses.	As with earlier 'Spanish Mission', core features of genuine Mission or Mediterranean architecture not incorporated: 'superficial facadism', in order to make house look attractively different.

Source: Compiled from Chappel (1958, 1972a), Real Estate Institute of South Australia (c1971), Marshall (1963a) and other sources such as house facade photographs.

Plate 4.01. Symmetrical front, built c 1895, Clarence Park; bluestone walls, galvanised iron roof.

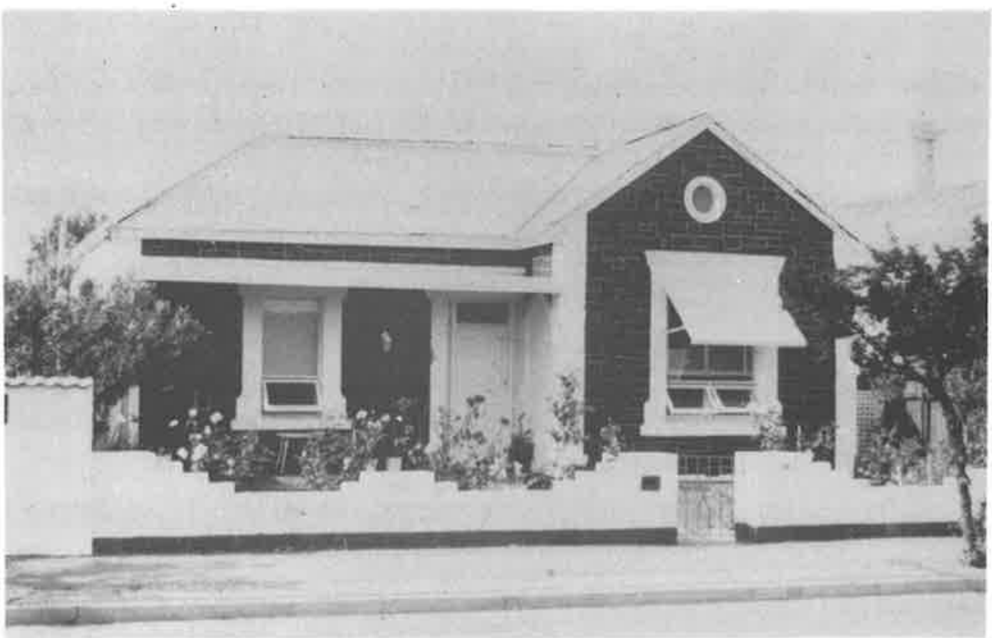

Plate 4.02. Plain Villa, built c 1900, Hyde Park; bluestone walls, galvanised iron roof.

Plate 4.03. Return Verandah Villa, built c 1905, Hyde Park; freestone walls, galvanised iron roof.

Plate 4.04. Louvred Roof Villa, built c 1905, Unley; red brick and freestone walls, galvanised iron roof.

Plate 4.05. "Queen Anne", built c 1920, Hyde Park; red brick and sandstone walls, galvanised iron roof.

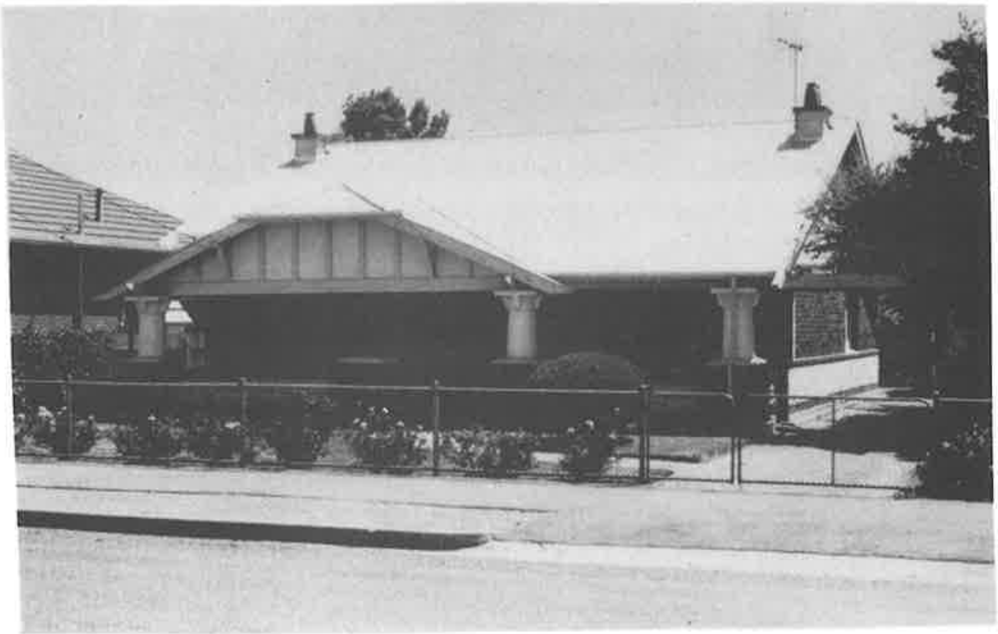

Plate 4.06. Bungalow, built 1925, Clarence Gardens; red brick and sandstone walls, galvanised iron roof.

Plate 4.07. Tudor, built 1930, Unley; red brick and sandstone walls, tiled roof.

Plate 4.08. Spanish Mission, built 1935, Clarence Park; red brick walls with stucco finish, tiled roof.

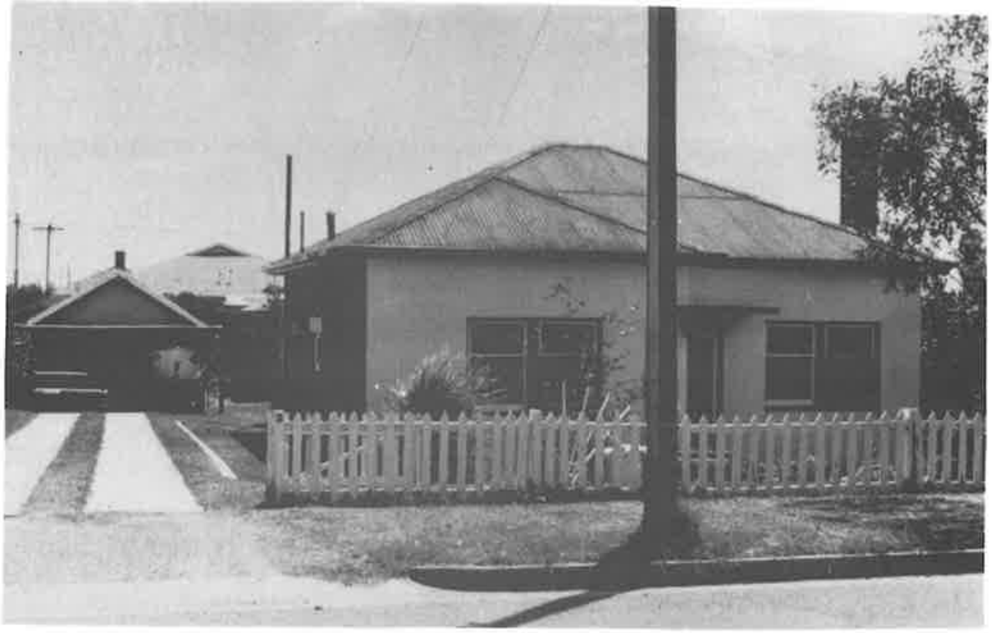

Plate 4.09. Austerity, built 1946, Somerton Park; red brick walls, galvanised iron roof.

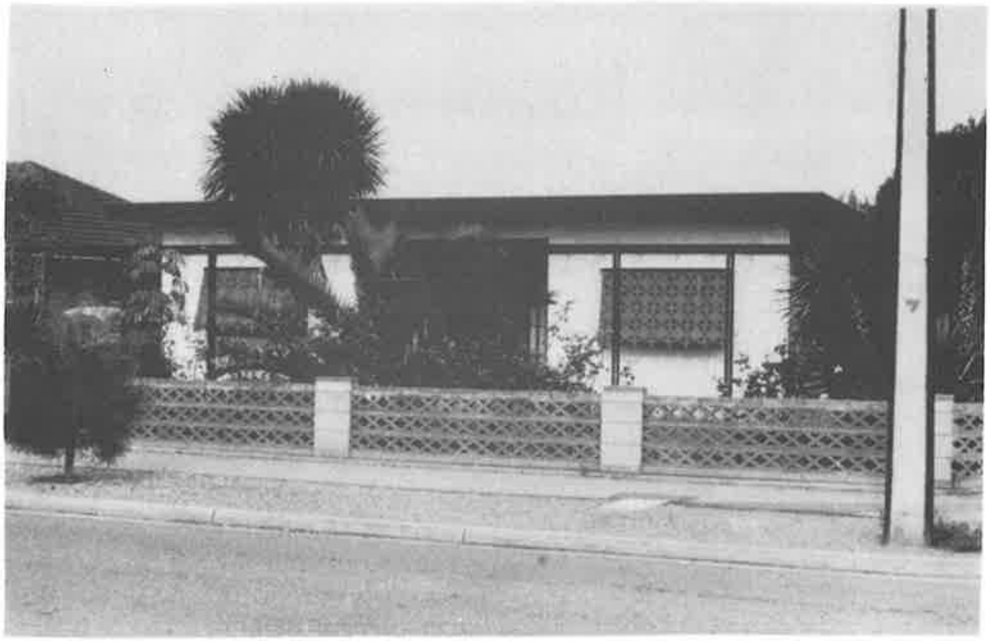

Plate 4.10. Contemporary, built 1950, Somerton Park; cement block walls, steel roof.

Plate 4.11. L-shape, built 1959, Ascot Park; cream brick walls, tiled roof.

Plate 4.12. Triple-front, built 1968, Edwardstown; cream brick walls, black tiled roof.

Plate 4.13. Colonial, built 1972, Salisbury East, red brick veneer walls, white tiled roof.

Plate 4.14. New Spanish, built 1976, Flagstaff Hill; cream brick walls, tiled roof.

House Design and House Construction in Adelaide Today

Much of the information on house design and construction prior to the 1970's is derivative and speculative, because it deals with processes of the past. The remaining section of this chapter deals with "the present", aiming first, to establish the general nature of the house design and construction process operating in Adelaide in the mid 1970's and, second, to consider in detail the priorities given to design-for-climate principles by present-day designers and builders. Information on the nature of current design and construction in Adelaide was obtained by a variety of methods, described in more detail in Chapter 3 (pp. 85-91).

The Process of House Design

Housing statistics currently available do not specify the source of design for Adelaide housing, and provide only limited information on the nature of construction. Williams (1974, 464) suggests that, in the past, most houses were "designed" and constructed by local builders from various-sized firms, and that only the larger homes were built under architectural supervision.

The situation in the mid 1970's appears to reinforce this dominant role played by building firms. Using interviews with designers and builders, and information from other sources (such as the South Australian Housing Trust and the Master Builders Association) it was possible to allocate the probable design-source of Adelaide housing in a particular year (1974). Table 4.02 shows that, contrary to popular opinion, commercial builders designed sixty-eight per cent of the

1974 total of Adelaide's new houses. Architects, mainly in the public-sector and project housing fields, designed approximately sixteen per cent and building design firms ten per cent of the total. The remaining six per cent of houses were designed by owners. Each design-method, however, contributes to the setting of general housing trends and standards in South Australia.

The Role of Architects. In terms of clients, three groups of architects are involved in domestic design in South Australia: those who provide a service for the individual client, those who design for "project-housing" firms, and those involved in public sector housing as employees of the South Australian Housing Trust. Houses designed by individually commissioned architects are smallest in number, approximately one per cent of the new houses each year. The main reason (for this low percentage) seems to be that of cost. With architect's fees adding seven to ten per cent to the contract price of a house, and normal housing loans unavailable to cover such fees most prospective house builders look to cheaper, alternative means of obtaining a design.

TABLE 4.02

ESTIMATED DESIGN-METHOD OF ADELAIDE HOUSING CONSTRUCTED DURING 1974

Design-Source	Number of houses (approximate)	Percentage of total
Architects: individual	70	1
project home	400	6
public sector	600	9
Building design firm	670	10
Building firms	4,600	68
Owners	400	6
Total	6,740	100

Source: Interviews, other information

As one architect explained, his clients for domestic work came only from the innovative, educated, articulate, design-conscious middle-to-upper income groups, with access to money and resources. The architectural profession in South Australia has continued to strive for improved domestic design, with its Architects Advisory Service and inexpensive handbooks on house design and construction[1]. However, few architects specialise in domestic design, so that such individually - designed houses play a relatively minor role in the setting of general trends and standards.

Table 4.02 shows that, in 1974, approximately six per cent of the houses being built in Adelaide were architect designed for project home builders. The system of project housing was pioneered in Sydney during the 1960's by builders Pettit and Sevitt, using designs by Ken Woolley, and in Melbourne by Merchant Builders, offering designs of the architect Graeme C. Gunn. By definition

> A true project house is one designed by an architect to the order of a project builder, who then constructs that design (or modified version) on a repeat basis for prospective clients. It provides home owners with the prestige and expert planning of an architect-designed home while eliminating the fees which many find prohibitively expensive... (plus) the economics inherent in repetitive building.
> Royal Australian Institute of Architects (1970, 74)

With four or five project builders operating in South Australia, but none in large numbers (the largest builds approximately 80 homes annually), it can be estimated that no more than 300 project homes are build in South Australia each year. This contrasts with Sydney, where McCredie (1969, 5) estimates that project houses constituted half of the

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1. The underlying themes expressed in such publications are the strong relationships between the site, design and client requirements, and trends towards pitched, skillion roofs, raked ceilings, materials in their "natural state" and "wide verandahs" in recognition of the South Australian climate.

new home market in the mid 1960's. Though representing a small percentage of the total in Adelaide, with limited effect on general standards and trends, project housing appears to be significant in widening the choices available to a potential client.

The South Australian Housing Trust produces approximately ten to twelve per cent of the new detached houses in Adelaide each year. The Trust employs a large team of architects, planners, building designers, and draftsmen, but the very nature of the output, namely low-cost, standardised housing, has tended, until recently, to mask much of the creativity of individuals concerned with design. Nevertheless, some recent innovative housing designs and layouts (such as Villa Flats and the West Lakes Project) have widened the effect of public sector housing on general design and standards. Previously the Housing Trust had a more limited impact, except in some aspects of estate development, such as the residential street layout to minimise through-traffic and the underground wiring used in Elizabeth.

The Role of Building-design Firms. By providing a service incorporating plan design, architectural drafting and plan printing, the building design firm appears to fill the gap between the professionally trained architect and the "team approach" used by many commercial builders. Some building designers work mainly for individual clients (but at lower fees than those charged by architects); others work for building firms, either in providing individual designs or by leasing to them a range of standard designs[2]. Copyright designs from building designers are

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2. For example, in 1968, one building design firm established a "Book of Plans" especially for "speculative" builders. The service is leased on an annual basis and a fee paid to the company each time a copyright plan is built.

probably used for about ten per cent of Adelaide's new housing. Such designs seem to have wide circulation, without being formally used or acknowledged, so it is difficult to identify their effect on general trends and standards.

The Role of Owner-designers. Approximately five to six per cent of Adelaide's new housing is owner-built each year, and it is likely that most of these owner-builders use their own designs. An unknown number of potential house owners take their own designs to commercial builders. Since house designing involves a certain level of expertise, it is likely that owner-designers have gained their ideas from a variety of sources, including previous houses, display homes, building exhibitions, published plans, housing magazines and architectural literature. However, because owner-designed houses tend to be thinly spread in new housing areas, they probably have a very minor effect on general trends and standards.

The Role of Building Firms. An estimated seventy per cent of house-designing in Adelaide is carried out by commercial builders, most of whom build a range of "speculative" (ready-built) homes and/or offer a fairly standard number of designs from which a client selects. The varied origins of house designs used by building firms in the mid 1970's can be classified into five groups, shown in Table 4.03.

The most frequently used method is that of the "team approach" in which each house plan results from the collaboration of ideas from the staff, including the firm's director, sales/marketing manager, architect (if employed) draftsman and cost estimator. Once approved, such plans are built as part of the company's range, with new or modified designs introduced when necessary, frequently as part of a major marketing

TABLE 4.03

SOURCE OF HOUSE DESIGNS USED BY INTERVIEWED BUILDING FIRMS, 1974/1975 (N=19)

Design source	Number of interviewed firms using method as only source	part source
"Team approach"	6	6
Building design firm	1	5
Architect, individual or firm	2	2
Interstate (head) office	2	1
Client	-	4
Total	11	18

Source: Building Firm Interview, Question 2

scheme. Designs resulting from this method are thus based on a wide range of business experience, especially in sales.

Some building firms rely on a "Home Planning Service" from a building design firm, as well as using its drafting and plan-printing facilities. This design method is particularly useful to smaller builders, eliminating or reducing the need to employ such skills within the building firm. Less widely used sources of design originate from an individual architect or architectural firm, or from the company's interstate head office, often with design-modifications to suit local conditions or known regional preferences[3]. The least-used source is

3. For example, two firms stated that South Australians preferred homes with a separate entry hall, living areas to be closed off for heating, two eating areas (one formal, one family) and a W.C. separate from the bathroom.

that of building the client's design. Such "custom-built" housing is usually more expensive, with profit margins different from those of standard-designed housing.

The nature of the design-process for commercial builders in South Australia has significant consequences. The variety and large number of people and processes involved makes it difficult to trace the origin and spread of architectural ideas, and thus to make generalisations about their contribution to housing standards and trends. Furthermore, the number of designs available from each builder ranges from complete standardisation (repeatedly building a few different designs) to a selection of thousands of designs, one from each past client. In general however, and following the pattern of previous years, most house designs available in the 1970's appear fairly conventional in layout, with the exterior facade the focus for varied treatment. For example, one firm had three or four "Master Floor Plans", each of which could be built with three exterior stylings (Spanish, Mediterranean or Colonial), plus other modifications, to make a total of 37 combinations.

Apart from variations in plan and facade, design features stressed by different building firms included particular aspects of room layout and workability of the home, constructional features and the nature and quality of finishes. The larger building firms, especially those with major advertising schemes and display villages, appear to play a leading role in the setting of general housing trends and standards in South Australia.

House Construction

Prior to 1939, it is probable that the majority of houses in Adelaide were erected by amateur builders, with limited capital, and capable of building only a few houses at a time. The industry is still characterised by a large number of companies operating with minimum capital, although there have been two major changes since 1939. The first has resulted from the activities of the South Australian Housing Trust, which has progressively increased its building programme to have completed, by 1978, more than 35,000 single-unit houses (and nearly 20,000 double units) in metropolitan Adelaide. This was approximately 13 per cent of Adelaide housing in 1976, and made the Trust the major single source of construction.

The second change has been the expansion of some business organisations to include all aspects of estate development, from planning and subdivision to construction of houses and shopping centres. Such organisations, responsible for much of the housing of outer suburban areas, have become known as "Developers".

Statistics on the number of houses approved, commenced, under construction, and completed, show fluctuations from year to year in the Adelaide Statistical Division. Private housing is differentiated from government housing, though construction of both types is undertaken by private contractors. From Table 4.04 it can be shown that for detached houses completed in Adelaide during the four years 1974 to 1977, an average of 88 per cent were classified as private, and 12 per cent government, according to ownership at date of commencement[4]. Included in the 88 per cent private houses, were an average of seven per cent "owner

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4. Comparative percentages for the State of South Australia during the four year period 1973-1974 to 1976-77 were 80 per cent privately built under contract, eight per cent owner-built and 14 per cent Government houses. For both the State and Adelaide, 1978 was an atypical year, with the number of privately built houses under contract approximately half that of the previous year.

TABLE 4.04

PERCENTAGE OF DETACHED HOUSES COMPLETED, BY TYPE OF OWNERSHIP, ADELAIDE STATISTICAL DIVISION, 1974 - 1978

Type of Ownership	Year (January to December)				
	1974	1975	1976	1977	1978
Private:owner-built	5	6	8	9	17
contract-built	87	80	82	76	62
Government houses	8	14	10	15	21
Total	100	100	100	100	100
	N=6,695	N=6,295	N=8,660	N=7,575	N=5,287

Source: Personal Communication, G.D. Carey, Australian Bureau of Statistics, Adelaide, 26th February, 1979.

built", that is, constructed by the owner or under the owner's direction without the services of a contractor responsible for the whole job. Most of the new houses were built in the Salisbury, Tea Tree Gully and Noarlunga Local Government areas, namely outer northern and outer southern suburbs.

Details on the size of operations of individual firms in the private sector were obtained from The S.A. Builder which, during the first ten months of 1974 , listed 912 builders for 3,618 Council approvals for proposed house building or major alterations[5]. Fifty-eight builders, with four or more approvals, were collectively responsible for 2,725 approvals, 75 per cent of the total.[6]. This serves to illustrate the fragmented nature of the house building industry in Adelaide in the 1970's. Of the 7,000 (approximately) detached houses built in the Adelaide Statistical Division, the South Australian Housing Trust builds approximately 500 to 1,000 each year. Six or seven private builders together are responsible for an additional 2,000 or so. The remaining 4,000 houses are built by scores of smaller companies. The stated (or estimated) number of houses built by each building firm was used as one of the criteria in sample selection of builders (see Chapter 3, p. 86).

The Significance of Design-for-Climate Principles During House Design and Construction

The preceding discussion has demonstrated the fragmented nature of design and construction of houses in Adelaide in the mid 1970's, and the varying contributions of architects, building-design firm, owner-designers/ builders and building firms to the setting of general standards and trends. The chapter concludes with a detailed consideration of the priorities given to design-for-climate principles

5. The S.A. Builder is a fortnightly Trade Journal of the Building and allied industries in South Australia. It lists "Notices of Intentions to Build" for most metropolitan Council areas, giving the nature, location and builder of the proposed construction (for example Dwelling, Lot 1278, Chappel Avenue, Morphett Vale, Hooker Homes). The figure of 3,618 approvals is about ten per cent less than the Bureau of Census and Statistics figure for the Adelaide Statistical Division during the same period, due to exclusion, in the S.A. Builder, of approvals' listings from five council areas.

6. The South Australian office of the Cement and Concrete Association of Australia (254 Melbourne St., North Adelaide) carried out the onerous task of compiling the individual entries for ten months of 1974.

by these groups of designers and builders. The lesser-used sources of design (architects, building-design firms and owners) are discussed first, followed by a lengthier treatment of building firms.

Designers

Architects. It has already been stressed that a relatively small number of houses in Adelaide have been architect-designed. Nevertheless this low quantity might be partially offset by the quality. Professionally-trained architects should be able to produce house designs of high standard. Furthermore, the awareness of fundamental principles of climatic design should be highest in this group of designers.

This supposition was substantiated. During discussions with architects involved in domestic design, their knowledge of a wide range of design for climate principles emerged. As Table 4.05 shows, the most frequently mentioned feature was that of orientation and siting, followed by the size and nature of overhangs and of glass areas. However, the highest practical application by architects tended to be in individually-designed houses, the lowest in public-sector housing, with project homes ranging between. Consideration of completed houses designed by each group showed further wide variation, with some excellent and some poor examples of designs suitable to Adelaide's climate.

The South Australian Housing Trust has provided the largest number of architect-designed houses in Adelaide, and thus warrants particular attention. Even though the chief design architect of the South Australian Housing Trust considered the climatic aspect of house-design

TABLE 4.05

FREQUENCY OF LISTING OF CLIMATIC DESIGN PRINCIPLES BY TEN INTERVIEWED ARCHITECTS

Design Principle	Frequency (N=10)
Orientation/siting of house to face main rooms north for best utilisation of sun	10
Large overhangs (eaves, verandahs) for weather protection, outdoor living, children's play	10
Glass areas of sensible size and protected	10
Cross-ventilation, especially live-dine area and bedrooms; use of breezeways	8
Integrated indoor-outdoor living areas; use of courtyards	7
Ceiling insulation and sensible management of houses (more important than artificial aids to comfort)	6
Minimum or no glass on east and west walls	5
Use of deciduous vegetation for shading	5
Heavy-weight construction for living areas, light-weight for sleeping	3
Light-coloured surfaces for roof/walls	2

Source: Architect Interviews

to have been low in priority in previous years, many Housing Trust estates of the 1950's and 1960's incorporated commendable features. In the town of Elizabeth, for example, houses were as carefully orientated as the street layout permitted, glass used in house-designs to a limited extent, and extensive tree planting programmes carried out. For several years it was the Trust's policy to install reverse-cycle air conditioners in living rooms, as a substitute for open fireplaces. Since the latter half of the 1970's the architectural section of the Housing Trust has been attempting to improve the climatic aspects of house design by taking more care with such features as orientation, amount of glass, cross-ventilation, self-shading, and integrated outdoor living areas[7]. The type of housing built at West Lakes during 1974/1979 is evidence of the application of these principles.

Some transportable homes designed by the South Australian Housing Trust in 1975 (and constructed by one interviewed builder) featured insulated walls and ceiling, good cross-ventilation, 900mm (3ft) eaves to the front and rear, and windows absent on end walls. Although it will take many years for all public sector housing to be of an improved design, such changes described above could be significant in their influence on general trends and standards.

Building-design Firms. Knowledge of design-for-climate principles among building design firms varied a great deal, as did the ability to incorporate such features in actual designs. In general, most design-for-climate principles could be incorporated in the individualised house, planned for one site or one client. Least consideration of climatic design principles occurred in the standardised designs, intended for repetitious building on many different sites. Similar to most published plans, those of building design firms nearly always omitted a recommended orientation for the house[8].

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7. One design for semi-arid areas of South Australia features a heavy-weight core for daytime living, connected by a breezeway to a transportable, light-weight section of bedrooms. Twenty four such houses (built in groups of four, with fenced courtyards for private outdoor living) were built in Port Pirie. (Personal Communication, I. Halkett, South Australian Housing Trust, February 5th, 1979).

8. Although during 1978, at the request of the South Australian Land Commission (inheritors of a housing estate at Hallett Cove), an Adelaide architectural firm carried out a site development study, evaluated standard house designs in terms of their siting potential, and prepared a brochure a "Planning and Siting Your Home" for all prospective land purchasers (and builders). (Personal Communication, R. Cheesman, Gerner Sanderson Faggetter Cheesman, March 6th 1979.)

Owner-designers. Owner-designers gain expertise from a wide range of sources (Chapter 4, p. 110) and the nature and type of their designs, and their knowledge of design-for-climate principles are highly variable. Such differences are illustrated by two owner-designed houses in the same street in a western Adelaide suburb. As Figure 4.2 shows, one was designed in an efficient manner to suit Adelaide's climate. The owners of House A deliberately chose a deep east-west block in order to maximise north-facing glass for living areas (protected with sufficient overhang) and to use minimum glazing on east and west walls. The house was designed to obtain good cross-ventilation, private outdoor living areas and to minimise artificial heating and cooling. The other (House B of Figure 4.3) was a conventional triple-front with dark-grey roof tiles, large west-facing windows, (of the living room and two bedrooms), poor cross-ventilation, and minimum private outdoor living space. This latter house was consistently colder during winter and hotter during summer, with the three west-facing rooms at the front of the house unbearable during heatwaves[9].

Building Firms

It has already been shown that, in the mid 1970's in Adelaide, building firms were responsible for almost seventy per cent of house design and over ninety per cent of house construction. In the discussion that follows, the views of nineteen building firms are represented. Small, medium and large builders are included, of both "speculative" and contract homes, with various price-levels and sales

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9. The author lived in House B for four years, and was a frequent visitor to House A.

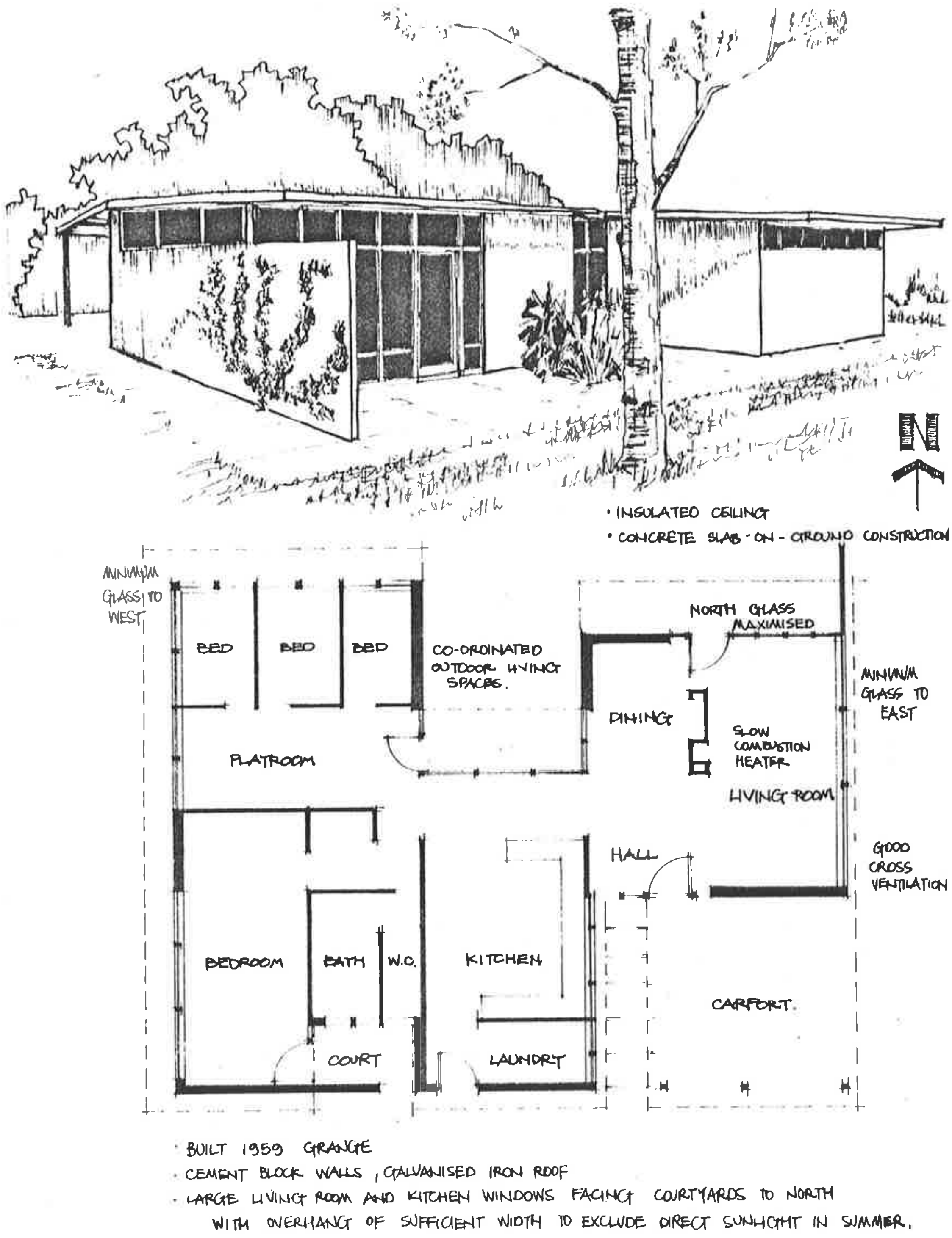
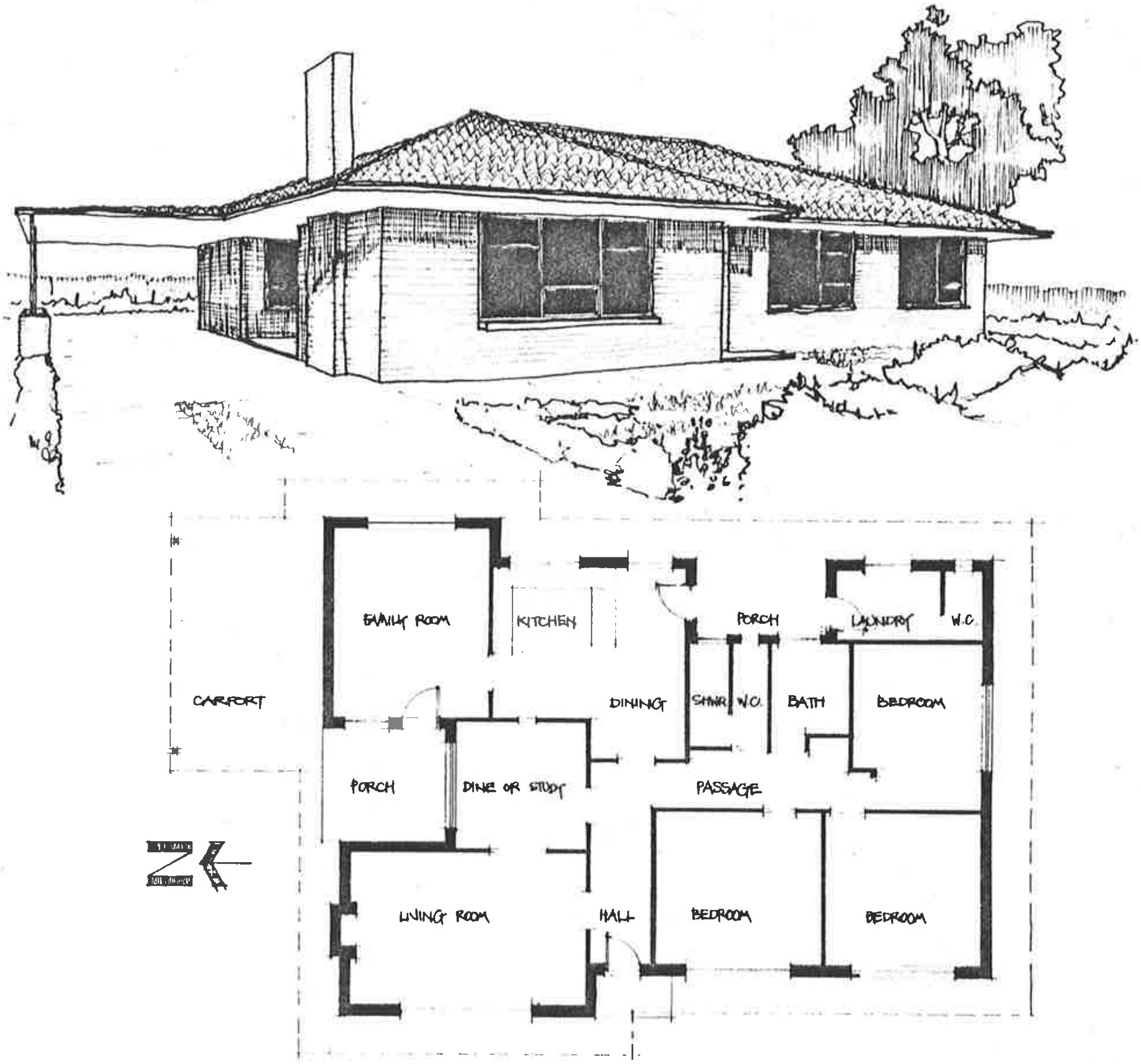


FIG. 4·2 HOUSE A, OWNER-DESIGNED IN AN EFFICIENT MANNER TO SUIT ADELAIDE'S CLIMATE



- BUILT 1966, GRANGE
- CREAM BRICK WALL, DARK GREY TILED ROOF
- LARGE WEST-FACING WINDOWS, INADEQUATELY SHADED
- NO ATTEMPT TO MAXIMISE WINTER SUNSHINE (ON NORTH SIDE), CROSS VENTILATION OR INTEGRATION WITH OUTDOOR LIVING AREAS.

FIG. 4·3 HOUSE B, CONVENTIONAL TRIPLE-FRONT, OWNER-DESIGNED WITH MINIMUM CONSIDERATION OF CLIMATIC SUITABILITY AND COMFORT methods. The interviewed builders obtained house designs from varied sources, including architects, building design firms, and clients. These same firms were responsible for building during 1974 an estimated 2,855 houses, or 43 per cent of the total new housing in the Adelaide Statistical Division[10]. Thus the views of these builders can be regarded as representative of both the design and construction of Adelaide housing in the mid 1970's. The building firm questionnaire/interview [11] was used to obtain information on the general nature, size and methods of the organization, with particular emphasis on the use of "design for climate" principles. Knowledge of such principles, and their inclusion in the building programme, ranged widely.

Consideration of Specific Design-for-climate Principles. The following seven principles were incorporated in the building firm interview, and were also listed, independently, by the interviewed architects (Table 4.05, p. 117):

(i) Siting of house on land, especially orientation to utilise the sun: Most builders (and real estate agents) stated that, due to public demand, the house must face the street regardless of orientation (Table 4.06). Maps of Adelaide's suburbs show streets in all directions, although north-south, east-west grids predominate. Land subdivision on estates (an additional activity of several building firms interviewed) was nearly always on the basis of practicality and economics, rather

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10. Table 4.04 shows 6,695 houses completed in the Adelaide Statistical Division. The estimated total of 2,855 built by the interviewed builders excludes 200 "transportables" built as part of one firm's operations, because they were sold mainly to country clients.

11. The Building Firm Questionnaire/ interview appears in Appendix II pp. 408-410.

TABLE 4.06

POLICY USED BY INTERVIEWED BUILDING FIRMS TO SITE HOUSE ON LAND

Siting Policy	Number and percentage using policy		Estimated number and percentage of houses constructed during 1974	
	Number	Percentage	Number	Percentage
House always faces street	8	42	1,050	37
House occasionally re-oriented to utilise sun on a particular site	5	26	640	22
House often facing north or south due to nature of estates	3	16	880	31
House usually oriented to utilise sun	3	16	285	10
Total	19	100	2,855	100

Source: Building Firm Interview (Question 2).

than orientation to utilise sunlight. A typical statement was,

> on our estates we take into account the contours (for drainage), aesthetics (cul-de-sacs look good) and costs (the need to maximise the number of blocks in a given space).
> (Building Firm Interview, June 1975).

Some exceptions occur: three firms stated that, their subdivisions were designed with primarily east-west running streets for the climatic advantage; another stated that west-facing blocks were sometimes treated with special care or that a minority of their clients did consider orientation in terms of the view, prevailing winds, sun and rain[12].

12. Blocks in the foothills presented special problems, with the view of the plains and coast nearly always to the west.

Nevertheless, observation of the type of estates and houses built on individual blocks demonstrated that, overall, low priority was given to orientation, by both builders and clients[13].

(ii) Selection of suitable building material and style: Table 4.07 shows that the most frequently selected method of construction and building materials were cavity brick or brick veneer walls, tiled, pitched roofs, timber or concrete floors, ceiling heights of 2400mm (8ft), ceiling insulation rarely included, and eaves 600mm (2ft) wide. Almost all designs had a front entry porch, and about half of the houses had either a verandah or carport under the main roof, and sometimes both. In discussing these selections of building material and style builders stressed requirements of the Building Acts, costs, public demand, or appearance of the completed building. Rarely was a feature considered in terms of its possible contribution to the comfort of the house. For example, in the selection of roof-tile colour, there was some tendency, in the 1970's for builders to choose white. However, the reason most frequently offered was the need to mix wall and roof colours on estates, or because white was fashionable, rather than the possible cooling effect. One of the nineteen builders stated his preferences for brick veneer construction on the basis of its thermal performance, but the

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13. Jenkins and James (1978,35) analysed 50 project house-designs built by a number of builders in Victoria during 1976, and concluded that, if only orientation and plans were considered (not choice of wall and roof materials or insulation) 49 of the 50 houses could be significantly improved in thermal performance by correct orientation - some of it unconventional - or by slight adaption.

nature of Adelaide's soil or the relative costs of construction were more frequently cited. Two builders varied eave size according to orientation or size of glass areas, but most used the basic minimum in both eave width and ceiling height (600mm and 2400mm, respectively). Insulation installed during construction was considered an unnecessary luxury by most builders and their clients, and was included only when required by the Building Regulations[14]. One building firm stated that about 30 per cent of its clients asked for the optional ceiling insulation to be included during construction. This firm built the individual designs of clients, usually their second or third home in the middle to upper price bracket. Such evidence suggests the ceiling insulation is considered a "hidden factor" by builders and their clients, since it increases the price of a new home without visible results, and because it can be installed above the ceiling at a later time, presumably when the owner is more affluent.

(iii) Self-shading and use of trees: "Self-shading" is the extent to which the overhangs of the house (eaves, verandahs, pergolas) provide shade to walls and windows. It is best achieved in a north-facing house, with a long east- west axis, minimum glazing on east and west walls, and overhangs of variable width to eliminate summer sun, but permit winter-sun penetration. Deciduous trees or vegetation, especially on the north side of the house, assist in screening unwanted summer heat. The low priority given to orientation, and the fact that most builders used the minimum 600mm-wide (2ft) eave resulted in poor

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14. Insulation is required in the walls of "transportable" houses and in any roof pitched below 17.5 degrees.

TABLE 4.07

CONSTRUCTIONAL DETAILS OF HOUSES CONSTRUCTED BY INTERVIEWED BUILDING FIRMS

Type or Style of Construction		Interviewed Builders		
	Number and Percentage Using Type or Style of Construction		Estimated Number and Percentage of Houses Built During 1974	
	Number	Percentage	Number	Percentage
Wall type: cavity brick	8	42	740	26
brick veneer	6	32	1,160	41
cavity and veneer	5	26	955	33
Total	19	100	2,855	100
Roof type: tiles, pitched 17½°-22½°	16	84	2,145	75
tiles and other	3	16	710	25
Total	19	100	2,855	100
Floor type: timber	10	53	1,550	54
concrete	1	5	50	2
timber and concrete	8	42	1,255	44
Total	19	100	2,855	100
Ceiling height: 2400 mm (8 ft)	14	74	2,455	86
2550-2700 mm (8½-9 ft)	3	16	270	9
Varying 2100-4200 mm (7-14 ft)	2	11	130	5
Total	19	100	2,855	100
Ceiling insulation: not included	6	32	890	31
optional extra, rarely used	11	58	1,760	62
quite often included	2	11	205	7
Total	19	100	2,855	100
Eave width: 600 mm (2 ft)	12	63	1,800	63
900 mm (3 ft)	2	11	140	5
Varying 600-1200 mm (2-4 ft)	5	26	915	32
Total	19	100	2,855	100
Verandahs: not included	2	11	75	3
on some designs	15	79	2,575	90
on most designs	2	11	205	7
Total	19	100	2,855	100
Carports: not included	3	16	760	27
on some designs	11	58	1,665	58
on most designs	5	26	430	15
Total	19	100	2,855	100

Source: Building Firm Interview, Question 2.

self-shading in house-designs analysed. Only the two project-home builders stressed orientation, varied eave size according to aspect, and aimed to retain as many trees as possible on the site. One large company stressed the pine forest location of one of its 1976 display villages and adjacent subdivision, and continued to feature garden land-scaping, pergolas and courtyards in all its display homes.

(iv) Window size and placement: Most interviewed building firms built houses with large windows, especially on the street facade (Table 4.08). Fewer than half the houses with large windows had any form of protection by large overhangs, verandahs or pergolas. The reasons stated for the large areas of glass were remarkably consistent; for appearance and attractive display of the home, and people's preferences for a well-lit house. Some firms have reduced window-size in the 1970's, partly for structural reasons, partly to permit better furniture placement. A minority of houses have smaller windows only if the client selects a "Spanish" or "Mediterranean" facade. Approximately half the interviewed firms stated that no adjustment to size or placement of windows occurred when their houses were built on a particular site, such as on a west-facing block. Representatives of these firms held the opinion that almost all their clients were not concerned with house orientation and future comfort, and that, although large windows added to the costs of moving in (for blinds and curtains), problem windows could be protected later with outside awnings or their equivalent. The remaining nine firms included five who occasionally discussed orientation with clients, or who modified a design for a "problem" site, three who usually considered orientation (such as placing the largest windows under verandahs, or placing carports on the western side) and two firms whose

TABLE 4.08

WINDOW SIZE AND PLACEMENT AND PROVISION FOR
CROSS VENTILATION IN HOUSES CONSTRUCTED BY INTERVIEWED BUILDING FIRMS

Feature	Interviewed Builders			
	Number and percentage using design feature		Estimated number and percentage of houses built during 1974	
	Number	Percentage	Number	Percentage
Usual size of living room window				
large, with protection	4	21	710	25
large, unprotected	5	26	990	35
moderate to large	7	37	885	31
variable, according to choice of facade	3	16	270	9
Total	19	100	2,855	100
Adjustment of window size or placement for particular sites				
no adjustment	9	47	1,590	56
occasional adjustment	5	26	610	21
usual adjustment	3	16	525	18
always	2	11	130	5
Total	19	100	2,855	100
Provision for cross-ventilation				
no special provision	8	42	1,025	36
minor provision	6	32	1,140	40
moderate provision	5	26	690	24
Total	19	100	2,855	100

Source: Building Firm Interview (Question 2).

designers always considered size and placement of windows relative to the size. These two firms were both builders of project homes, using architect designs, but responsible for only two per cent of the 1974 total of new housing in Adelaide. The overwhelming majority of houses being built in the 1970's contained windows placed for aesthetic or functional reasons, with little or no concession to climate.

(v) Provision for cross-ventilation, exclusion of draughts: Table 4.08 shows that slightly fewer than half the builders stated that cross-ventilation was not a special consideration in their house-designs. Approximately one-third claimed their houses to be well-ventilated because of the type and placement of windows and other openings. The remaining builders described several aspects of their houses designed to aid cross-ventilation, such as open-plan living areas, doors and windows on opposite walls, large window openings and sliding doors to patios. Most builders considered that cross-ventilation was not an important feature for clients when compared to window appearance and sometimes safety aspects. They stated that the exclusion of draughts during winter was similarly ignored by most clients. Doorsills were fitted to the exterior doors by some builders, but in general they were considered an unnecessary expense.

(vi) Provision for private outdoor living: Outdoor living facilities provided by builders range from fully-developed patios with pergolas, in-built barbecues and seating, to designs incorporating verandahs or courtyards, to the basic minimum of a sliding glass door from the kitchen/dinette or family room into the garden. Only one interviewed builder made no provision for private outdoor living, building houses in which the laundry door provided the sole access to the garden. He explained that, as a builder of low-priced economy houses for first-home buyers, his clients had never requested outdoor living facilities. As Table 4.09 shows, several builders included a relatively expensive aluminium frame, sliding glass door in some or all of their houses, stating that potential clients expected such provision. Patios, verandahs, balconies or decks and pergolas appeared frequently on house-plans. A few builders publicised designs with front courtyards, usually in houses with Spanish or Mediterranean-styling providing a link between carport and front entry[15]. True courtyard houses, with all rooms grouped around a centrally placed court or atrium, were almost non-existent. One such design, part of a project-home builder's range, featured living and sleeping areas on opposite sides of a courtyard and the wet areas (bathroom, laundry and W.C.) forming a link between them[16]. The firms stated that most houses of this design were being sold to younger couples, because the living room faced the court and not the street. Two builders made outdoor-living facilities a special feature of all their designs and their display homes in particular, and another five builders scored moderately well on this index (Table 4.09)[17]. Not only were these seven builders collectively responsible for approximately 1,000 new homes in 1974, about 15 per cent of the total, but they were also able to attract thousands of visitors to their display villages.

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15. Presumably these front courtyards were intended to improve the appearance of the house for they were rarely sufficient secluded for private outdoor living.

16. The building firm stressed the value of the secluded court for South Australia's climate, and its versatility from a siting point of view, able to be arranged on the site in any one of three aspects with equal success.

17. For example, the "Garden Home" of one large builder - "It's a new approach in home design featuring country kitchen, spacious living areas planned around inviting sunshine courtyards and private patios".

TABLE 4.09

PROVISION OF FACILITIES FOR PRIVATE OUTDOOR LIVING IN HOUSES CONSTRUCTED BY INTERVIEWED BUILDING FIRMS

Type of Provision	Interviewed Builders			
	Number and percentage using type of provision		Estimated number and percentage of houses built during 1974	
	Number	Percentage	Number	Percentage
None	1	5	350	12
Minimum provision[a]	6	32	900	32
Some provision[b]	5	26	565	20
Moderate provision[c]	5	26	630	22
Major feature[d]	2	11	410	14
Total	19	100	2,855	100

Source: Building Firm Interview (Question 2)

a. such as that provided by a sliding glass door from living areas

b. sliding glass door, plus/or other features, such as pergolas, verandahs, patios, balconies

c. all features of a and b, plus some "courtyard" designs (living or entry courts)

d. designs incorporating most of the above features, plus plans involving room re-arrangement around a courtyard and/or outdoor living a major aspect of display homes

(vii) Provision for artificial heating and cooling: For efficient supply of fuel and power, most heating and cooling systems are best installed during construction. Since thermal comfort is such a personal matter, many builders merely make provision for a future heating system (such as a gas connection point) or provide a space-heater in display homes on the understanding that it is an optional extra in contract homes.

Table 4.10 shows that only one third of the builders provided all their houses with a heating system, most frequently oil or gas. Air conditioning (reverse cycle or cooling only) was even less frequently installed during construction. Almost half the builders stated that they made no provision for air conditioning, nor were asked to do so by clients. One third made it an optional extra, requested by very few clients, or they made allowances for future installation, such as straight-jointing in an exterior brick wall. Three firms installed an air conditioning system in ten per cent or more of houses during construction. These houses were the "executive" models of the firm's range, with reverse-cycle or fully-ducted air conditioning systems an additional "drawcard". The reasons given for the general lack of air conditioning systems was the expense of installation, and the questionable value in terms of the relatively low number of hot days in an Adelaide summer. Several builders believed that house air conditioning would be a selling feature, especially if it were a multi-room or fully-ducted system but, as one builder stated "It is up to the manufacturers and suppliers to design and sell an air conditioning and heating unit for houses at a reasonable price". Three builders stressed the need to insulate the house if air conditioning was also being installed (during or shortly after construction); one stated that it was far more important to insulate the house than to use artificial aids to comfort.

<u>Overall evaluation of climatic suitability of houses constructed by interviewed building firms.</u> Prior to a request for statistical information, the final question in the building firm interviewed was

> If you had a client wanting to build or buy a new house in Adelaide without air conditioning and who wanted to
> (a) make the most of winter sunshine and warmth, and
> (b) minimise the sun's effects in summer, what advice would you give?

TABLE 4.10

PROVISION FOR ARTIFICIAL HEATING AND COOLING IN HOUSES CONSTRUCTED BY INTERVIEWED BUILDING FIRMS

Type of Provision	Interviewed Builders			
	Number and percentage using method		Estimated number and percentage of houses built during 1974	
	Number	Percentage	Number	Percentage
Provision for artificial heating				
gas connection point only	4	21	250	9
heaters in display homes only	3	16	630	22
heater an optional extra or included in some homes	6	32	795	28
heaters included in all homes	6	32	1,180	41
Total	19	100	2,855	100
Type of heating (if used)				
oil space-heater	3	16	425	17
gas space-heater	8	42	1,545	60
oil or gas	3	16	605	23
Total	14	74	2,575	100
Provision for air conditioning				
no provision	9	47	1,000	35
optional extra, rarely included	7	37	1,175	41
included in some houses	3	16	680	24
Total	19	100	2,855	100

Source: Building Firm Interview, Question 2.

Table 4.11 shows that five of the builders stated that they would not be able to offer advice, and, unless one of their standard houses were suitable, the client would need to go elsewhere for such specialised attention and design. Another seven builders, responsible for almost half of the housing, had some advice to offer, but fairly meagre in nature, and showing no great depth of understanding. For example, a north-facing house was suggested by two builders, but the rationale was not forthcoming. The remaining seven builders were able to make useful suggestions, such as:

> Orientate homes to take advantage of winter sun, use white roof tiles and insulation, erect pergola over and in front of main windows to carry seasonal climbing plants.
> (Building Firm Interview, 1975)

One project housing firm made the climatic suitability of its designs a significant selling feature. To quote from one of its publicity leaflets:

> a house specifically designed for Adelaide's climate .... wide verandah, roof insulation, limited glass on direct sun aspects ... so cool in summer, warm in winter, it feels as though it were air conditioned.

On the basis of replies to this final question and weightings given for eight other design for climate features, each building firm was given a score on the overall climatic suitability of its house design and construction (Table 4.11)[18]. Ranking of scores enabled three groups of builder to be differentiated, ranging from high to low climatic suitability. This gradation is shown in Table 4.12.

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18. These eight features were siting of house on block, width of eaves, size/protection of largest window, adjustment of window size/placement for particular sites, level of provision for cross-ventilation, outdoor living, artificial heating and air conditioning.

TABLE 4.11

OVERALL EVALUATION OF CLIMATIC SUITABILITY OF HOUSES CONSTRUCTED BY INTERVIEWED BUILDING FIRMS

Quality of design for climate	Interviewed Builders			
	Number and percentage with particular ability of score		Estimated number and percentages of houses built during 1974	
	Number	Percentage	Number	Percentage
Ability of firm to advise on design for climate[a]				
not able to give advice	5	26	835	29
some advice	7	37	1,195	42
several suggestions	5	26	695	24
competent advice available	2	11	130	5
Total	19	100	2,855	100
Overall score on design for climate[b]				
low	4	21	635	22
low to medium	4	21	465	16
medium	7	36	1,140	40
medium to high	2	11	485	17
high	2	11	130	5
Total	19	100	2,855	100

Source: a Building Firm Interview (Question 5)
b Compiled from responses to questions 3 and 5, Building Firm Interview.

The four building firms responsible for the design, construction and sale of houses most suited to Adelaide's climate concentrated on contract homes in the medium-to-high price range. Heading the list are the two project housing firms, with their local architect designs,

TABLE 4.12

CHARACTERISTICS OF BUILDING FIRMS RANKED ON CLIMATIC SUITABILITY OF HOUSE DESIGN AND CONSTRUCTION

Size and Nature of Building Firm

Size (houses built in 1974)	Price-range of Houses a	Type of Housing	Design Method Used	Marketing Methods 1974-75
Medium (80)	Medium to high	Project	Architect	Advertising. One display village.
Small (50)	Medium to high	Project	Architectural firm	Advertising. Display homes.
Large (330)	Medium to high	Contract and speculative	Team approach, head office, local architects	Major advertising. Two display villages. Estate development.
Large (155)	High	Custom-built	Clients, building designer firm	Personal recommendation (no advertising).
Large (250)	Medium to high	Contract and speculative	Team approach	Major advertising. Three display villages. Estate development.
Large (300)	Low to medium	Public-sector	SAHT architects	Some advertising.
Small (40)	Low to medium	Contract	Team approach, clients	Advertising.
Small (25)	Low to medium	Speculative	Building designer firm	Advertising.
Large (350)	Low-medium to medium-high	Contract and speculative	Head office (interstate)	Major advertising. Three display villages. Estate development.
Medium (100)	Medium	Contract and speculative	Building designer firm, clients	Some advertising. Estate development.
Medium (75)	Medium to high	Contract and speculative	Team approach, clients	Little advertising. One display village
Large (175)	Medium	Contract and speculative	Team approach	Advertising. Show homes.
Small (50)	Low to medium	Contract and speculative	Team approach, building designer	Advertising.
Large (200)	Medium	Contract and speculative	Team approach	Advertising. One display village. Estate development.
Small (40)	Medium to high	Contract	Team approach	Advertising. Display homes.
Medium (125)	Low to medium	Contract and speculative	Team approach	Advertising. Show homes. Estate development.
Small (60)	Low to medium	Speculative	Head office (interstate)	One display village. Estate development.
Medium (125)	Low to medium	Contract and speculative	Team approach	Some advertising. One display village.
Large (350)	Medium	Mainly speculative	Team approach	Major advertising. Three display villages. Estate development.

Source: see text for method of ranking; other information from Building Firm Interviews.

a. In mid-1975, typical house prices (excluding land) were

high - $29,000 or more
medium-high - $25,000
medium - $22,000
low-medium - $20,000
low - $18,000

followed by a large firm which used locally commissioned architects for 15 per cent of its designs, the "team approach" for 75 per cent, and its interstate head office for the remaining ten per cent of designs built. The fourth firm specialised in highly priced custom-built housing designed by or for individual clients. Typical clients for all firms were either first home buyers with above-average finance, or second or third home buyers. A market research survey commissioned by one of the project housing firms during 1973 had revealed that 75 to 80 per cent of its clients were teachers and other design and environmental-conscious people wishing to build in the Adelaide Hills or on sloping land in the outer suburbs. A typical house built by this project-housing firm is shown in Plate 4.15.

Collectively this group accounted for one fifth of the houses built by the interviewed builders, and therefore approximately nine per cent of the total of new houses in Adelaide in 1974. Thus, to find a "potentially comfortable" new house in the mid-1970's in Adelaide, clients would need to be most particular in their choice of designer and builder, preferably selecting a design process involving architects or some other well-tested method, and be prepared to pay above-average costs for their home.

The eight builders scoring lowest on the climatic suitability of their house design and construction were collectively responsible for 40 per cent of the total houses built by the interviewed builders or 17 per cent of Adelaide's total of new housing during 1974. As Table 4.12 shows, most builders in this group specialised in ready-built ("speculative"), or contract, housing priced sufficiently low to attract first home buyers with limited finance.

An example of the type of housing constructed by a builder of this group is shown in Plate 4.16. The most frequent design method used was that of the "team approach", with one firm using designs from its head office in Sydney. Each firm's limited range of plans were usually built on a repetitive basis in a variety of locations. Such standardisation left no room for modification of the plan to suit local climate, the particular site, or the individual client. As one builder and real estate agent stated so clearly:

> Housing designs are influenced by price mainly, then available materials and tradespeople, then tradition and 'trends'. The new Building Acts, Government and Local Council Regulations impose countless restrictions - as well as good trade practice and workmanship.
>
> In my considered opinion, climatic effects of design is about the last possible consideration of a buyer of a new or old home (except perhaps for temporary consideration during a heatwave).

This builder went on to explain his firm's efforts to build and sell homes of good value, appearance and functional design, in which climate and comfort were taken into account ("we have to really sell people on the excellent gas space heaters in our new homes - most people don't even notice them"). However, he considered that potential clients had quite unrealistic expectations relative to their finance, and concluded "I'm fighting a losing battle in trying to upgrade climate consciousness".

The above builder is characteristic of the middle group of interviewed firms, which are those with moderate scores in terms of design and constructionn of houses suited to Adelaide's climate. The type of housing, price-levels, design methods and typical clients were the most varied for this middle group of builders, so that it is difficult to generalise. Numerically, the greatest component is provided by medium

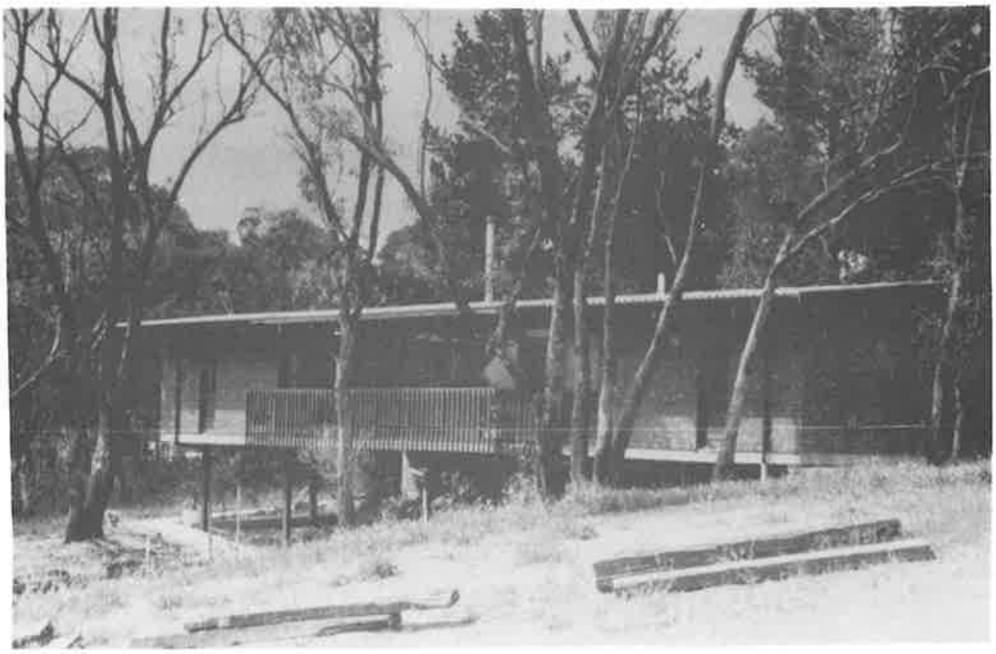

Plate 4.15. Example of project housing, built 1976, Blackwood; well-suited to Adelaide's climate.

Plate 4.16. Example of low-priced "speculative" housing, built 1974, Salisbury East; not well-suited to Adelaide's climate.

to high priced homes (contract or speculative) designed by members of the firm. The public sector housing, designed by South Australian Housing Trust architects also appears in this group. Collectively, the seven building firms were responsible for almost the same number of houses as the third group, that is, 40 per cent of the houses built by the interviewed builders, or 17 per cent of Adelaide's new housing in 1974. In other words, suitability to the local climate was of little or no significance in the design and construction of 80 per cent of the houses built by the interviewed builders.

Discussion and Conclusion. The building firm interviews reveal that the climatic suitability of house-plans has low priority during design and construction. Since the interviewed builders are representative of Adelaide house-builders as a whole, it can be assumed that suitability to the local climate was either given low priority, included by chance or completely ignored as a factor in the design and construction of the vast majority of Adelaide houses in the mid-1970's. This conforms with McCredie's (1971) thesis on newly built single detached houses in the outer suburbs of Sydney, in which she states that the designers failed to consider the limitation of climate, ignoring such aspects as summer sun protection, window size and placement, cross-ventilation and methods of heating. Marshall (1963a) argues that the reasons for the climatic unsuitability of Adelaide building styles since 1842 lie in the low percentage of dwellings built under architectural supervision, the builders' desire "to please and not to educate the client"and the dominating influence of overseas architectural fashions and trends, especially as seen in the "great number of attractively illustrated magazines". Even the architect designs of the South Australian Housing Trust and of project home builders are built on a repeat basis on a variety of sites which limits the ability to incorporate individualised climatic design features, such as maximum glazing to the north.

These reasons continue to be important in the late 1970's, but the single factor most often emphasized during interviews was the need to minimise building costs[19]. This was further accentuated by the general credit squeeze of 1974 and 1975. Sales appeal, tradition and trends, and other factors such as the Building Regulations and the availability of materials and tradespeople were mentioned as significant factors in the successful operation of a building firm. Climatic suitability of designs was not rated as a major factor, though three or four firms did regard it as important. These firms built higher priced homes, often designed by architects or custom-built for a client, and purchased by more discerning second or third home buyers, or first home buyers with considerable finance. The minority of clients who were concerned with the climatic suitability and potential comfort of the home tended to be better educated, more articulate, and more design-conscious than the average house buyer. This type of client would also be more likely to incorporate some of the energy-related options (such as solar water heating, ceiling or wall insulation, open fireplaces, central heating) being offered by an increasing number of builders in 1978-79.

Thus in both house design and construction of the past and of the present, very little effort has been made to provide houses which are suited to the local climate and which provide optimum comfort for their occupants. In the vast majority of houses, design-for-climate principles have been ignored or neglected, largely from ignorance or lack of understanding by designers and builders alike.

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19. This is likely to become even more apparent as costs continue to increase , particularly of skilled labour and building materials.

CHAPTER 5

CLIMATIC SUITABILITY AND PHYSICAL COMFORT AS FACTORS IN HOUSE SALES OR PURCHASES

Many people and processes are involved in the design, construction, sale, occupation and subsequent modification of a house. In each stage, there are a number of influencing factors, and consideration of (local) climate is only one of these. The preceding chapter revealed the low priority given to climatic suitability and physical comfort during the design and construction of most Adelaide houses. Although serious, the long-term effect of this deficiency might be lessened if salesmen and purchasers were more attentive to the possible effect of the design, structure and orientation of the house on future comfort (and discomfort). Such awareness would enable the consumer to make a better informed selection of a house. This chapter explores the nature of the house purchase decision, with an emphasis on climatic suitability and physical comfort in the ordination of priorities, and evaluates the significance of other factors such as location, finance, size and external appearance.

Although Australia has one of the highest levels of home-ownership in the world, Australian studies on moving behaviour, residential location decisions and home purchase decisions are comparatively few. Furthermore, most of the Australian and overseas research concentrates on house-evaluation studies (based on the attitudes and stated levels of satisfaction of the householder) rather than on the ordination of priorities in the decision to purchase a home. Examination of the decision making studies of residential location gives little indication that home-seekers consider either climatic suitability or potential indoor comfort in selecting a house, or the climatic implications of a home site. Presumably, such considerations are taken for granted, since studies suggest that the choice of a home is governed by the desire to be in a pleasant physical and social environment and by features of the individual dwelling such as cost, appearance or size (National Co-operative Highway Research Program, 1959; Weiss et al., 1966; Menchik, 1972). In those studies in which particular attributes of the dwelling are specified (either by the householder in an open-ended question, or listed in the questionnaire schedule for the householder to rank or categorize), climate-related features are rarely mentioned. The classic study of Rossi (1955), for example, shows that the choice of a new dwelling was influenced by purchaser "specifications" of space requirements, particular dwelling unit designs (such as heating, layout, utilities) and neighbourhood location, but that the most important "attractions" in the final choice were costs, space, household location and neighbourhood social composition. Australian studies of housing choice and preferences show similar results whether in Yass, New South Wales (King, 1972), Melbourne's urban fringe (Pryor, 1969; Raufer and Marriott, 1972), or Brisbane (Gibbings, 1973). In her survey of the values, attitudes and decision making in the choice of a house (project housing in the outer suburbs of Sydney) McCredie (1969) makes no reference to climate or comfort considerations. Apparently, it is only in northern Australia that the choice of a dwelling is influenced by climate (Brealey, 1972b)[1].

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1. When asked to select a number of improvements to upgrade a basic house, residents of all six communities of tropical Australia selected fans (ceiling or exhaust) and air conditioning among their first eight options.

The Ordination of Priorities in the House Purchase Decision

Views on the house purchase decision were obtained by posing similar or identical questions to the sample of householders, real estate agents and building firms, each of whom is involved in the buying or selling of houses from different viewpoints[2]. Each group was asked to specify the relative importance, on a five-point scale, of twelve listed features in house purchase or sale. In Figure 5.1 the column totals show the percentage of each sample group who rated the feature as "very important" or "important", enabling the answers from each group to be compared. Table 5.01 shows the ranked lists for each sample. As expected, cost [3] was ranked highest by all three groups, being ranked "very important" or "important" by 82 per cent of southwestern suburbs householders, 92 per cent of Salisbury East householders and 94 per cent of real estate agents. Although not specifically asked to rate the listed items, all building firms interviewed also stressed the importance of costs[4]. Of the twelve listed features in the questionnaire, "suitability to Adelaide's climate" was, with one exception, ranked lowest, being rated "not very important" or "not"

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2. The selection of two groups of householders (one occupying older, mixed housing in the southwestern suburbs, the other occupying houses constructed during the 1970's by one builder in the Salisbury East area) permitted the comparison of views from recent and longer established residents.

3. The word "cost" was deliberately unspecified, in that it could refer to purchase price, mortgage repayments, rental payments or resale value of the house.

4. For building firms the importance of several of the listed items varied according to the nature of the house being built: for example, in a ready-built "spec" house, general location, nearness to shops and schools, and the block were far more important to the builder than in a contract house on the client's own land.

considered" by 51 per cent and 38 per cent of the two groups of the sampled households, and 60 per cent of real estate agents[5]. Ranking of the remaining features was relatively inconsistent, with many variations according to the nature of the sample. The newly established householders of Salisbury East considered inside appearance, room layout and size of the house to be more important than the outside appearance or locational factors[6]. Householders from the southwestern suburbs, who had selected their houses an average of 21 years earlier, rated house-size, its general location and room layout to be next most important after cost. As Figure 5.1. and Table 5.01 show, the two groups of householders agreed closely in the relative importance of the size of the house, nearness to shops and schools, and the nature of the block or garden.

For builders and real estate agents concerned with sales, the outside and inside appearance of the house and its size were the next most important features after cost. For all groups, locational factors and the nature of the block or garden were considered moderately important, with convenience to employment, climatic suitability and special

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5. Detailed results appear in Appendix V, p. 430.

6. Seventy per cent of the household heads of Salisbury East were born in the United Kingdom. For those whose migration had been sponsored by Hickinbotham Pty. Ltd. (the builder), their choice of location was limited to Hickinbotham-owned land or housing estates.

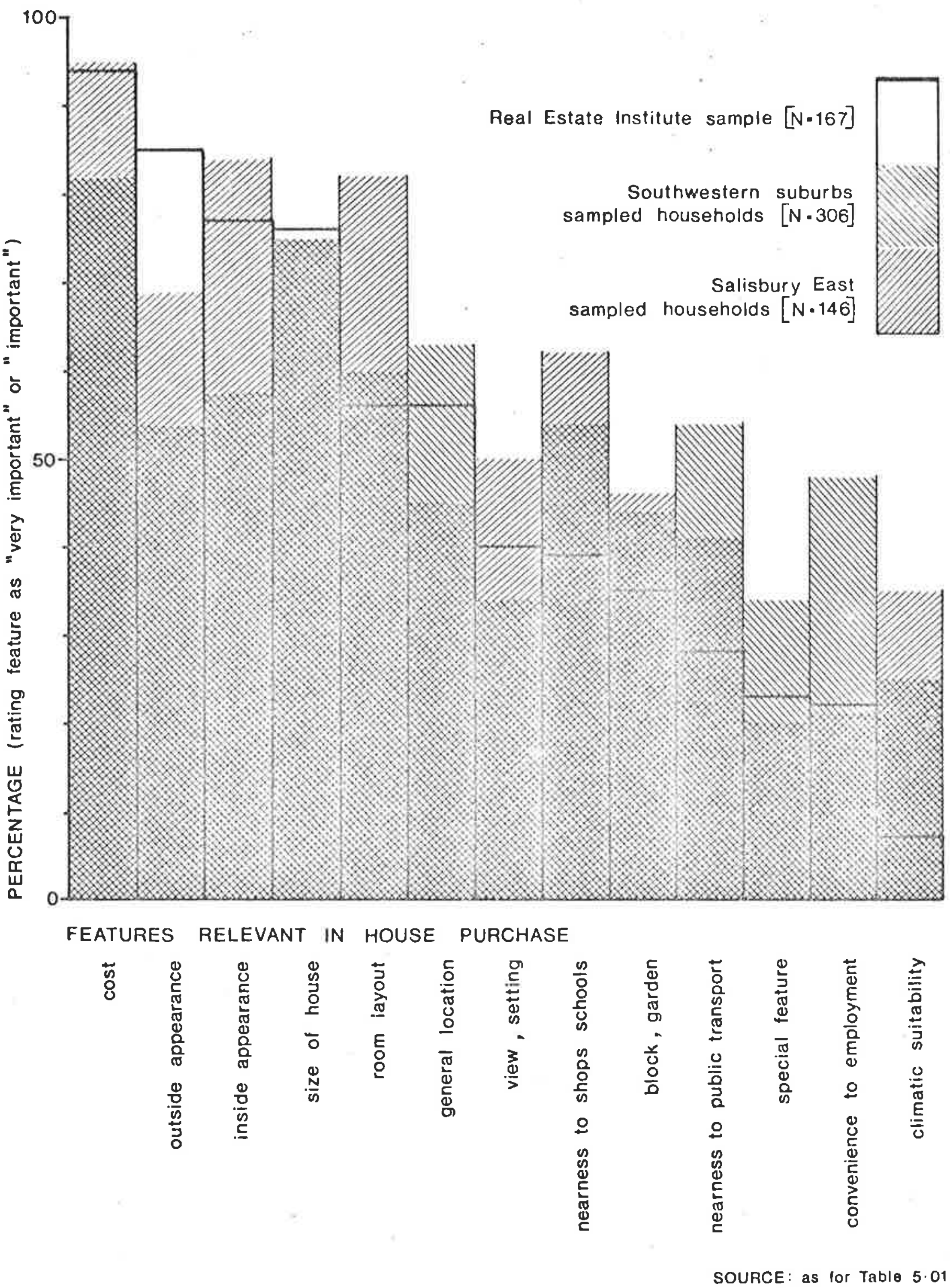

FIG. 5·1 IMPORTANCE OF FEATURES WHEN BUYING OR SELLING A HOUSE

TABLE 5.01

IMPORTANCE OF VARIOUS FEATURES IN HOUSE PURCHASE (HOUSEHOLD SAMPLES) AND HOUSE SALES (REAL ESTATE AGENTS)[a]

	Households	Households	Real Estate Agents
	Southwestern Suburbs (N = 306)	Salisbury East (N = 146)	(N = 167)
1.	Cost	Cost	Cost
2.	Size of house	Inside appearance	Outside appearance
3.	General location	Room layout	Inside appearance
4.	Room layout	Size of house	Size of house
5.	Inside appearance	Outside appearance	Room layout
6.	Nearness to shops, schools	Nearness to shops, schools	General location
7.	Outside appearance	View/setting	View/setting
8.	Nearness to public transport	Block/garden	Nearness to shops, schools
9.	Convenience to employment	General location	Block/garden
10.	Block/garden	Nearness to public transport	Nearness to public transport
11.	Special feature	Climatic suitability	Special feature
12.	View/setting	Convenience to employment	Convenience to employment
13.	Climatic suitability	Special feature	Climatic suitability

a. Ranked on basis of percentage of sample rating feature as 'very important' or 'important'.

Source: Householder's Questionnaire (Question 9) and Real Estate Institute Questionnaire (Question 1).

features the least important[7]. Figure 5.1 indicates that real estate agents seem to predict, fairly accurately, home owners' responses on cost and structural attributes of the dwelling (excluding outside appearance) but consistently under-estimate the importance accredited to environmental and accessibility requirements. Nevertheless, since climatic suitability was rated so low by all sample groups, one can conclude that, in almost all Adelaide houses being sold or bought, potential comfort of the occupants is very much an after-thought.

Other studies on house selection provide data of a different, but comparative nature, depending on the type of information sought and sample used. In six such studies [8] open-ended questions were used, often requesting general and specific reasons for selection, rather than rating the importance of pre-selected features as in this study[9]. Nevertheless, the most common features were costs, followed by particular design attributes (such as layout, appearance or utilities)

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7. Special features, nominated by the interviewees, varied widely. For example, householders stressed particular locational or design features of the house (such as nearness to relatives, or the house's potential for renovation), the effect of post-war restrictions, houses inherited from family or friends, and the nature of the site, block or street. Climate-related features were listed by five per cent of respondents. Real estate agents stressed the availability of finance and the importance of an ensuite or second bathroom, family room, garaging or carport. Builders commented on particular aspects of design or some other selling feature of their houses such as outdoor living areas, architect design, low-cost package deal or choice of facade/plan.

8. These were Rossi (1955), National Co-operative Highway Research Program (1959), Weiss, Kennedy and Steffens (1966), Pryor (1969), King (1972), and Michelson (1977).

9. For example, King (1972) investigating residential quality in Yass, New South Wales, asked "What made you decide on this street? And this house?"

and space requirements (of house or of land), and then by locational features such as availability, nature of neighbourhood or nearness to work. This correlates closely with the features highest ranked by householders in this study, namely cost, size of house, general location and room layout by one sample group, and cost, inside appearance, room layout and size by the other. It is significant that climate-related features are not listed as separate items in response to the open-ended questions used in other studies. The only exception is the seminal work of Rossi (1955) in which "heating" is grouped with other features and listed as "particular design requirements", the second most important "specification" for the purchaser. In the more extreme winter climate of parts of North America, central heating systems are considered essential, and play a significant part in the assessment of housing quality.

Twenty-five per cent of householders in the southwestern suburbs and 35 per cent in Salisbury East rated "suitability to Adelaide's climate" as very important or important when choosing their house. Among the significant factors in the rating of climatic suitability in house selection were house style and age, the place of birth of the household head and the method of questionnaire completion. Householders occupying older houses (built before 1949), who were born overseas, and who self-administered the questionnaire were more inclined to rate climatic suitability higher in their ordination of priorities.

Significance of Climate-Related Features in House Sales

Real estate agents were asked to assess the importance to clients of nine climate-related features such as the size and placement of windows, or room temperatures in winter. Table 5.02 lists these features, and shows that real estate agents considered no feature to be of much importance. The items rated highest overall were outdoor living areas (81 per cent of replies ranking them "important" or "moderately important") followed by size and placement of windows and amount of daylight indoors. The least important feature (33 per cent of respondents rated it "not very important", 25 per cent as "not considered") was the amount of air movement indoors and cross-ventilation. One-fifth of real estate agents listed other (climatic) features which they considered important to clients, when inspecting a house for sale. Of these additional features, orientation, air conditioning, ceiling insulation and particular aspects of windows were most frequently mentioned.

It is useful to compare the opinions of real estate agents and of householders on the relative importance of climate-related features in a house. In the Householder's Questionnaire, for example, the householders were asked to indicate, with respect to their own homes, levels of satisfaction with each of the nine comfort-related features mentioned above. The results are examined in detail in Chapter 7, and are shown in Table 5.02 for comparative purposes only. It is interesting to note that the sampled householders were most satisfied with features relating to windows (their size and placement, amount of daylight and cross-ventilation) and with outdoor living areas. These same features were assessed by real estate agents as being of some importance to clients, when inspecting a house for sale.

A later question in the Real Institute Questionnaire asked respondents to list any climatic aspects of housing specifically mentioned by salesmen during a normal selling procedure. Of the 119 replies to this question, house orientation (especially if north-south) was mentioned

TABLE 5.02

LEVELS OF IMPORTANCE OF, OR SATISFACTION WITH, SELECTED CLIMATE-RELATED FEATURES

Climate-related Feature	Percentage of Real Estate Agents - Rating Feature as "Very Important", "Important" or "Moderately Important" (N = 167)	Percentage of Householders "Satisfied" or "Very Satisfied" with Feature	
		Southwestern Suburbs (N = 306)	Salisbury East (N = 146)
Window-related features:			
Size and placement of windows	74	83	91
Amount of daylight indoors	80	84	97
Summer comfort features:			
Amount of air movement indoors in summer.. ..	59	89	82
Outdoor living facilities	87	85	79
Room temperatures in summer and/or cooling system	63	66	45
Amount of shade on house	67	76	58
Cooling ability of house after heat wave.. ..	49	76	69
Winter comfort features:			
Room temperatures in winter and/or heating system	70	82	77
Amount of draught in winter	50	87	72

Source: Householder's Questionnaire (Question 14) and Real Estate Institute Questionnaire (Question 2).

Chi-square (original data) = 61.39, df = 16, s = .001

by 68 per cent of respondents, heating or cooling devices by 49 per cent, followed by protection from sun, rain and wind (39 per cent), ceiling insulation (34 per cent), ventilation (inside the house or from gully or sea breezes) and shading features (both 28 per cent). Nearly half of the respondents added further comments, usually stressing price, finance arrangements, external appearance and house presentation as the major considerations in house sales. Several agents stated that, although each buyer has different needs, most are severely limited in their choice, and therefore non-climatic considerations must (or always) take priority.

The underlying assumption among real estate agents seems to be that a well designed, physically comfortable house costs more, and that the large majority of clients are not interested in the climatic suitability of the house at the time of purchase. Perusal of real estate advertisements over several months revealed sparse mention of climate-related features. "Fully ducted, reverse cycle air conditioning", "fully insulated throughout", "oil-heated living room" or "covered courtyard and patio" appear occasionally, but nearly always in higher priced homes. References to width of eaves, protection of windows, or suitably oriented rooms are even less frequent. Although, in such consumer publications on house selection as those of the Australian Women's Weekly (1974) and Mochalski and Olding (1974), there is usually some mention of orientation, aspect, indoor-outdoor relationships and other climate-related features, far greater emphasis is placed on costs, location, size, appearance and room layout. However, confusion is often evident in advice on climate-related features:

> the best concentration for your living areas is on the north side. Careful placement of eaves and sunshades will allow all sun and light into the areas all year round. This will make the rooms bright, compared with the gloomy appearance of rooms facing south, unless there are large windows facing sunny courts and gardens.
>
> (Mochalski and Olding, 1974,63)

Given such statements, it is not surprising that climatic suitability and physical comfort are such under-rated features in house sales and purchases.

CHAPTER 6

THE CLIMATIC SUITABILITY OF THE SAMPLED HOUSES

> "I don't think the houses matter: it depends on what equipment you have to warm the house in winter and cool it off in summer."
>
> (Householder Interview, October, 1974)

This attitude was typical of many of the interviewed householders, probably resulting from a lifetime of house design and construction bearing little relationship to the local climate. Throughout southern Australia it is rare for houses to be sited and designed to maximise the amount of sun entering the house in winter and minimise its entry in summer, to be insulated against the effects of climate and to provide optimum indoor comfort from the structure alone. Instead, Australians have tended to rely on energy consuming devices to heat, and to a lesser extent, cool their houses.

In this chapter the sampled houses are assessed for suitability to the local climate. In Chapter 2, a number of attributes contributing to thermal performance (and thus to comfort) are listed: some result from the design and construction of the house (such as the orientation of main glass areas, the width of eaves or provision for cross-ventilation); others from later modification carried out by the householder (such as the addition of ceiling insulation, outside awnings, a change in roof colour or planting of vegetation for summer shade). Each feature contributes separately to the climatic suitability of the house, but the seasonal and all-year performance depends on the combined (and complex) effect of the house structure and house modification, as well as on individual management by the householder[1]. Investigation of the way in which housing meets the basic criteria of suitability to the local climate and the physical comfort of occupants is difficult, and most methods are necessarily selective in their approach (Kerby, 1977b).

The method described here concentrates on evaluating the climatic suitability of existing Adelaide houses by first, identifying those attributes of house design and structure contributing most to thermal performance and, second, identifying the different features of each attribute which commonly appear in Adelaide and then ranking their performance on a five-point scale from "well above average" to "well below average" . (An example of an important attribute is " material of outer walls" ; in Adelaide the most common materials are stone, cavity brick, brick and stone, brick veneer, fibro-cement and concrete block, each of which are "features" of the attribute.) The separate rankings are combined (by assigning and adding numerical values) in order to derive a single "measure" of climatic suitability for each house.

Each attribute of house design and structure contributing to thermal performance is discussed in three ways:

(i) previous research[2] is examined in the context of design and construction in Adelaide;

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1. For example, Marshall (1957,30) compares three Elizabeth houses with identical design and orientation, and shows considerable variation (3^{o} to 10^{o}F) in indoor temperature, according to the method of house management. Temperature surveys carried out by the author are discussed in Chapter 7.

2. Australian research findings are emphasized, supported by South Australian research, when available.

(ii) the local practice, particularly the distribution of the feature in the sample is described;

(iii) the method of ranking the features is explained.

Several difficulties had to be overcome in ranking the features of the selected attributes. The first was that the features of many attributes required different or conflicting rankings for summer and winter conditions. (For example, large evergreen trees provide useful summer shade but can also block winter sunshine). Furthermore, some attributes such as "external sun protection for windows" or "provision for cross-ventilation", were applicable only in the summer months. Thus it became necessary to develop separate evaluations for the two seasons.

A second problem was that although the features of most attributes (such as outer walls of cavity brick) could be ranked on the basis of previous research, some attributes (such as shading from garden vegetation) were difficult to quantify and the ranking had to remain subjective. This element of subjectivity was minimised by having one person (the author) determine the "rank" for each house using all available evidence (namely the House Details form, facade and aerial photographs and the Householder's Questionnaire).

A third difficulty was that of the relative significance of individual features of the attributes. If, for example, a north-facing house was given the rank "well above average" should a "fully insulated ceiling" also be ranked "well above average"? Any other studies (such as Ballantyne 1975a, 1975b) which had (computer) calculated thermal performance and/or heating and cooling loads of various "building envelopes" were consulted to help determine attributes of major importance. In the apparent absence of previous use of the method used in this study of evaluating climatic suitability, professional advice was sought, and the method was later published (Kerby, 1977b). The use of the system for particular dwellings and for comparative purposes is discussed below.

Attributes of House Design, Construction and Modification Contributing to Thermal Performance

Orientation and Siting

Previous Research. Orientation and siting are stressed as the fundamental planning principles by almost all authors concerned with house design for temperate climates in the southern hemisphere. Such data as the amount of direct and diffuse radiation on vertical and horizontal surfaces (Spencer, 1965c) demonstrate the importance of a northern aspect for best seasonal control of sunshine. Calculations by the NCDC (1977,24) show that the optimum orientation of a building to collect solar heat gain in winter is one with a longer facade to the north, oriented between 45^{o}W and 30^{o}E, but that summer considerations restrict the west orientation to 15^{o}W. Other studies (Olgyay,1963) suggest an optimum (rectangular) shape of 1.5:1 to 1.6:1 north-facing to the east or west-facing side. NCDC conclude (1977,25) that the fundamental need, in latitudes such as those of Adelaide, is to ensure that a house can be sited on a block so that the living area windows are facing between 15^{o}W and 30^{o}E, and that there is unobstructed "sun access" from the north all year.

Orientation and Siting of the Sampled Houses. With only two exceptions[3], the planners (or developers) had sited the sampled houses facing the street, at regulation or conventional distances from the front, side and rear boundaries[4]. Thus the orientation of the houses (Table 6.01) was determined by street layout. In the southwestern suburbs sample area several major roads run north-south, so that the suburban streets were mainly east-west links providing a large number of north or south facing building blocks (see Figure 6.1). However, it is doubtful if this high ratio of desirable north-south facing houses was little more than coincidence, as there is generally little evidence of adjustment to house shape, room layout, or window placement to maximise or minimise the effects of orientation. For example, verandahs were built on the front of nearly all pre-war houses, regardless of the direction the house faced.

The housing estate of Salisbury East was planned and laid out by the building firm with a fairly conventional street network to maximise the number of building blocks, and minimise through traffic (see Figure 6.2). Three-quarters of the houses faced north-east, north-west, or south-west, which, combined with the large windows and relatively narrow eaves, could rapidly create discomfort on hot summer days, although

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3. The two exceptions, one in each sample area, were houses which "turned their backs to the street", and were built with main rooms facing side gardens, and minimum windows and car storage on the street facade.

4. Site requirements, under South Australian building regulations specify minimum frontages, areas, distances from side and rear boundaries and street access for detached single dwellings. Planning regulations for Council areas specify distances from the street.

TABLE 6.01

ORIENTATION (FRONT OF HOUSE) OF SAMPLED HOUSES

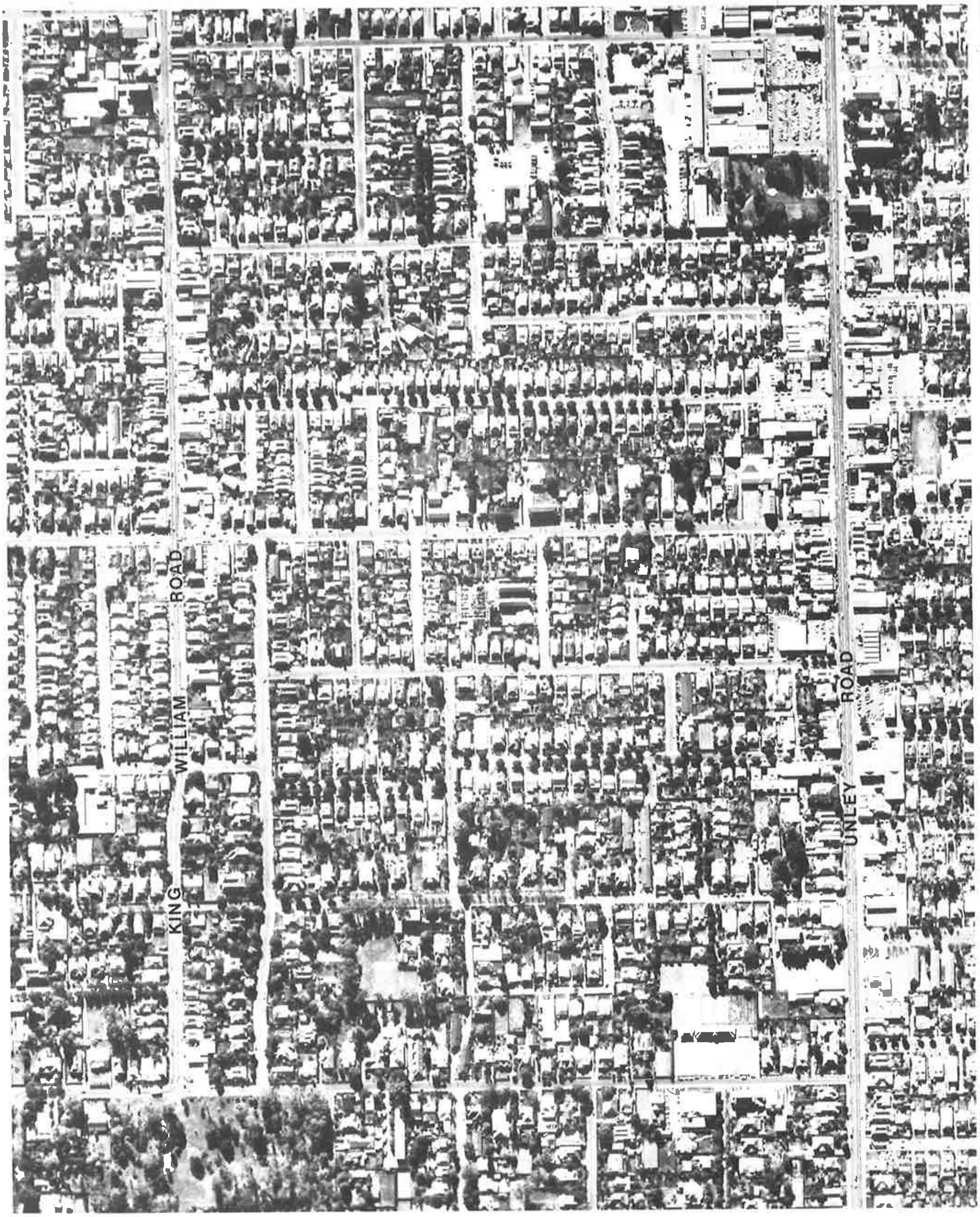
Front Facing Direction	Percentage of sampled houses	
	Southwestern Suburbs	Salisbury East
North	35	6
North-east	2	25
East	14	2
South-east	2	14
South	30	6
South-west	3	27
West	14	1
North-west	1	20
Total	100	100
	N = 306	N = 146

Source: House Details Form (Item 4).

there were winter compensations for the north-east and north-west facing houses. The large ratio of houses with mediocre or poor orientations seems to have played a major part in the summer discomfort expressed by many of the Salisbury East householders.

Method of Ranking. For use in the evaluation of climatic suitability, the attribute "orientation" was interpreted as "orientation of main glass areas" since glass transmits almost all short-wave radiation received (Givoni, 1969, 211)[5]. Using data provided by Spencer (1965c),

5. Most frequently the main glass areas faced the street; in a few houses, however, largest windows or a glass-walled sunroom were at the side or rear.



SOURCE: S.A. Department of Lands

0 km (approx.) 0·25

FIG. 6·1 AERIAL PHOTOGRAPH, 1975, OF SOUTHWESTERN SUBURBS - UNLEY, HYDE PARK.

SOURCE : S.A. Department of Lands

FIG. 6·2 AERIAL PHOTOGRAPH, 1975, OF SALISBURY EAST.

0 km 0·25

TABLE 6.02

TOTAL DIRECT AND DIFFUSE RADIATION (MJ per m^2 per day)

RECEIVED AT ADELAIDE ON VARIOUS SURFACES ON

DECEMBER 22ND AND JUNE 21ST

Type of surface	December 22nd (MJ/m^2 per day)	June 21st
Vertical surface facing		
north	9.9	21.0
northeast	15.7	16.0
east	19.3	7.9
southeast	15.7	2.8
south	10.0	2.5
southwest	15.9	2.7
west	19.4	7.6
northwest	15.7	16.2
Horizontal surface	33.4	11.1

Source: Adapted from Spencer (1965c)

and shown in Table 6.02, it can be seen that, during summer, when minimum direct and diffuse radiation is desirable, a north or south-facing building is best. A house with most glass area facing north or south was, therefore, rated "well above average"[6]. Houses facing northeast, southeast, southwest and northwest receive similar amounts of radiation (on December 22nd), whereas houses with main glass facing east and west received most radiation, and were rated "below average".

6. The ranked positions designated to each feature of this and other attributes are shown in Table 6.27 (summer climatic suitability) and Table 6.28 (winter climatic suitability).

At the winter solstice (June 21st), however, a northerly component is necessary to maximise winter sunshine: south-facing surfaces receive no direct radiation on this date. Using the data provided in Table 6.02 it is possible to rank orientations for use in the evaluation of winter climatic suitability, from north ("well above average"), followed by northeast and northwest ("above average"), east and west ("average") and, finally, southeast, south and southwest, which receive least radiation ("below average").

Material and Colour of Outer Walls

Previous Research. There are numerous studies which demonstrate the effect of the weight of construction on indoor temperatures and comfort, of which the following are four examples: Drysdale (1948b,1948c) shows, from model structures, that the likely indoor temperature with 100°F in the shade outdoors ranges from 96° - 100°F (36° - 38°C) for a frame construction or brick veneer, to 83° - 89°F (28° - 32°C) for a brick cavity wall of 11 inches, or reversed brick veneer; Ballantyne (1975a) demonstrates that the annual index of uncomfortable conditions in Melbourne is highest in a rectangular "envelope" of timber frame, timber floor and iron roof, and lowest in an envelope of brick veneer, concrete floor and insulated tiled roof; NCDC (1977) shows that the exterior walls account for approximately 28 to 30 per cent of winter heat loss in an uninsulated brick veneer dwelling; Cummings and McNeilly (1979) demonstrate the year-round advantages of brick cavity construction. Since the heavier the thermal mass and the greater the ability of the house to reduce daily temperature variations, heavy weight construction (outer walls of stone, cavity brick or insulated brick veneer) is recommended for South Australian conditions. The disadvantage of high heat-storage capacity at night or at the end of a heat wave can be overcome with sufficient natural or forced ventilation.

Since the amount of solar energy absorbed by any material depends upon the colour, texture and nature of the surface material (Barned and O'Brien, 1976), the colour and texture of outer walls of houses each affect thermal performance. Light reflective wall colours can be used to decrease the absorption coefficient of solar radiation in summer and dark colours to increase its absorption (where desired) in winter. Since the rate of flow of heat into a dwelling can be increased several times when walls are sunlit (Drysdale, 1975,27), seasonal control of shading is desirable.

Material and Colour of Outer Walls on the Sampled Houses. Tables 6.03 and 6.04 show the high percentage of sampled houses of heavy-weight construction, and the gradual change in outer wall material, from stone, brick and stone prior to 1930, to cavity brick, brick veneer and other materials in later years[7]. The reasons, however, for the overwhelming dominance of stone and brick construction in Adelaide appear to be economic and aesthetic, rather than climatic. Abundant local supplies of stone and clay for bricks[8] (and the relative inferiority of local timber), the relatively similar costs of construction of cavity brick

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7. The method of placing 23 house-styles/ages from the two sample areas into five classes, for use in tables of this and subsequent chapters, is shown in Appendix IV, p. 426.

8. Approximately 80 per cent of all stone houses in Australia in 1961 were located in South Australia.

TABLE 6.03

OUTER WALL MATERIAL OF SAMPLED HOUSES

Type of material	Percentage of sampled houses	
	Southwestern Suburbs	Salisbury East
Cavity brick	59	84
Brick veneer	2	14
Stone	9	-
Brick and stone	23	-
Other	8	1
Total	100 N = 306	100 N = 146

Source: Householder's Questionnaire (Question 4).

TABLE 6.04

OUTER WALL MATERIAL BY HOUSE STYLE AND AGE

House Style and Age	Wall material (percentage)				
	Cavity brick	Brick veneer	Stone	Brick and stone	Other
Symmetrical Front and Early Villas, 1850-1905	1	-	58	23	-
Later Villas, Bungalows and Tudor, 1905-1945	13	-	4	39	8
Austerity, 1946-1952	14	7	4	13	46
S.A.H.T., L-shape, Conventional, 1952-1965	29	7	35	26	39
New, 1966-1974	43	85	-	-	8
Total	100 n = 303	100 n = 27	100 n = 26	100 n = 70	100 n = 26

Source: House Details Form (Item 1) and Householder's Questionnaire (Question 3).

and brick veneer[9], and the importance to consumers of clay bricks' appearance, prestige and durability[10] can be offered in explanation.

The colour of the outer walls on the sampled houses was either predetermined by the nature of the building material, or selected for its appearance, rather than any climatic function. Table 6.05 indicates a preference for light-coloured exterior walls in both sample areas, with a second preference for medium colours in the southwestern suburbs, and dark colours in Salisbury East. However, the variety in wall colour in the southwestern suburbs reflected changes in outer wall material (from dark bluestone to mixed red-brick and freestone, and medium-coloured red brick, to light cream brick) whereas colour variations in Salisbury East merely reflect the range available in modern clay bricks. The relationship between the style of the house and the colour of exterior walls is shown in Table 6.06.

Method of Ranking. Since daily temperature variations are reduced by heavy thermal mass (a factor of greatest benefit on hot days in summer, when peak indoor temperatures are significantly less in heavy-weight buildings) the thickness of the outer wall material was used to rank the attribute "material of outer walls" for evaluating the summer climatic suitability of houses. Outer walls of (blue) stone were ranked highest

9. A survey (by the Commercial Banking Corporation) of all building costs in capital cities in the first half of 1975 found that typical costs in Adelaide were $155 - 160 per sq. metre for brick veneer, and $150 - 160 per sq. metre for cavity brick. (The Advertiser, June 21st, 1975, 14). Brick veneer is popular in some parts of Adelaide where the soils have high swelling coefficients, leading to severe cracking in stone or solid brick houses.

10. A survey which investigated the attitude of Adelaide's consumers to the use of clay bricks concludes that "clay bricks have a strong aesthetic appeal to most homeowners who feel there is prestige in owning a brick house" (Townsend, 1976b, 24). Colour, texture, the natural look of bricks, sound proofing and heat insulating qualities were considered by consumers, with costs playing a less dominant role in selection.

TABLE 6.05

COLOUR OF EXTERIOR WALLS ON SAMPLED HOUSES

Colour tone	Percentage of sampled houses: Southwestern Suburbs	Percentage of sampled houses: Salisbury East
Light	44	57
Medium	25	18
Dark	9	25
Mixture	22	-
Total	100 N = 306	100 N = 146

Source: House Details Form (Item 10).

Chi-square (original data) = 54.14, df = 3, s = .000

TABLE 6.06

COLOUR OF EXTERIOR WALLS BY HOUSE STYLE AND AGE

House Style and Age	Colour of Exterior Walls (Percentage of houses): Light	Medium	Dark	Medium
Symmetrical Front and Early Villas, 1850-1905	4	5	8	25
Later Villas, Bungalows and Tudor, 1905-1945	7	16	14	42
Austerity, 1946-1952	14	22	13	9
S.A.H.T., L-shape, Conventional, 1952-1965	34	30	8	24
New, 1966-1974	41	29	58	-
Total	100 n = 219	100 n = 102	100 n = 64	100 n = 67

Source: House Details Form (Items 1 and 10).

Chi-square (original data) = 127.83, df = 12, s = .000

("well above average"), followed by cavity brick ("above average"), brick veneer ("average") and finally, timber and uninsulated fibro-cement ("below average"). For the winter months, however, Walsh (1976a) demonstrates the good performance of brick veneer. Lower minimum indoor temperatures and higher energy requirements for heating occur both in houses of heavier construction (such as brick and stone) due to the higher thermal capacity of the wall material, and in houses of light-weight construction (such as fibro-cement) due to the lack of insulation. Thus the ranked positions designated for winter climatic suitability became brick veneer ("above average"), cavity brick, brick and stone, and concrete-block ("average"), stone ("below average"). and finally, uninsulated timber and fibro-cement ("well below average"). The ranking of "colour of the exterior walls" is explained in the following section on roof colour.

Roof Material, Pitch, Colour

Previous Research. Since the major heat gain of any structure in summer is usually received from the sun's energy through the roof, the interior temperature is largely dependent upon material, colour and shape of the roof. In an uninsulated brick veneer dwelling 25 to 28 per cent of heat loss occurs through the ceiling and roof (NCDC, 1977, 13). Most roofs on Australian houses are medium-to-steep pitched,[11] designed originally to shed rain and snow, and considered (erroneously) to offer the best protection against climatic conditions by the large mass of air above the ceiling. As Hassall (1965, 30) explains, in an uninsulated roof during the summer, this air does provide thermal

11. Rand (1972) explains the retention of pitched roofs (and other dominant features) in terms of the development of children's images of houses, as revealed through their drawings: Cowburn (1966) stresses the link between a tiled, pitched roof and "security".

inertia which helps to delay downward transfer by conduction and convection. However, 75 per cent of the heat flow through the ceiling is by radiation and only additional insulation can combat this. In winter the large roof space, if ventilated, encourages heat loss from rooms below. This results in extra heating costs in addition to the higher construction costs of a pitched, tiled roof. A flat roof, with one or two layers of reflective insulation provides the same thermal resistance as the traditional pitched roof. Nevertheless, pitched roofs do facilitate the later addition of thermal insulation on the upper side of the ceiling. The thermal resistance of roofing materials can serve to lower temperatures below the roof, but the high thermal conductivity of metal sheeting leads to minimal differences between the upper and underside of the roof, which can be reduced only by effective ventilation of the roof space. The resulting high radiant temperature of iron is of special importance when it is used for the (unlined) roofs of verandahs (Drysdale, 1975, 24). It has been found experimentally (Drysdale, 1950c, 24) that an unlined verandah with a galvanised-iron roof and enclosed with a single thickness of sheet material and casement windows will cause air contained within it to rise at least $3^{o}C$ above the temperature of shade-air when the verandah is sunlit and the outdoor temperature is only $32^{o}C$.

The colour of the irradiated surface can be important. If no ceiling insulation is present, a light reflective roof (and exterior wall colour) reduces indoor temperatures appreciably in summer, whereas a dark-coloured roof and walls assist in maximising winter absorption of radiation (Givoni, 1969; Drysdale, 1975, 42).

Roof Material, Pitch and Colour on the Sampled Houses. Table 6.07 shows the high percentages of tiled roofs on the sampled houses, predominantly of medium pitch. Nearly all houses built before 1930 had galvanised iron roofs, whereas most houses built since World War II had tiles[12] (Table 6.08). High-pitched roofs, fashionable during the inter-war years for such bungalows and pseudo-Tudor styles, have not reappeared (Table 6.09). Roof ventilation, considered essential by some architects and designers, occurred only in older houses, especially Villas. Only one sampled house, with a 60 degree pitched roof, used roof ventilation for summer cooling[13].

Table 6.10 shows that almost half the houses in both samples had medium-coloured roofs (most frequently with light-coloured walls, reflecting popular taste for contrasting tones in walls and roof). Only a few householders consciously chose white roof tiles or light, reflective paint for an iron roof in an effort to reduce the summer heat load.

Method of Ranking. Colour-tone of the roof and walls was incorporated in the climatic suitability evaluations only if the ceiling was not insulated. For summer, light reflective roof and exterior wall colours were ranked "above average", medium "average" and dark "below average".

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12. Boyd (1965, 9) explains that the attempt, in 1955, to introduce "contemporary" house-style, featuring wide windows, a longer plan and a low pitched roof "was the mortal enemy of the heavy roof tile which Australia had adopted from Marseilles 70 years earlier and now used more than any other place in the world, including Marseilles."

13. The householder explained that the height from the ceiling to the apex was approximately 8 ft 6 ins, and that cooling was achieved by opening the trap a few inches to allow hot air from inside the house to be sucked into the roof-space at night.

TABLE 6.07

ROOF MATERIAL AND ROOF PITCH OF SAMPLED HOUSES

Type of material or pitch		Percentage of sampled houses: Southwestern Suburbs	Percentage of sampled houses: Salisbury East
Roof material:	tiles	64	99
	galvanised iron	32	1
	other	4	-
Total		100	100

Chi-square (original data) = 63.32, df = 2, s = .0001.

Roof pitch:	flat or low, $<17\frac{1}{2}^{o}$	5	1
	medium, $17\frac{1}{2}$-25^{o}	89	99
	high, $>25^{o}$	7	-
Total		100 N = 306	100 N = 146

Source: House Details Form (Items 8 and 9)

Chi-square (original data) = 12.23, df = 2, s = .01.

TABLE 6.08

ROOF MATERIAL BY HOUSE STYLE AND AGE

House Style and Age	Roof material (percentage)		
	Tiles	Galvanised iron	Other
Symmetrical Front and Early Villas, 1850-1905	1	31	8
Later Villas, Bungalows and Tudor 1905-1945	3	55	31
Austerity, 1946-1952	16	10	8
S.A.H.T., L-shape, Conventional, 1952-1965	35	4	31
New, 1966-1974	45	-	23
Total	100 n = 340	100 n = 99	100 n = 13

Source: House Details Form (Items 1 and 8).

TABLE 6.09

ROOF PITCH BY HOUSE STYLE AND AGE

House Style and Age	Roof pitch (percentage of sampled houses)		
	Flat or low 17°	Medium $17\frac{1}{2}-25^{\circ}$	High 25°
Symmetrical Front and Early Villas, 1850-1905	6	7	20
Later Villas, Bungalows and Tudor, 1905-1945	6	13	65
Austerity, 1946-1952	41	14	15
S.A.H.T., L-shape, Conventional, 1952-1965	29	29	-
New, 1966-1974	18	37	-
Total	100 n = 17	100 n = 415	100 n = 20

Source: House Details Form (Items 1 and 9).

Chi-square (original data) = 61.963, df = 8, s = .000

TABLE 6.10

COLOUR OF ROOFS ON SAMPLED HOUSES

Colour tone	Percentage of sampled houses	
	Southwestern Suburbs	Salisbury East
Light	18	38
Medium	47	44
Dark	36	18
Total	100 N = 306	100 N = 146

Source: House Details Form (Item 10).

Chi-square (original data) = 28.11, df = 2, s = .000

For winter, climatic suitability, the rankings were reversed. Roof material and pitch were not included since they seem to have a negligible effect (CEBS,NSB No 21, 1973) particularly in comparison with the effect of ceiling insulation and roof colour.

Floor Material

Previous Research. Concrete floors are recommended for stabilizing indoor temperatures, both in panelized buildings (Gupta and Spencer, 1970; Gupta and Anson, 1972) and in houses of conventional design and structure (Muncey, 1954b). Concrete slabs on the ground lose little heat into the "ground" underneath as the earth is usually a relatively poor conductor of heat (NCDC, 1977, 16). Thus they reduce heat loss in winter as well as heat gain in summer, and, provided areas exposed to the sun in winter are not covered by carpet or other insulating surfaces, act as a very efficient thermal mass. (Quarry tiles, or similar, are recommended for areas behind north-facing glass in living areas). The "cold sensation" of concrete on bare feet (due to the greater thermal conductivity of concrete compared with timber) can be overcome by the use of a "warm surface" such as cork tiles or carpet in areas which are not heated by the sun.

Floors in the Sampled Houses. No data were collected on the nature of the floor in the sampled houses, since it was assumed that almost all floors were of timber construction. Thus the attribute was not included in the climatic suitability evaluations.

Height and Insulation of Ceiling

Previous Research. Many householders believe that a high ceiling promotes coolness in summer, but it has been demonstrated that an increase in ceiling height above 2.5 metres (8 feet) only serves to increase construction costs, without any thermal benefit accruing (Givoni, 1969, 153; Drysdale, 1959). It is far more important that the ceiling be insulated and there is abundant information available on the insulating value of various materials (Barned and O'Brien, 1970; NCDC, 1977); the economic worth of insulation (Muncey, 1955; White, 1975; Coldicutt et al., 1977a); the estimated fuel savings from insulating the ceiling and/or walls (O'Brien, 1973); the actual savings in energy costs from an insulated ceiling (Blakeley and Cook, 1974); and the value of ceiling insulation to the normal householder (Wilson and Baker, 1964; Australian Consumers Association, 1975,1979). For the heated parts of cavity brick houses in Adelaide approximately 50 mm (two inches) of mineral wool insulation [14] (or its equivalent) is recommended (Muncey, 1955,493). A later calculation (Halligan and Vigh, 1979,20) recommends 100 mm of (fibreglass) ceiling insulation as the optimum thickness for Adelaide's air conditioned houses in summer. Nevertheless, a thickness of 50 mm can help to prevent excessive heat loss in winter and heat gain in summer [15], raise the mean radiant temperature during winter, and enable possible fuel savings of up to 25 per cent. Ballantyne (1975b,11) concludes that "insulation is economically mandatory when high cost fuels are used".

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14. Reflective insulation reduced heat flow by reflecting most of the radiation (on the warm side) and/or by not emitting much radiation (on the cool side). It is more effective in limiting heat gain in summer (sun's radiant heat) than in limiting heat loss in winter (NCDC, 1977, 15).

15. Givoni (1969, 150) shows that 50 mm of mineral wool insulation can reduce maximum temperatures (in the rooms below) by at least 2.2^{o}F (1.2^{o}C) in hot weather.

Height and Insulation of Ceilings in the Sampled Houses. No data were collected on the height of ceilings in the sampled houses, but from observation inside the house during the interview, and from outside, it can be stated that a progressive reduction in ceiling height has occurred from 3.1 metres (10 ft) or more in pre-1900 houses to the minimum 2.8 metres (8ft 4.5 ins) in all the Salisbury East sampled houses built in the early 1970's.

The presence and type of ceiling insulation in the sampled houses, as stated by the householder in the interview or questionnaire, is shown in Tables 6.11 to 6.13. Clearly, post-war and modern houses were more likely to be insulated, and most houses were insulated some years after construction. Almost half the sampled houses had some form of ceiling insulation.

TABLE 6.11

CEILING INSULATION IN SAMPLED HOUSES (AS INDICATED BY RESPONDENTS)

Existence of ceiling insulation	Percentage of sampled houses	
	Southwestern Suburbs	Salisbury East
Insulation added since moving in	28	51
Insulation bought with house	13	7
Part of ceiling insulated	1	-
No ceiling insulation	58	42
Total	100	100
	N = 306	N = 146

Source: Householder's Questionnaire (Question 12).

Chi-square (original data) = 26.53, df = 3, s = .000

This percentage of insulated ceilings was higher than anticipated by the major insulation manufacturer in South Australia [16] and the President of the Thermal Institute of Australia[17], but the findings were similar to those of the Electricity Trust of South Australia and the Australian Consumers Association[18].

The higher ratio of insulated ceilings in the Salisbury East sampled houses, after only three or four years of occupation, is of special significance. It correlates with the strong degree of summer discomfort expressed by the Salisbury East householders and their tendency to modify their houses in an attempt to improve summer conditions. The effect of an insulated ceiling on indoor comfort and on energy consumption is discussed in Chapters 7 and 8 respectively.

Table 6.13 shows that the most popular materials chosen for insulating the ceiling were rockwool, fibreglass and cellulose fibre. For domestic

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16. Bradford Insulation (S.A.) Pty. Ltd. estimates to have insulated 30,000 houses in Adelaide with rockwool to 1975, approximately 13 per cent of the total number of houses.

17. Personal communication, E.R. Ballantyne, CSIRO Division of Building Research, 16th February, 1976.

18. The Electricity Trust of South Australia conducted domestic consumer surveys in 1972, 1975, 1976 and 1977, in which approximately 1,000 randomly-selected electrical consumers provided information on the ownership and use of electrical appliances. In 1972, 35 per cent of all consumers had insulated ceilings, increasing to 50 per cent in 1976, which agrees closely with the 42 per cent in 1974 (southwestern suburbs) and 58 per cent in 1975 (Salisbury East) of this survey. An Australia-wide survey (Australian Consumers Association, 1978a, 120) found that 54 per cent of 2,171 respondents had some form of insulation in their houses, indicating that Adelaide in 1974-5 (with 47 per cent with some form of insulation) was close to the national average.

TABLE 6.12

PRESENCE OF CEILING INSULATION BY HOUSE STYLE AND AGE

House Style and Age	Number of Houses in Sample	Percentage of House-style Insulated
Symmetrical Front and Early Villas, 1850-1905	34	26
Later Villas, Bungalows and Tudor, 1905-1945	69	28
Austerity, 1946-1952	67	34
S.A.H.T., L-shape, Conventional, 1952-1965	126	55
New, 1966-1974	156	58
Total	452	47

Source: House Details Form (Item 1) and Householder's Questionnnaire (Question 12).

TABLE 6.13

TYPE OF MATERIAL USED FOR CEILING INSULATION IN INSULATED HOUSES

Type of material	Percentage of insulated houses	
	Southwestern Suburbs	Salisbury East
Rockwool	38	24
Fibreglass	28	16
Cellulose Fibre	6	46
Aluminium foil	6	1
Other	6	2
Combination of types	4	-
Not stated	13	11
Total	100 n = 127	100 n = 83

Source: Householder's Questionnaire (Question 12).

Chi-square (original data) = 50.99, df = 6, s = .000

construction, rockwool (fibres spun from blast furnace and other selected minerals) and fibreglass (produced from pure glass marbles) are most frequently used in batts of 50 mm thickness, sized for easy placement between ceiling joists. Householders living in the older, established housing of the southwestern suburbs preferred ceiling insulation in batt form[19]. Cellulose fibre (macerated waste-paper, chemically treated to be fireproof, then applied by blowing equipment as loose-fill material at a recommended thickness of 100 mm or four inches) was used in 38 per cent of the Salisbury East insulated houses. A door to door sales programme of cellulose-fibre insulation manufacturers during the 1970's in various suburban areas may have contributed to this high percentage of houses insulated with loose-fill material. Only three per cent of the insulated houses in the southwestern suburbs used this method. The remaining houses of both samples used aluminium foil (often for low-pitched roofs, or in combination with other types), a combined method of insulation, or other types such as seaweed or straw ceilings[20]. Over ten per cent of householders living in insulated houses were vague or uncertain about the type of insulating material used. Five per cent of householders in the southwestern suburbs, and seven per cent in the Salisbury East area stated that they would like to insulate the ceilings of their homes in the near future.

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19. The survey conducted by the Australian Consumers Association (1978a, 120) showed that, of the people with insulation, most had fibreglass installed in the roof; fewer houses had insulated walls, and reflective foil insulation.

20. The small number of houses insulated with aluminium foil agrees with the findings of the 1976 Electricity Trust of South Australia Survey, in which 94 per cent of consumers with insulated ceilings used thick material, and 6 per cent thin material.

Method of Ranking. The importance of a ceiling insulated with batts or loose fill material was recognized by its high ranked position ("well above average") in evaluating both summer and winter climatic suitability. The reduced value of reflective insulation in winter accounts for the lower rank ("above average") in the winter evaluation. No ceiling insulation was considered "average". Despite the probable effect of a high ceiling on winter room temperatures, ceiling height was not included.

Window Size, Placement, Protection

Previous Research. The amount and placement of glazing is of fundamental importance both in terms of heat gain during summer (the so-called "greenhouse effect") and heat loss during winter, in addition to the requirements for natural lighting, ventilation, acoustic and visual privacy. The extensive and injudicious use of glass in "modern" buildings of the 1950's did much to create serious thermal problems (Lotz and Van Straaten, 1968), comfort and glare problems (Hutcheon, 1964; Marshall, 1961-62, 1963b) and high air conditioning costs (Wright, 1955). Special heat-absorbing glass is not always the solution (Ballantyne, 1960; Ballantyne and Spencer, 1961; Cuttle, 1971; Cooper *et al.*, 1974): it is obviously far better to attend to building shape and orientation, the size and location of windows, and scientifically designed sun control devices.

The thermal effect of living room glazing of various orientations has been clearly shown by NCDC (1977, 29) in which west-facing windows resulted in an indoor temperature above 27°C (the upper level of comfort) for seven hours, peaking at 32°C at 6 p.m., when the maximum outdoor temperature was only 28°C. This effect of orientation on the temperature of particular rooms (rather than the whole house) has also been demonstrated by Ballantyne and Spencer (1972). This is of particular importance in suburban locations, where the "best" (and largest) windows face the street, regardless of direction (Russell, 1979). An additional problem in the foothills suburbs of Adelaide is that the view lies to the west. Furthermore, "windows larger than necessary for good natural lighting can create problems of solar heating, deterioration of fabrics, noise and loss of privacy" (CEBS,NSB No 21, 1973).

Tables are available (such as Drysdale, 1975, 28) which demonstrate the need to intercept summer sunshine externally rather than internally; excellent texts are available (such as Phillips, 1975; Olgyay and Olgyay, 1957; Coldicutt et al., 1977b) to help determine the size and shape of shades required and to provide ideas for possible solutions. If maximum comfort is to be achieved, external shading of windows should vary according to orientation. Suitable control is most easily obtained on walls facing north; for walls facing north-west, west and south-west, it becomes increasingly difficult to exercise desirable control with projecting hoods or eaves (Phillips, 1975, 19-20). Adjustable outdoor blinds, wooden shutters or deciduous creepers are a good solution: fixed controls such as tinted or reflective glass to reduce solar heat gain are not desirable for dwellings (Ballantyne, 1975b) because they reduce solar heat gain when it would be welcomed in winter (and probably spring and autumn, also). Another possibility, that of double-glazing, will increase the insulation value of windows, but is rarely economic in houses in temperate climates (Wheeler, 1977, 65). Good, tight-fitting curtains can offer a satisfactory reduction in either direction (as well as serving functions of privacy and light-control) particularly if fitted with a pelmet to help prevent air circulating from between the curtains and the glass.

Window Size, Placement and Protection in the Sampled Houses. Tables 6.14 and 6.15 show that the mixed age and style of housing in the southwestern suburbs have a wider variety of window sizes than the newer, homogeneous houses of Salisbury East. Furthermore, the size of windows gradually increased as house styles changed from villas and bungalows to the contemporary and conventional styles of the post-war era.

Table 6.16 shows that the windows of houses in the southwestern suburbs tended to have a greater degree of protection than the windows of the sampled houses of Salisbury East. (It is also important to remember that the average size of windows in houses of the southwestern suburbs was less than that in the new houses of Salisbury East). Although no data were collected on the relationship between the direction the window faced and the type of shading used, house facade photographs revealed that fixed awnings and small pergolas appeared most frequently over the front, exposed window of villas and bungalows, regardless of orientation. Pergolas were integral in several of the Salisbury East range of designs, usually across the front of the house, connecting the carport to front entry, and of very limited shading value until covered with vegetation (Plate 6.01). A very small percentage of sampled houses used functional shutters, and two modern houses featured decorative shutters of the pseudo-Colonial building style of the mid-1960's.

The most popular treatment for windows were outside awnings, ranging in number from one to eight per house (Table 6.17). The houses with

TABLE 6.14

RATIO OF WINDOW TO WALL IN THE FRONT WALL OF SAMPLED HOUSES

Ratio of window to wall		Percentage of sampled houses: Southwestern Suburbs	Percentage of sampled houses: Salisbury East
Low	<1:3	40	1
Medium	1:3 to 2:3	44	29
High	>2:3	10	66
Mixture		6	3
Total		100 N = 306	100 N = 146

Source: House Details Form (Item 11).

TABLE 6.15

RATIO OF WINDOW TO WALL BY HOUSE STYLE AND AGE

House Style and Age	Ratio of window to wall (percentage of houses) low	medium	high	mixture
Symmetrical Front and Early Villas, 1850-1905	25	1	-	8
Later Villas, Bungalows and Tudor, 1905-1945	41	6	-	29
Austerity, 1946-1952	23	20	1	8
S.A.H.T., L-shape, Conventional, 1952-1965	9	47	19	33
New, 1966-1974	2	26	81	21
Total	100 n = 123	100 n = 177	100 n = 128	100 n = 24

Source: House Details Form (Items 1 and 11).

TABLE 6.16

WINDOW SHADING IN THE SAMPLED HOUSES

Type of window-shade	Percentage of sampled houses: Southwestern Suburbs (N = 306)	Salisbury East (N = 146)
Fixed awning	6	-
Pergola	7	13
Shutters	4	1
Outside awnings	57	39
Reflective film	-	2

Source: House Details Form (Item 14)

Chi-square (original data) = 24.02, df = 4, s = .000

TABLE 6.17

PRESENCE OF OUTSIDE AWNINGS ON SAMPLED HOUSES

Number of awnings	Percentage of sampled houses: Southwestern Suburbs	Salisbury East
None	43	60
One	9	5
Two	13	10
Three	12	8
Four	12	8
Five	6	5
Six, seven or eight	4	5
Total	100 N = 306	100 N = 146

Source: Householder's Questionnaire (Question 12).

Chi-square (original data) = 12.87, df = 6, s = .05.

outside awnings faced all directions (Table 6.18) and since details were not obtained on the direction of the windows with awnings, it is not possible to specify which glass was most frequently shaded, or to verify the manufacturers' and retailers' claim that west and east-facing windows provide most of their sales, followed by north-facing and sometimes south-facing[21].

TABLE 6.18

PRESENCE OF OUTSIDE AWNINGS BY ORIENTATION OF FRONT OF HOUSE

Direction of front of house	Percentage of sampled houses			
	Southwestern Suburbs		Salisbury East	
	with awnings n = 175	without awnings n = 131	with awnings n = 57	without awnings n = 89
North	21	15	3	3
North-east	1	-	8	16
East	7	7	1	1
South-east	1	1	5	9
South	15	14	1	5
South-west	2	1	10	18
West	9	5	1	1
North-west	1	-	11	8
Total	57	43	40	61

Source: House Details Form (Items 4 and 14).

Chi-square (original data, Southwestern Suburbs) = 4.87, df = 7, s = .70
(original data, Salisbury East) = 11.15, df = 7, s = .20

21. Personal Communication, J. Teague, Burns Blinds and Curtain Centre, 4th April, 1975.

Approximately half the awnings on all windows in the sampled houses were made of canvas, and about a third of more expensive, but longer-lasting aluminium. A few houses had awnings of plastic vinyl (trade-name "Vynapruf"), a recently introduced material which provides a more durable, non-fading alternative to canvas, at the same price. Plastic and bamboo, the cheapest but least durable types of material were used on one tenth of windows with awnings, and had the additional advantage of permitting the occupants to see out of the window[22].

A product first introduced to Adelaide domestic consumers in 1973, used on the windows of three of the sampled houses in Salisbury East, is reflective "solar control" film, a transparent coating of aluminium laminated to polyester on both sides and adhesively applied to the inside of the glass. Manufacturers claim a reduction of up to 78 per cent in direct radiation, and up to 75 per cent in ultra-violet transmission, as well as other advantages[23]. Three new methods of window-protection were not represented in the sample[24].

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22. Marshall (1963a, 19) is highly critical of the window size and placement in the contemporary-style houses built in the foothills-suburbs of Adelaide during the 1960's, in which the view from the west windows was obliterated, for seven or eight months of the year, by canvas outside and Venetian blinds inside.

23. The film permits normal outward vision, strengthens the glass against shattering, allows normal window-cleaning and reduces airconditioning load. Its two main disadvantages are the reduced transmission of desirable sun's energy in winter-time, and the mirror-like appearance of the treated windows from the outside (which enables day-time privacy, but is considered unattractive by many people).

24. The three products, which overcome some of the disadvantages of outside awnings and of reflective film, became commercially available in South Australia during 1976. One was a roller blind of silver plastic 3 mm thick which permits seasonal use of the relfective solar film principle; the second was a non-reflective film for application to windows; the third a fibreglass screening fabricated into a mesh for exterior window screens.

Method of Ranking. Two attributes of window size, placement and protection were incorporated in the evaluation of winter and summer climatic suitability, namely the ratio of window to wall and the type of external window shading. For summer conditions, a low ratio of window to wall was ranked highest ("above average"), followed by a medium ratio or favourable mixture [25] ("average"), high ratio or unfavourable mixture ("below average") and finally, large windows facing east or west ("well below average"). Conversely, large windows facing north ranked highest for winter ("well above average"), followed by large windows facing other directions ("above average"), medium ratio of window to wall or a favourable mixture ("average") and finally, small windows or unfavourable mixture ("below average"). The type of external window shading was ranked for the evaluation of summer climatic suitability. Adjustable protection (outside awnings, shutters or a large, vine-covered pergola) was ranked higher ("well above average") than reflective film, fixed awnings or a bare pergola ("above average").

Self-shading and Verandahs

Previous Research. "Self-shading", the desirable shading for walls provided by the eaves and roof overhangs, is most easily achieved on north-facing walls. For latitudes of approximately 35^{o} south (or north), a roof overhang equal to half the distance from the eaves to the bottom of the glass will suffice. Verandahs, placed almost indiscriminately on many country and city houses before 1930, were often too wide to permit winter sunshine to enter, and provided little

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25. A favourable mixture (for summer conditions) could be a house with a large window facing south, and small or medium-sized windows elsewhere. An unfavourable mixture could be a house with small or medium windows except for a glass-walled sun-room on the north-west corner.

protection from eastern or western sun. An unlined, galvanised iron verandah, if placed on the windward side of a house, may further increase the summer temperatures of rooms opening onto it (Drysdale, 1975). Nevertheless, Paynter (1965, 99) argues that, even for modern temperate Australia, the verandah should be recognised as a most desirable outdoor living space, and not discarded as a design aspect without first considering all its merits. The number of new homes in South Australia with verandahs show that they are still a popular design feature.

Self-shading and Verandahs on the Sampled Houses. Tables 6.19 and 6.20 show that the width of eaves increased as house-styles changed, with narrow or no eaves on older houses built before 1952, and wider eaves on most houses built after 1955. Eaves of 900 mm (3 feet) width peaked in popularity during the early 1960's. There was little evidence, however, of attempts to relate the width of eaves either to the direction the wall faced, or the size of windows in the wall.

Verandahs appeared more frequently on older houses. Seventy one per cent of the sampled houses in the southwestern suburbs had sizeable verandahs, two metres (6 feet) or more wide, on one, two or three sides of the building. On 40 of these 200 houses with verandahs, part of the verandah had been lined, enclosed, glassed and furnished as a sunroom or sleepout (Plate 6.02). Table 6.21 shows that front verandahs and multiple verandahs occurred more frequently on the older houses, whereas side or rear verandahs were more prevalent on post-war housing.

In the Salisbury East area, 20 per cent of sampled houses had verandahs, most of which had been added by the householder during the

TABLE 6.19

WIDTH OF EAVES ON THE SAMPLED HOUSES

Width of eaves	Percentage of sampled houses: Southwestern Suburbs	Salisbury East
None	5	-
Less than 450 mm (1½ ft)	48	-
450 to 900 mm (1½ to 3 ft)	39	99
Over 900 mm (3 ft)	9	1
Total	100 N = 306	100 N = 146

Source: House Details Form (Item 12).

TABLE 6.20

WIDTH OF EAVES BY HOUSE STYLE AND AGE

	Width of eaves (percentage of houses)			
	none	450 mm	450-900 mm	900 mm
Symmetrical Front and Early Villas, 1850-1905	71	16	1	-
Later Villas, Bungalows and Tudor, 1905-1945	14	34	7	-
Austerity, 1946-1952	14	29	8	4
S.A.H.T., L-shape, Conventional, 1952-1965	-	20	29	68
New, 1966-1974	-	-	56	29
Total	100 n = 14	100 n = 147	100 n = 263	100 n = 28

Source: House Details Form (Items 1 and 12).

first four years of residence [26], to provide shade for large windows, and space for children's play and outdoor living. A few designs extended the roof line as a narrow verandah over the large living room window.

Almost all Salisbury East sampled houses had 600 mm (2 feet) wide eaves and a front porch, sometimes linked to the carport by a pergola. Carports or garages provided some shade to the house, as well as the original function of car-shelter. In general, however, as Table 6.22 shows, houses in the southwestern suburbs had more shading features (including an open or enclosed verandah or porch, carport or garage providing shade, outside awnings, fixed awnings, pergolas and shutters) than the Salisbury East houses [27].

Method of Ranking. The combined shading effect of eaves, verandahs and other structural features was included in the evaluation of summer climatic suitability with highly effective shading ranked "well above average" and effective shading "average". Particular attention was paid to the north and west sides of the house.

In winter, however, weather protection and shelter is desirable on the south and west sides of the house (the directions of cold winds and rain). Extra attention was paid to access from car into the house and

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26. Past and anticipated house-modification by the present householder is discussed in Chapter 7.

27. Forty nine per cent of the southwestern suburbs sampled houses had one or two shading features per house, compared to 71 per cent of the Salisbury East houses. No statistical relationship could be discerned between the number of shading features and the orientation of the house.

TABLE 6.21

PRESENCE OF VERANDAHS BY HOUSE STYLE AND AGE

House Style and Age	Location and number of verandahs: Front verandah	Side or rear verandah	Two or more verandahs	No verandahs
	(percentage of sampled houses)			
Symmetrical Front and Early Villas, 1850-1905	13	3	28	3
Later Villas, Bungalow and Tudor, 1905-1945	35	3	41	6
Austerity, 1946-1952	12	24	7	15
S.A.H.T., L-shape, Conventional, 1952-1965	27	36	24	27
New, 1966-1974	13	34	-	50
Total	100 n = 98	100 n = 67	100 n = 46	100 n = 241

Source: House Details Form (Items 1 and 14).

Chi-square (original data) = 148.3, df = 12, s = .0001

TABLE 6.22

STRUCTURAL SHADING FEATURES ON THE SAMPLED HOUSES

Type of shading features	Percentage of sampled houses: Southwestern Suburbs (N = 306)	Salisbury East (N = 146)
One verandah	45	20
Two or more verandahs	15	-
One porch	52	87
Two porches	8	-
Carport or garage (providing shade)	37	45
Enclosed sleepout, verandah or porch	13	-

Source: House Details Form (Item 14).

Chi-square (original data) = 85.42, df = 4, s = .000

Plate 6.01. Pergola on Salisbury East house, connecting carport to front entry; of limited shading value until covered with vegetation.

Plate 6.02. Enclosed front verandah on bungalow, built 1929; east-facing house.

the sheltering of the main entrance. Effective protection was ranked "well above average", while lesser amounts of protection were ranked "above average". Minimum weather protection and shelter (such as 600 mm wide eaves, and front porch over the front door) was considered "average".

Vegetation

Previous Research. The methods described so far are instantaneous but relatively costly methods of intercepting the sun's rays before they strike or penetrate into the house. Trees, large shrubs, creepers and vines provide a cheaper alternative, but take longer to produce the same effect.

A carefully planned garden, integrated with the house, can be used to improve the climatic environment by the following methods[28]:

* as a windbreak (to deflect cold winds away from the walls of a house during winter time)
* for privacy, to create outdoor living spaces or patios for summer and winter living
* in the provision of summer shade (particularly on the north and west sides of the house)
* deciduous, to allow winter sun to penetrate
* as a filter to hot, north winds.

Deciduous creepers, whose foliage is shed during the cold months when shading is not required, provide automatic control for glazing on the

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28. The use of planting for these purposes is clearly explained by NCDC (1977), Jenkins and James (1978) and, for South Australia, by the Electricity Trust of South Australia (1978b).

north-face (Drysdale, 1975, 28) and protection from hot, north winds in summer. Furthermore, any type of vegetation affects the climate near the ground (Geiger, 1966; Clarke and Bach, 1971). On hot, calm summer days, the maximum air temperature in fully tree-planted suburban areas[29] is approximately 5°C lower than the temperature recorded above impervious, urban areas such as major roadworks or parts of the central business district (Schwerdtfeger, 1976,82).

Vegetation of the Sampled Houses. The nature of the garden and the shading effect of vegetation surrounding the sampled houses is shown in Tables 6.23 and 6.24. Trees in neighbouring gardens and in the street were included in the assessment of shading effectiveness. Furthermore, the cooling effect of air flowing from shaded gardens, even in the absence of direct shading of roof or window, was also taken into account. There is some householder resistance to large trees close to buildings which can cause foundations to crack.

As expected, the older, established housing of the southwestern suburbs tended to have more shade from vegetation, especially from mature trees, largely absent in the Salisbury East area. Approximately a third of the gardens in both samples had insufficient vegetation to provide shading on the house (Table 6.23). Of those gardens where vegetation provided shade for part of the house, the most effective shading tended to occur in the morning and the afternoon during the summer months. Nevertheless, in most gardens, the provision of shading

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29. Such tree-planted areas are more likely to occur in the longer-established middle and upper-class suburbe of Adelaide. The idea (proposed by Dr. J.D.R. Wallman) of "two tall trees at each back fence" (at Government expense) for the regeneration of greenery on the Adelaide Plains received considerable publicity (Chappel 1973b, 20; 1974b, 16), but little action.

TABLE 6.23

NATURE OF GARDEN SURROUNDING SAMPLED HOUSES

Type of garden	Percentage of sampled houses: Southwestern Suburbs	Percentage of sampled houses: Salisbury East
Mainly lawn	3	3
Lawn and garden beds	7	2
Lawn and shrubs or few trees	13	19
Lawn and shrubs or garden beds and few trees	40	34
Lawn, and shrubs or garden beds	23	13
and many trees	9	1
Other combinations	5	2
Recently established	-	25
Total	100 N = 306	100 N = 146

Source: House Details Form (Item 3)

TABLE 6.24

SHADING EFFECTIVENESS OF VEGETATION SURROUNDING SAMPLED HOUSES

Level of effectiveness	Percentage of sampled houses: Southwestern Suburbs	Percentage of sampled houses: Salisbury East
No effect	30	35
Some effect	55	36
Potential effect	-	30
Moderate effect	15	-
Very effective	1	-
Total	100 N = 306	100 N = 146

Source: House Details Form (Item 13).

Chi-square (original data) = 28.22, df = 3, s = .000

from vegetation seemed to have been planned for aesthetic and functional reasons, rather than to improve comfort.

Method of Ranking. For inclusion in the evaluation of summer climatic suitability, vegetation was considered in terms of its shading effect (particularly on the north and west sides of the house) and its ability to filter hot north winds. For winter-time, wind-break protection on the south and west was considered, as well as the use of deciduous vegetation on the north side to allow winter sun to penetrate. The actual ranking, however, was largely subjective.

Ventilation, Infiltration

Previous Research. In the early housing of North Queensland (Sumner, 1975a) and in the houses of Port Moresby (Ballantyne and Spencer, 1972), ventilation was a most important determinant of indoor temperatures and comfort. For temperate houses, Williamson and Coldicutt (1974,3-4) estimate an upward increase is possible in the zone of domestic comfort if there is air movement of one metre/second (see Figure 2.1). Good air flow can either be achieved naturally by the use of design (particularly the overall shape of the house, the room layout and the placement of windows and doors) or by the use of a fan which is often sufficient to render air conditioning unnecessary (Ballantyne, 1975b). Either way, the objective is to encourage air movement at the desired seating or sleeping height.

During cold weather, heat losses by infiltration and ventilation (11 to 15 per cent of the total in an uninsulated brick veneer dwelling) can be reduced by the use of good weather-stripping and tight-fitting doors and windows. These fixtures, more effective than wall ventilators[30], help control the ventilation rate while allowing for sufficient air to help remove condensation and unpleasant odours (NCDC, 1977).

Ventilation Infiltration in the Sampled Houses. Few detailed data on rates of ventilation and infiltration were collected, other than the shape of the house. Table 6.25 shows that houses with an overall square shape dominated in both household samples, although as Table 6.26 shows, there was a greater variety of house-shapes in post-war housing. Older-style houses, often with rooms symmetrically placed each side of a central passage usually have good ventilation of the hall or passage area, and poor ventilation elsewhere. Later house-plans, with complex layouts or L-shapes, and larger, more numerous window and door openings tend to have better cross-ventilation overall, but may suffer from poor ventilation in one or two rooms, such as bedrooms on hot summer nights. The size and number of openings also influences the rate at which the house cools down with the arrival of a summer cool change (usually from the south-west) at the end of a heat-wave (Australia, Bureau of Meterology, 1971).

Since no measurements of natural air movement within the house were taken, the householders' assessments must suffice[31]. In the southwestern suburbs, 16 per cent of householders expressed

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30. J.S. Howard (1966) measured the effect of wall ventilators and concluded that they have only a slight and not significantly useful effect on ventilation in warm or cold weather.

31. The householders' evaluations of various comfort features of their houses are discussed in Chapter 7, pp. 249-264.

TABLE 6.25

OVERALL SHAPE OF SAMPLED HOUSES

Shape	Percentage of sampled houses: Southwestern Suburbs	Salisbury East
Elongated	8	26
Square	67	51
Complex/other	12	15
L-shape	13	8
Total	100 N = 306	100 N = 146

Source: Aerial Photographs and House Details Form (Item 7).

Chi-square (original data) = 31.86, df = 3, s = .000

TABLE 6.26

OVERALL SHAPE OF HOUSE BY HOUSE STYLE AND AGE

House Style and Age	Floor plan (percentage): Elongated	Square	L-shape	Other
Symmetrical Front and Early Villas, 1850-1905	2	10	2	7
Later Villas, Bungalows and Tudor, 1905-1945	-	24	-	5
Austerity, 1946-1952	8	17	17	9
S.A.H.T., L-shape, Conventional, 1952-1965	27	21	58	33
New, 1966-1974	64	28	23	46
Total	100 n = 63	100 n = 280	100 n = 52	100 n = 57

Source: House Details Form (Items 1 and 7).

Chi-square (original data) = 90.55, df = 12, s = .000

dissatisfaction with the house's ability to cool down, eight per cent with summer air movement and 11 per cent with draughts during winter. The corresponding percentages for Salisbury East householders were 30, 15 and 22 respectively, twice as high as in the southwestern suburbs.

Method of Ranking. The overall shape of the house was used to indicate the possibility of cross-ventilation for inclusion in the evaluation of summer climatic suitability. L-shapes, elongated and complex shapes, were considered to have better cross-ventilation ("above average") than compact, square houses. The immense difficulties in measuring infiltration in individual houses resulted in its exclusion from the winter evaluation.

The Climatic Suitability of the Sampled Houses

Each of the 452 sampled houses was evaluated for summer and winter climatic suitability using the methods described in this chapter and the ranked positions shown in Tables 6.27 and 6.28. This gave each house a "qualitative description" with (say), three summer attributes "well above average", four "above average", one "average" and one attribute "below average", but did not enable comparison of one house (with its particular combination of features) with others in the sample. Nor did it enable analysis of (other) factors associated with various levels of climatic suitability.

A quick, simple method was necessary to give an indication of the level of summer and winter climatic suitability of the 452 sampled houses of Adelaide, using the data collected in the household survey of

1974-75[32]. To meet this problem, numerical values were assigned to the five qualities, ranging from (+2) for "well above average" to (-2) for "well below average". It was considered that, for example, the beneficial effect of cavity brick outer walls and a fully insulated ceiling would be considerably reduced by large, unshaded windows facing west and a sparsely-planted garden. In this way, a house with every feature ranked "well above average" or "above average" would receive a higher total score than a house with "average" or "below average" features. Since each of the features of the attributes had been carefully ranked on the basis of previous research, the simple addition of the assigned numerical values could be used to derive a "climatic suitability score" for each house, as an indicator of its performance in summer and/or winter[33]. Overall climatic suitability scores were obtained by adding the summer and winter scores.

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32. NCDC (1977, 33) argue that, due to the complexity of the interactions between parameters governing thermal comfort (and energy consumption) in housing, relationships are best analysed by computer. Although several programs for this purpose have been developed in Australia (see Table 2.04) none were accessible for use in this study. For example, the lack of suitable solar radiation records over a period of years for Adelaide precluded the use of the SUSTEP program for Adelaide dwellings in 1975 (Personal Communication, E.R. Ballantyne, CSIRO Division of Building Research, 9th July, 1975) and climatic data in the form necessary for the TEMPAL program existed only for Melbourne and Hobart in 1978 (Coldicutt, 1978a, 116).

33. Other methods which utilize a more complex form of "addition" are the nomograms (graphic methods) explained and demonstrated by Coldicutt et al. (1977a) for determining the value of insulation for individual (heated) buildings and later developed by NCDC (1977) to indicate the effectiveness (in Canberra's climate) of proposed house designs and the magnitude of likely energy consumption. Necessary data, or multiplying factors, for Adelaide are provided, and approximate figures (for insulation, energy consumption, required heater capacity) can be obtained if all the detailed information (on the design and structure of the house) is known. The methods would be too cumbersome for 452 dwellings.

TABLE 6.27

RANKED FEATURES OF ATTRIBUTES USED TO DETERMINE THE SUMMER CLIMATIC SUITABILITY OF ADELAIDE HOUSES

Attribute of Design or Structure	Ranked Position of Feature				
	Well Above Average	Above Average	Average	Below Average	Well Below Average
(a) Orientation (of main glass areas)	north south		northwest northeast southwest southeast	east west	
(b) Material of outer walls	(blue) stone	cavity brick brick and stone Mt Gambier stone	concrete block brick veneer	timber fibro-cement (uninsulated)	
(c) Colour-tone of roof (if ceiling not insulated)		light	medium	dark	
(d) Ceiling insulation	whole ceiling	part of ceiling	none		
(e) Ratio of window to wall		low	medium or favourable mixture	high or unfavourable mixture	high facing east or west
(f) Shading from eaves and verandahs, other structural features	very wide eaves, well-designed verandah(s)	moderate eaves, verandah	narrow eaves, no verandah		
(g) Shading from garden, especially deciduous vegetation	effective	some	none		
(h) External window shading	effective outside awnings or shutters	reflective film, or some awnings	none		
(i) Cross-ventilation (as indicated by shape of house)		elongated complex L-shape	square		

TABLE 6.28

RANKED FEATURES OF ATTRIBUTES USED TO DETERMINE THE WINTER CLIMATIC SUITABILITY OF ADELAIDE HOUSES

Attribute of Design or Structure	Ranked Position of Feature				
	well above average	above average	average	below average	well below average
(a) Orientation (of main glass areas)	north	northwest northeast	east west	south southwest southeast	
(b) Material of outer walls		brick veneer	cavity brick brick and stone concrete block	(blue) stone	timber fibro-cement (uninsulated)
(c) Colour tone of walls and of roof (if ceiling uninsulated)		dark	medium	light	
(d) Ceiling insulation	whole ceiling (batts or loosefill)	part ceiling or reflective type	none		
(e) Ratio window to wall	high facing north	high facing other directions	medium or favourable mixture	low or unfavourable mixture	
(f) Weather protection and shelter from eaves, verandah etc.	effective, especially on south and west	some	poor or none		
(g) Garden vegetation		main deciduous vegetation		mainly ever-green vegeta-tion.	

Table 6.29 shows that the sampled houses of the southwestern suburbs showed a wider range of "scores" in both summer and winter than the more homogeneous housing of Salisbury East. Furthermore, the houses of the southwestern suburbs scored, on average, slightly higher in summer. One factor is the dominant east-west orientation of residential streets in the southwestern suburbs, resulting in a high percentage of north or south-facing homes. Furthermore, more sampled houses in the south-western suburbs had cavity brick and stone outer walls, small windows and effective shading methods. The Salisbury East houses scored higher in winter, since most houses had large windows and many had a northerly component; 58 per cent of the ceilings were insulated.

When the two sample groups were combined, older houses still had generally higher summer scores, but newer houses scored better for winter conditions (Table 6.30). The correlation coefficients of "Year of house construction" with the climatic suitability scores provided further evidence of these relationships, particularly the increase in the winter score as the age of the house decreased.

Within the two sample areas the individual houses scoring highest in summer was a large, bluestone bay window villa, built in 1875, facing north, with small windows (all with working shutters) plus three verandahs, insulated ceilings and a large tree-filled garden (Plate 6.03). Other houses with high summer scores varied in age and style. The type of house which scored lowest in summer was west-facing, with no structural or garden shading or ceiling insulation (Plate 6.04).

Seven houses scored highest on winter suitability, all of which were built after 1962, with large windows facing north, insulated ceilings

TABLE 6.29

LEVELS OF CLIMATIC SUITABILITY OF THE SAMPLED HOUSES

Climatic Suitability Score[a]		Sample Area: Southwestern Suburbs (N = 306)	Sample Area: Salisbury East (N = 146)
Summer:	Mean	4.951	4.370
	Minimum	-2	0
	Maximum	12	9
Winter:	Mean	1.696	2.692
	Minimum	-3	-1
	Maximum	7	7
Overall:	Mean	6.637	7.062
	Minimum	-3	1
	Maximum	16	14

a. See text for method of derivation.

TABLE 6.30

AVERAGE CLIMATIC SUITABILITY SCORES AS A FUNCTION OF HOUSE STYLE AND AGE

House Style and Age	Sample size	Average Climatic Suitability Score: Summer	Winter	Overall
Symmetrical Front and Early Villas, 1850-1905	35	5.7	0.9	6.5
Later Villas, Bungalows and Tudor, 1905-1945	69	4.9	1.3	6.2
Austerity, 1946-1952	66	4.3	1.3	5.7
S.A.H.T., L-shape Conventional, 1952-1965	126	5.1	2.1	7.2
New, 1966-1974	156	4.4	2.8	7.2
Total	452	4.8	2.0	6.8
Correlation Coefficient with "Year of House Construction" (Significance)		-.120 (.005)	.316 (.100)	.107 (.011)

Source: Household data.

and good weather protection on the south and west sides of the house (Plate 6.05). Houses scoring lowest on winter suitability included two built of asbestos-cement about 1945 (Plate 6.06) and other houses which faced south, with small windows, no ceiling insulation and poor weather protection.

Although a few houses had markedly different summer and winter scores, there was a degree of correlation between the two[34]. Thus the houses which scored the highest combined totals were those with features which tended to score positively in both summer and winter, namely orientation of main glass areas to the north, "climatically" designed roof overhangs for shade (summer) and weather-protection (winter), a fully-insulated ceiling, and deciduous vegetation near the house. Apart from the previously mentioned bay window villa (Plate 6.03) and three houses built in the 1930's (one shown in Plate 6.07), the remaining highest scoring houses were all built during the 1960's (Plate 6.08). In contrast, houses with low combined scores were mainly fibro-asbestos (Plate 6.09) or post-war austerity homes with none of the above features.

Other Factors Related to and Affecting the "Measured" Climatic Suitability of the Sampled Houses

Having demonstrated the derivation and pattern of the climatic suitability of scores of the sampled houses, it is now proposed to discuss the relationships between these scores and various other dwelling and household characteristics. This enables a composite

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34. Pearson's r = .418 (significance = .00001)

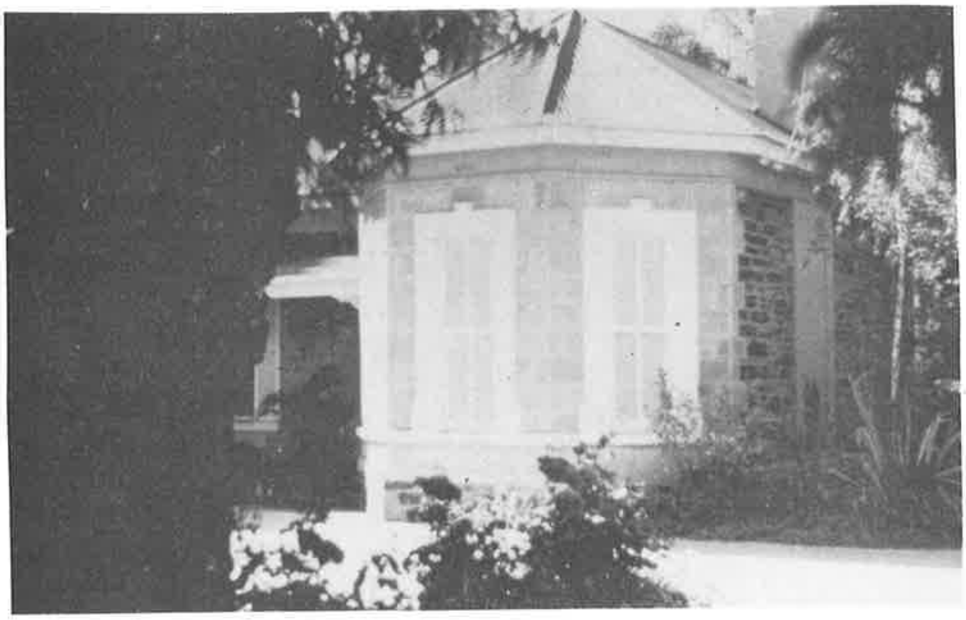

Plate 6.03. Highest scoring house in summer : large bluestone, bay-window villa, facing north-south, built 1875, Cumberland Park.

Plate 6.04. Low score in summer : west-facing SAHT house, built 1955, Morphettville; front porch enclosed by owner.

Plate 6.05. High score in winter : brick veneer, facing north-east, built 1971, Salisbury East.

Plate 6.06. Low score in winter : south-facing stone house, built 1890, Unley.

Plate 6.07.

High combined score : north-facing L-shaped house, built 1937, Millswood; note shutters and deciduous vegetation.

Plate 6.08.

High combined score : SAHT house (design modified by owner), built 1962, Park Holme; faces north.

Plate 6.09.

Low combined score : uninsulated fibro-cement house, facing south, built 1946, Ascot Park.

picture to be developed of the type of house "best suited" to Adelaide's climate. Some factors, such as the size of the house, are related to the physical structure of the house; others, such as the occupation of the head of the household, are related to the structure and characteristics of the occupying households.

Factors Related to the Physical Structure of the House

The Size of the House. House size, as indicated by the number of main rooms and the roof area (from aerial photographs) was most varied in the sample area of the southwestern suburbs, ranging from four to ten main rooms, covering 90 to 200 square metres. In contrast, the sampled houses of Salisbury East were more homogeneous in size, 85 per cent having five or six main rooms, covering approximately 120 to 140 square metres (house only).

Since there was this basic difference in the size of houses in the two sample areas, the effect of "house size" is partially over-shadowed by the effect of "house style and age", and other factors. Thus, for example, a tendency for larger houses to have more shading features was likely to result from the higher ratio of verandahs, porches, shutters and fixed awnings on houses built before 1940, many of which were larger than average. Alternatively, smaller houses were owned by less affluent householders who could not afford the additional cost of ceiling insulation. Thus, as Table 6.31 shows, the average summer, winter and overall climatic suitability scores increased as house size increased.

TABLE 6.31

AVERAGE CLIMATIC SUITABILITY SCORES AS A

FUNCTION OF HOUSE SIZE

House Size (Number of main rooms)	Sample size	Average Climatic Suitability Score		
		Summer	Winter	Overall
Four	25	3.8	0.4	4.2
Five	177	4.7	2.1	6.8
Six	161	4.7	2.0	6.6
Seven	57	4.8	2.4	7.2
Eight or more	32	6.0	2.2	8.2
Total	452	4.8	2.0	6.8

Source: Household Data.

The Designer-Builder of the House. Tables 3.03 and 3.04 (Chapter 3) showed that the sampled houses in the southwestern suburbs included 18 per cent of South Australian Housing Trust houses, 13 per cent designed by the householder, and 17 per cent known to be builder-designed (and probably most of remaining 50 per cent, whose method of design and construction was unknown). In contrast, 95 per cent of the sampled houses of Salisbury East were designed by a commercial builder, and five per cent by the householder or some other method. Thus the effect of the method of design and construction of the house is constrained by the high number of missing observations, and the small sub-groups. Nevertheless, Table 6.32 shows that the average climatic suitability scores were influenced by the design-method used. Houses designed by an individual (the owner, previous owner or architect) scored highest in summer, winter and overall. Lowest average scores were achieved by those houses designed by the South Australian Housing Trust and those whose design-method was unknown.

Energy-related Features. Although the level of climatic suitability of a house is most likely to result from the decisions of its designer-builder, the level of thermal comfort and household energy consumption is more likely to result from the decisions and actions of the householder - particularly in relation to ceiling insulation, space heating and air conditioning.

The relationships between these three features and the climatic suitability scores of the house varied. Table 6.33 shows that the component contributing most to climatic suitability was the presence of ceiling insulation, largely because an insulated ceiling scored positively in the calculation of both summer and winter scores. The presence of space-heating or of air conditioning made no similar contribution to the climatic suitability scores.

Factors Relating to the Structure and Characteristics of Households

Throughout most of the following discussion the household structure is described in terms of the size of the households and the presence of children. The characteristics of households are described in terms of the occupation of the head of the household (used with any occupation of a second adult to estimate "household income"), the age of the head of the household, the place of birth of the head of the household, and the date of occupation.

TABLE 6.32

AVERAGE CLIMATIC SUITABILITY SCORES AS A FUNCTION OF DESIGN-METHOD OF HOUSE

Design Method	Sample size	Average Climatic Suitability Scores		
		Summer	Winter	Overall
Owner, previous owner or architect	52	5.6	2.8	8.3
S.A.H.T.	55	4.9	1.4	6.2
Commercial builder (small firm)	37	4.4	1.9	6.3
Commercial builder (large firm)	152	4.4	2.6	7.0
Not known	156	4.9	1.4	6.4
Total	452	4.8	2.0	6.8

Source: Household Data.

TABLE 6.33

RELATIONSHIP BETWEEN PRESENCE OF CEILING INSULATION, SPACE HEATING, AIR CONDITIONING AND CLIMATIC SUITABILITY SCORES

Feature of house		Sample size	Average Climatic Suitability Scores		
			Summer	Winter	Overall
Ceiling insulation	- present	210	6.2	3.3	9.5
	- absent	242	3.5	0.9	4.4
Space-heating	- present	261	4.8	2.3	7.2
	- absent	191	4.7	1.6	6.2
Air conditioning	- present	124	5.4	2.5	7.9
	- absent	328	4.5	1.8	6.3

Source: Household Data.

In cases where the household is described in terms of the circumstances of the head of the household, the treatment of households as users of energy, for example, assumes the behaviour of other members of the households reflects or is influenced by the head, or that particular attributes of the head are indicators of the characteristics of the household. Thus the occupation of the head of the household is assumed to provide an indication of the socio-economic status of the household, the age of the head to indicate the household's stage in the life cycle, and the place of birth of the head to indicate the ethnicity of the entire household.

Size of Household. Although there was a tendency for the average number of persons in a household to decrease as the age of the house increased[35] (and thus a significant relationship between the size of the household and many of the other structural features that changed with house style and age), this relationship did not extend, in any uniform way, to the effect of the size of the household on summer, winter and overall climatic suitability scores. Table 6.34 shows a slight tendency for larger households to be occupying houses with higher winter climatic suitability scores, but this would result mainly from the higher average number of persons in the new housing of Salisbury East[36], which scored well for winter time conditions.

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35. See Table 8.10, p. 318.

36. See Table IV C, Appendix IV, p. 420.

TABLE 6.34

AVERAGE CLIMATIC SUITABILITY SCORES AS A FUNCTION OF HOUSEHOLD SIZE

Number of persons in household	Sample size	Average Climatic Suitability Score		
		Summer	Winter	Overall
One	30	4.7	1.2	5.9
Two	117	5.1	1.8	6.9
Three	92	4.6	2.1	6.7
Four	111	4.6	1.9	6.5
Five	58	5.0	2.8	7.7
Six or more	44	4.5	2.3	6.8

Source: Household Data

The Occupation of the Head of the Household. The occupations of the heads of the sampled households in the southwestern suburbs and in Salisbury East, grouped into six classes as shown in Table 6.35, differed in the two samples areas. There was a higher percentage of professional, administrative, retired and pensioner-heads in the southwestern suburbs, and a higher percentage of craftsmen and tradesmen in the Salisbury East area. Thus there is a significant relationship between occupation of the household head and house style and age (Table 6.36). Households whose head was in a high status occupation tended to live in the oldest or newest housing, households with a retired or housewife head occupied older or post-war austerity housing, whereas households with a head in a middle-status occupation tended to occupy houses of a wide range of house-styles and age, but predominately recently constructed.

TABLE 6.35

OCCUPATIONS OF THE HEADS OF THE SAMPLED HOUSEHOLDS

Class	Components	Number of Household Heads	
		Southwestern Suburbs (N = 306)	Salisbury East (N = 146)
Professional	Medical practitioners, nurses, vetinarians	5	3
	Teachers	11	2
	Draftsmen and technicians	11	6
	Architects, engineers or surveyors	3	8
	Other professional, technical or related workers	14	2
	Total	44	21
Administrative	Government administrative and executive officers	6	2
	Non-government administrative and executive officers	26	11
	Total	32	13
Service	Sales workers	24	11
	Service, sport and recreation workers	9	5
	Clerical workers	24	18
	Total	57	34
Manual	Farm workers	1	-
	Toolmakers, machinists, plumbers, welders	21	31
	Other metal workers	10	6
	Electricians	11	7
	Painters and decorators	9	3
	Carpenters, joiners, bricklayers, plasterers	11	5
	Freight handlers	5	2
	Workers in transport and communication	11	6
	Labourers	3	1
	Others	4	2
	Total	86	63
Non-working	Retired or on pension	57	4
	Housewives	24	-
	Tertiary student	1	1
	Unemployed or occupation not known	5	10
	Total	87	15

Source: Householder's Questionnaire (Question 8).

Chi-square (subtotals) = 22.497, df = 4, s = .0001

Table 6.37 shows that there was no systematic relationship between the occupation of the household head and the summer, winter and overall climatic suitability score of the house. In general, the climatic suitability scores increased as the occupation status of the household head increased. This is probably due to the ability of a higher income householder to select and purchase a well-designed home, and then carry out modifications, if considered necessary.

Age of the Head of the Household. The household heads of the Salisbury East sample area were generally younger than those of the sampled houses in the southwestern suburbs: for example, 28 per cent in the southwestern suburbs were aged over 60 years, compared to 3 per cent in Salisbury East. Similarly, 86 per cent of households in the Salisbury East sample had one or more children under 18 years of age, compared to 44 per cent in the southwestern suburbs. Half of these Salisbury East children were under ten years of age.

The relationship between the age of the household head and the style (and age) of house occupied is shown in Table 6.38, in which a corresponding decrease in the ages of the household head and age of the house can be seen. Nevertheless, there was no clear-cut relationship between the age of the household head and the climatic suitability score of the house, apart from a slight tendency for older household heads to occupy houses better suited to summer, and household heads aged 30 to 50 years to occupy houses better suited to winter. Once again, this was a reflection of the differences in the two sample areas rather than the ability of a particular age-group of householders to select a climatically-suitable house.

TABLE 6.36

OCCUPATIONS OF HEADS OF HOUSEHOLD BY HOUSE STYLE AND AGE

Occupation of household head	House Style and Age				
	Symmetrical Front and Early Villas 1850-1905	Later Villas, Bungalows and Tudor 1905-1945	Austerity 1946-1952	S.A.H.T., L-shape, Conven-tional, 1952-1965	New 1966-1974
Professional	27	17	9	13	15
Administrative, managerial	15	6	9	13	10
Sales, service, clerical	3	12	21	25	25
Craftsmen, tradesmen	36	23	30	27	46
Non-working	18	42	30	23	4
Total	100 n = 33	100 n = 69	100 n = 66	100 n = 124	100 n = 147

Source: Household Data.

Chi-square (original data) = 68.909, df = 16, s = .000

TABLE 6.37

AVERAGE CLIMATIC SUITABILITY SCORES AS A FUNCTION OF OCCUPATION OF THE HOUSEHOLD HEAD

Occupation of household head	Sample size	Average Climatic Suitability Scores		
		Summer	Winter	Overall
Professional	65	5.2	2.0	7.2
Administrative, managerial	45	5.2	2.0	7.1
Sales, service, clerical	91	5.0	2.5	7.4
Craftsmen, tradesmen	149	4.5	2.1	6.6
Non-working	102	4.5	1.5	6.0

Source: Household Data.

TABLE 6.38

HOUSE STYLE BY AGE OF HEAD OF HOUSEHOLD

House Style	Age of head (percentage of households)				
	29 years or less	30-39 years	40-49 years	50-59 years	60 years or more
Symmetrical Front and Early Villas	6	5	6	13	8
Later Villas, Bungalows and Tudor	21	9	5	14	34
Austerity	6	9	10	22	24
S.A.H.T., L-shape, Conventional	15	17	33	41	29
New	52	60	46	9	6
Total	100 n = 67	100 n = 78	100 n = 117	100 n = 85	100 n = 89

Source: Household Data.

Chi-square (original data) = 126.844, df = 16, s = .000

Kendall's tau_c (original data) = -.3062, s = .0000 (a negative tau indicates that the age of the house increased as the age of the household head increased.

<u>Place of Birth of the Head of the Household.</u> Details of the place of birth of the head of the household are shown in Table 6.39 below. Of the migrants, 86 per cent of those in Salisbury East had arrived within the last ten years, whereas fifty per cent of migrant heads in the southwestern suburbs had been resident in Australia for twenty years or longer.

Table 6.40 shows that 81 per cent of the migrant-heads from the United Kingdom had moved into "new" houses, built between 1966 and 1974, whereas migrant-heads from Italy and Greece had moved into houses of varied style and age. The distribution of house-style preferences of household heads from other overseas countries was almost identical to

TABLE 6.39

PLACE OF BIRTH OF HEAD OF SAMPLED HOUSEHOLDS

Place of Birth	Percentage of sampled households: Southwestern Suburbs	Salisbury East
Australia	77	22
United Kingdom	9	75
Italy, Greece	5	1
Holland, West Germany	3	-
Eastern Bloc	3	1
Other	2	2
Total	100 N = 306	100 N = 146

Source: Householder's Questionnaire (Question 8).

TABLE 6.40

HOUSE STYLE AND AGE BY PLACE OF BIRTH OF HEAD OF HOUSEHOLD

House Style and Age	Place of birth (Percentage)			
	Australia	United Kingdom	Italy, Greece	Other
Symmetrical Front and Early Villas, 1850-1905	9	2	29	13
Later Villas, Bungalows and Tudor, 1905-1945	20	4	24	23
Austerity, 1946-1952	19	6	12	16
S.A.H.T., L-shape, Conventional, 1952-1965	38	7	24	36
New, 1966-1974.	15	81	12	13
Total	100 n = 267	100 n = 137	100 n = 17	100 n = 31

Source: Householder's Questionnaire (Question 8) and House Details Form (Item 1).

that of household-heads from Australia, with half living in houses built since 1952[37]. This "mix" of preferences meant that the place of birth of the head seemed to have had little effect on the climatic suitability scores of the houses occupied.

Conclusion

The analysis suggests that a house with a high "measured" climatic suitability is one of brick cavity construction, with medium to large windows facing north, a fully insulated ceiling, roof overhangs and garden vegetation providing sufficient shade in summer and weather-protection in winter. Less than five per cent of the sampled houses had a high measured climatic suitability. In the vast majority of houses, climatic design principles had been ignored or neglected. Even those houses which performed reasonably well largely achieved this by chance, or from home improvements made by the occupants (such as adding outside awnings, insulating the ceiling or planting trees). Of the housing stock of Adelaide, the older styles, with thick walls, higher ceilings, small windows and verandahs tend to be better suited to hot summer conditions. Most were designed at a time when protection against summer heat was the primary concern of the settlers from northern Europe. As the perception of climate has changed, so too has house design. Newer dwellings, with their larger windows, brick cavity or brick veneer walls, tend to maximise the amount of sun entering the house in winter (when desired) and in summer (when the reverse should

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37. The number of households with heads born in countries other than Australia, the United Kingdom, Italy and Greece, were too small to permit tests of significance.

occur). Unfortunately, architectural styles from climates similar to Adelaide (such as Spanish Mission or Californian bungalow) never became popular. The resultant type of housing, designed with little consideration of Adelaide's climate, has obvious implications for the thermal comfort of the occupants, and energy requirements for heating and cooling.

The "climatically suitable" house of this study also tended to be larger than average, owner-or architect-designed and inhabited by a household whose head had a middle to high status occupation. Apparently, it is only the better educated, higher income, design-conscious members of the community who can reasonably expect to be able to select, purchase and occupy houses best suited to Adelaide's climate.

CHAPTER 7

THE INDOOR COMFORT OF THE SAMPLED HOUSES

Most people feel better and function more efficiently in environments which they perceive to be physically comfortable. Temperature-controlled environments, now almost mandatory in commercial and business premises, are rare in Australian houses, so that thermal comfort must be achieved by the design and structure of the dwelling itself, supplemented by heating and cooling appliances and sensible management of the house.

The provision of a suitable human thermal environment is constrained by the subjective nature of physiological comfort. The highly variable response to thermal stimuli is well recognized as is the relationship between human comfort and factors such as metabolic activity, clothing insulation and levels of acclimatisation[1]. Methods of measuring physiological comfort include monitoring the physical environment, descriptions of subject reactions (the so-called "comfort votes") and the taking of physiological measurements such as blood pressure or pulse rate. Where possible, a threefold approach is recommended. Each method has its difficulties and limitations, as does the attempt to measure the physical comfort of a house. Some previous studies have evaluated qualitatively) the comfort of local house-styles in terms of their climatic relevance (Marshall, 1954,1963a) or in terms of their environmental response (Sumner and Oliver, 1978); others have monitored the physical environment of unoccupied (Coldicutt, 1973a,1978b) or occupied rooms/ houses (Marshall, 1957; Sumner, 1975a; New Zealand

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1. Literature dealing with thermal comfort is discussed in Chapter 2, pp. 9-27.

Department of Statistics, 1976; CSIRO, 1978b). Such measurement is occasionally combined with householders' assessments of the comfort of their houses, but there are relatively few examples of studies in which occupant-evaluation of comfort is the only criterion (see Marshall, 1966). The link between expressed and revealed behaviour is more frequently made in energy-studies in which attitudes to household energy use are related to household energy-related behaviour (Newman and Day, 1975; United States, Federal Energy Administration, 1976; Phillips, 1976; Crossley, 1978). The relationship between energy consumption and levels of comfort is uncertain, however. As Coldicutt and White (1977) point out, good thermal design of buildings offers significant potential benefits in both energy and money economies, and in improved levels of comfort. They stress (1977,24) that the cost of poor thermal design in summer is borne principally in the form of discomfort, rather than as high levels of energy consumption.

The assessment of the physical comfort of the sampled houses is examined in four stages, in this and the following chapter. The first two stages are essentially descriptive, providing background information relevant to the discussion of householders' comfort and energy-related attitudes and behaviour. The physical comfort of the sampled houses is examined by way of:

(i) a small survey of temperatures in occupied dwellings, which attempted to monitor the effect of house-design, structure and type of house-management on the indoor thermal environment;

(ii) data on the type of heating and cooling equipment in the sampled houses,

(iii) householders' attitudes to (Adelaide's) climate, their two-fold evaluations of the comfort of their houses (their level of satisfaction with nine comfort-related features and their statements on weather-induced discomfort in their houses) and a description of the ways in which the house has been modified to alleviate summer and winter discomfort;

(iv) (in Chapter 8) an analysis of seasonal and annual energy consumption by individual households, relative to the house design/structure and household characteristics.

Temperature Survey

Seven houses in the southwestern suburbs, each representing a major housestyle, were chosen for installation of U-type maximum-minimum thermometers in one or two locations in each house[2]. The daily maximum and minimum dry bulb temperature was recorded on a chart by the householder during the March and April months of 1975[3], during which time the Adelaide Bureau of Meteorology recorded maxima ranging from 32.0° to 16.8° Celsius, and minima ranging from 19.3° to 8.0° Celsius. Although this was only a small temperature survey, involving simple instruments and householder observers, the results are interesting and comparable with the results of other surveys of a similar or more complex design (such as Sumner, 1975a).

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2. No Salisbury East houses were included in the temperature survey of March and April, 1975 since the Householder's Questionnaire was not administered in Salisbury East until April 30th, 1975. Mean maximum screen temperatures in summer can be expected to be 1-2°C higher in the outer northern suburbs (Salisbury and Elizabeth) than those recorded in the southwestern suburbs (Schwerdtfeger, 1976, 83), one degree warmer in Spring (October) but very similar for other seasons. The only comparative temperatures were those obtained at Elizabeth by Marshall (1957, 25) during the summers of 1956-7, 1957-8 when maxima were usually 1-2°F higher than Adelaide temperatures. Reasons for the temperature difference include proximity to the sea (and hence sea breezes), the parasol effect of Mt. Lofty's orographic cloud, and (in the late 1950's) the lack of watered gardens.

3. The temperature survey instructions and recording chart are shown in Appendix I, pp. 406-407.

Tables 7.01 and 7.02, and Figure 7.1 show the wide range of temperature at different places within the same house and between houses of varying age, architectural style, modification and management by the householder. Three of the houses had thermometers installed in two locations, usually one north-facing and one south-facing room: differences in maxima of two to seven degrees Celsius were recorded consistently. The widest temperature difference occurred in the 1920 bungalow (House B, Figure 7.2) between the kitchen on the south-east and a glass-walled sunroom added to the northwestern corner of the house[4]. During the month of March, 1975, the warmest daytime temperatures were recorded in this sunroom of House B, the north-facing kitchen of a conventional triple-front (House F, Figure 7.2) and the north-facing playroom of a modern ranch-style (House G). Each of these rooms had little or no external shading for glass areas. The coolest daytime temperatures were recorded in the central hall of a white-roofed bungalow (House C, Figure 7.2) and the south-facing kitchen of the 1920 bungalow (House B). The warmest night temperatures were in the kitchen of a small post-war "austerity" house (House E), and the central hall of House C, while the coolest locations were the sunroom and kitchen of House B and the kitchen of the 1900 villa (House A). Thus the sunroom of House B recorded the largest diurnal temperature range (averaging eight to nine degrees Celsius) while the central hall of the 1925

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4. This type of wide-ranging variation in temperature which occurs in different parts of a house is widely acknowledged by most householders and substantiated in this and other research. Temperature measurement in a brick veneer unit by Atkinson and Halkett, of the Architecture Department, the University of Adelaide, and a pilot survey by the author in a brick and stone Tudor bungalow, showed variations of up to 8°C from one room to another. (Personal Communication, Ian Halkett, Department of Architecture and Planning, The University of Adelaide, 14th November, 1975).

TABLE 7.01

SUMMARY OF INDOOR TEMPERATURES RECORDED IN SELECTED HOUSES OF SOUTHWESTERN SUBURBS DURING MARCH, 1975

House Style and Year Built	Location of Thermometer	March Temperatures (degrees Celsius)			
		Mean Maximum	Mean Minimum	Mean Diurnal Range	Mean Monthly
A Villa c.1900	Kitchen	23.2	18.2	5.0	20.7
B Bungalow c.1920	Kitchen	22.8	17.9	4.9	20.4
	Sunroom	26.5	17.3	9.2	21.9
C Bungalow c.1925	Hall	21.8	20.2	1.6	21.0
D Tudor c.1936	Lounge	24.8	19.7	5.1	22.3
E Austerity 1950	Kitchen	24.9	20.7	4.2	22.8
F Conventional	Lounge	23.1	19.4	3.7	22.3
Triple-front 1959	Kitchen	25.4	20.0	5.4	22.7
G Ranch 1969	Living room	23.6	18.8	4.8	21.2
	Playroom	25.2	19.0	6.2	22.1
Official temperature, Bureau of Meteorology, Adelaide		24.0	14.7	9.3	19.4

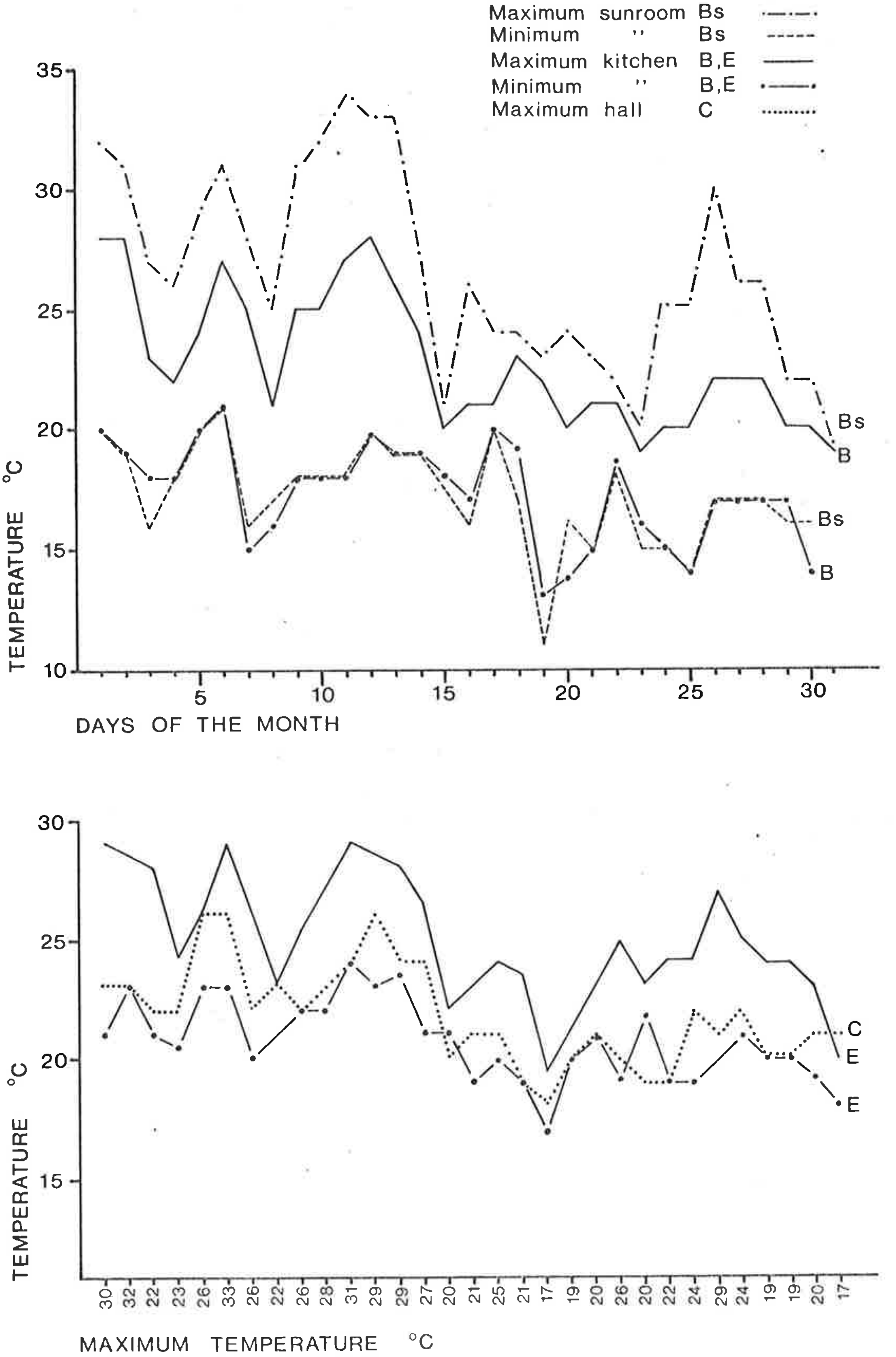
Source: Temperature survey data, and Bureau of Meteorology, Adelaide.

TABLE 7.02

MAXIMUM TEMPERATURES RECORDED IN SELECTED HOUSES ON FOUR DAYS

House Style and Year Built	Temperature in degrees Celsius			
	1/3/75	13/3/75	17/3/75	6/4/75
A Villa c.1900 (kitchen)	26	27	22	19
B Bungalow c.1920 (kitchen)	28	26	21	18
(sunroom)	32	33	24	22
C Bungalow c.1925 (hall)	23	24	21	21
D Tudor c.1936 (lounge)	27	26	23	23
E Austerity 1950 (kitchen)	29	28	24	22
F Conventional (lounge)	26	26	22	18
Triple-front 1959 (kitchen)	29	29	24	21
G Ranch 1969 (living room)	26	26	20	22
(playroom)	29	29	21	21
Range (hottest to coolest)	9	9	4	5
Official maximum, Bureau of Meteorology, Adelaide	32	29	25	17

Source: Temperature survey data and Bureau of Meteorology, Adelaide.



SOURCE : Householders' Temperature Survey

FIG. 7·1 MAXIMUM & MINIMUM TEMPERATURES, MARCH 1975, SELECTED HOUSES bungalow (House C) showed the smallest fluctuations, varying only two or three degrees Celsius in each 24 hours. This house was occupied by a retired couple, originally from the United Kingdom, who kept doors and windows closed during hot weather, and rarely used the south-facing front door opening into the central hall where the thermometer was located[5].

There was general agreement between the householders' assessments of conditions in their houses (obtained in the Householder's Questionnaire) and the later measurement of temperatures[6]. The occupants of House B, for example, stated that the rear of their 1920 bungalow could be 10°F cooler than other houses in summer, and that their sunroom (on the northwest corner) cooled so quickly after a hot day that they frequently slept there. Table 7.01 shows the low mean maximum and mean monthly temperature recorded in their south-facing kitchen (at the rear of the house), and the large diurnal range recorded in their sunroom[7]. "Uncomfortable in hot weather" was the description of two north-facing rooms by householders of Houses F and G. Tables 7.01 and 7.02 show the relatively high maximum temperatures recorded in the kitchen of House F

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5. The importance of householders' thermal management ability is well demonstrated by Marshall (1957). In a sample of South Australian Housing Trust houses of identical design and orientation, variation in indoor temperatures of up to 12°F occurred between houses. The owner of one sampled house "believed in ventilation and kept the windows wide open in hot weather, thus achieving the highest temperature in Elizabeth" (Marshall, 1957, 30).

6. Details of the householders' evaluations of the comfort of their houses are presented later in this chapter.

7. The value of a well-placed sunroom was also appreciated by the occupants of House E who claimed that temperatures in their sunroom often reached 70°F on sunny, winter days without the use of heater.

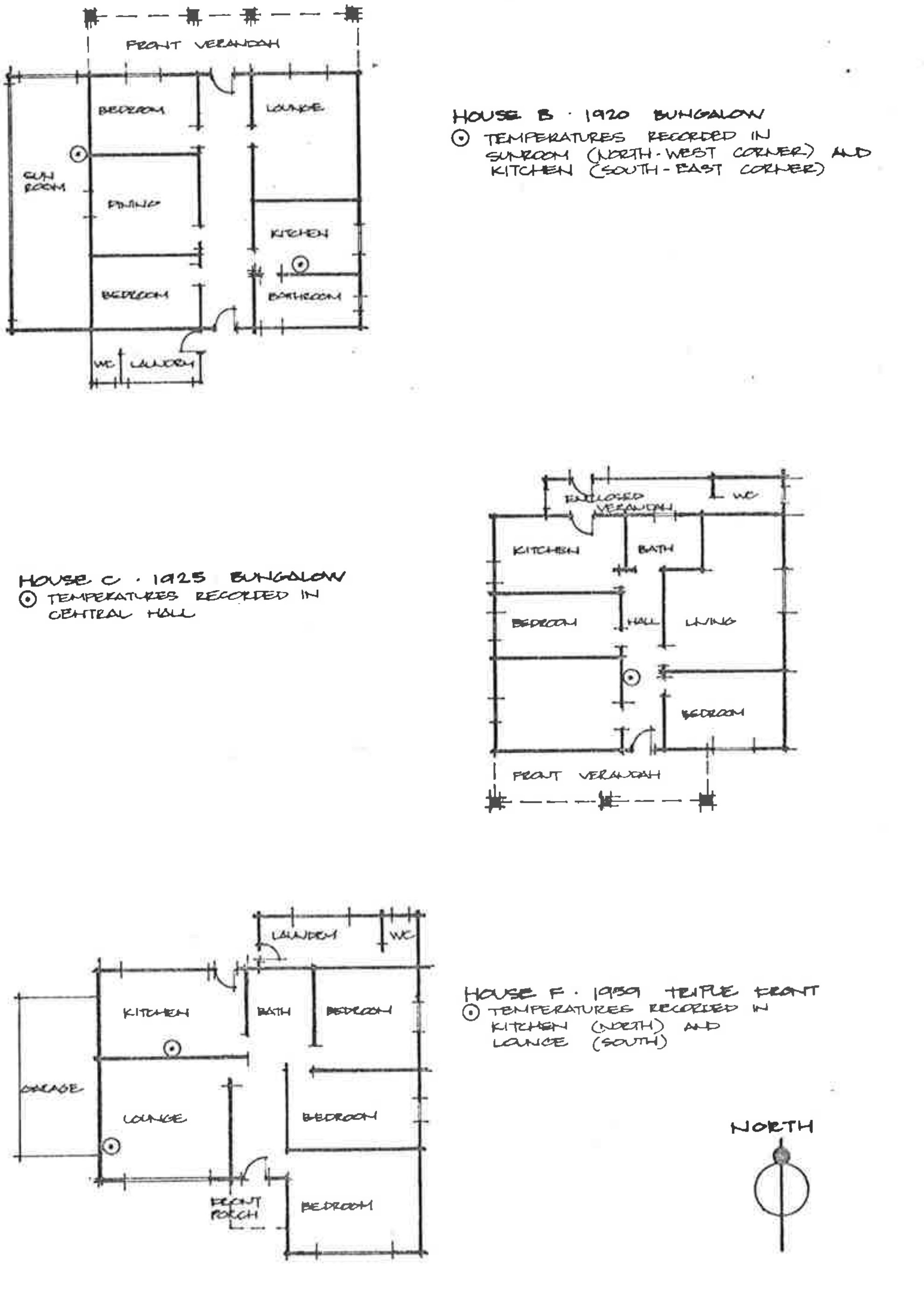

FIG. 7·2 LOCATION OF THERMOMETERS IN HOUSES B,C AND F (a conventional triple-front)[8] and the playroom of House G. The householder of House G (a 1969 ranch with large, unprotected windows) was generally dissatisfied with indoor temperatures in summer, despite the house's insulated ceiling and a room air conditioner in the living room. In contrast, House A (a 1900 stone villa) was described as "too cold" during winter: although no temperature readings were taken during the winter months, their kitchen recorded low maximum temperatures during March and April.

The recording of temperatures during March and April had the dual advantage of providing a variety of weather conditions while minimising the need for householders to use heating and cooling equipment. In this way, the temperature survey was able to demonstrate some of the effects of house-design, structure and type of house management or indoor thermal environment. Furthermore, if these houses and householders were typical, then the level of agreement between the householders' evaluations of comfort and the recorded temperatures indicates a general ability for householders to assess the comfort of their own homes[9].

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8. The householders of House F installed evaporative air conditioning (to all rooms) two years after the temperature survey.

9. Marshall (1957), however, encountered problems when attempting to relate outdoor to indoor temperatures of individual houses, and then to the stated level of comfort of the occupant. During the summer of 1956-57, residents of 156 houses (built by the South Australian Housing Trust at Elizabeth) were given simple observation charts and asked, at the end of the day, to give an estimate of the house comfort. Maximum-minimum temperatures were recorded in thirty houses. Marshall (1957, 27) states:

> The experiment was designed to show differences in comfort due to house design or house orientation, or both. At first, the results showed ... uncompromisingly the difference between individuals. Although each observer was quite remarkably consistent, the temperature for the onset of discomfort varied 10° F between the most and least heat-tolerant resident.

Heating and Cooling Equipment in the Sampled Houses

Nearly all the temperature survey data were (intentionally) obtained at a time when minimal or no additional heating or cooling was required. The nature of Adelaide's climate (Chapter 2, pp. 21-25) suggests that some form of heating is needed from April to October and that some form of cooling is necessary on nine to twenty-nine days during the summer.

Heating

Previous Research. The relationship between air temperature in a room and the sensation of comfort of the feet and the body were investigated by CSIRO scientists (Muncey, 1953a, 1954a; Muncey and Holden, 1959; Muncey and Bautovich, 1969). Most subjects found that air temperature near the floor (and thus foot temperature) was important in influencing comfort, and could be used as a comfort indicator for the whole body. Therefore, to effectively heat a whole room to a comfortable level, CSIRO recommends that warm air be discharged from floor- or baseboard radiator-convector units. Later research (CSIRO, 1977, 1978b) shows that most fan-assisted, non-ducted convection heaters (the most common form of space-heater, burning gas or oil) were discharging warm air at the incorrect height (and at insufficient velocity) to create an acceptable vertical air temperature gradient within the room. Thus occupants are conscious of inadequate heating near the floor (cold feet) and/or stuffiness at head level (hot head). Heated concrete floor slabs and forced-air ducted convection heaters produce the best heat distribution throughout the room, whereas the radiant heater (gas, electric, solid fuel or oil) provides adequate thermal comfort only within a limited zone around the heater.

In general, the Australian attitude towards space heating in homes has undergone a fundamental change during recent years. People's expectations (of quality and quantity of heating) have risen, parallelled by the availability of a wider range of more efficient appliances. There has also been a great increase in the amount of consumer information on domestic heating appliances and the physiological aspects of space heating[10].

Heating Equipment in the Sampled Houses. Many types of heating methods and appliances are available in Adelaide, ranging from ducted systems for the whole house, through space-heaters for one or two rooms, to portable electric radiators or kerosene heaters. Table 7.03 shows the type of fuel used as the main source of heating in the sampled houses. Gas predominated in both sample areas, largely as a result of Adelaide's conversion to natural gas during 1969-1970, and a major promotion of gas space-heating at the time[11]. In the southwestern suburbs, old fashioned gas fires outnumbered gas space-heating, whereas 90 per cent

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10. These include some of the CEBS Notes on the Science of Building (such as Nos. 46 and 95), publications by the Australian Consumers Association (ACA 1972a, 1973, 1978a, 1978b) and ETSA leaflets on home heating and costs (ETSA 1973, 1977a, 1977b).

11. Space-heating combines radiant and convection heating, whereas the traditional gas fire uses radiant heat only. Natural gas is available to approximately 65 per cent of the geographic area of Adelaide, with less than half the possible number of houses connected to the supply. The South Australian Gas Company reports highest sales of gas space heating to established houses, with a sizeable proportion of heaters bought in the outer suburban areas, being installed by householders shortly after moving into an unheated house. The Company also estimates that two-thirds of new houses supplied with natural gas in 1975 also installed a space-heater during construction. Fixed heating is more frequently omitted in "speculative" houses in order to reduce purchase price. (information from S.A. Gas Company representatives, 11th and 13th March, 1975).

TABLE 7.03

TYPE OF FUEL USED AS MAIN SOURCE OF ROOM HEATING IN SAMPLED HOUSES

Type of Fuel	Percentage of sampled houses	
	Southwestern suburbs	Salisbury East
Gas	35	90
Electricity	27	5
Solid fuel	20	2
Oil	14	3
Kerosene	4	-
Total	100	100
	N = 306	N = 146

Source: Householder's Questionnaire (Question 12).

of the Salisbury East houses had gas space-heaters installed in the living room during construction. Solid fuel, mainly for open fireplaces but also for slow combustion heaters, was used as the main source of heating in one fifth of the southwestern suburbs houses. Most pre-war houses had one or more fireplaces, providing a cheaper but relatively inefficient form of heating, using wood such as mallee roots, or other combustible material such as coke[12].

Oil burning space heaters were used in 14 per cent of the southwestern suburbs sampled dwellings, and in three per cent of those in Salisbury. Most oil heaters were installed several years after the construction

12. Recent reports (Clutterham, 1979; Gill, 1979) stress that, to overcome the rising cost of kerosene and oil, the open fireplace, burning mallee roots, is regaining popularity in both new and existing houses.

of the house[13]. Kerosene heaters, usually of the portable type, were used in four per cent of sampled dwellings. They use a relatively inexpensive fuel which can be purchased in small quantities as needed.

Electricity provides power for a variety of heating appliances, including radiant heaters (visible and infra-red), convection heaters (forced-air or natural) and air conditioning (reverse-cycle heating)[14]. Despite the relative cheapness of operating reverse-cycle heating, less than five per cent of sampled households used it as the main source of heating[15]. (Reasons for the resistance to reverse-cycle heating include the noise factor, the fact that many people consider "air conditioning" synonymous with "cooling", and the relatively lower heat output of an air conditioning unit, compared to oil or gas). Of the 83 dwellings in the southwestern suburbs using electricity as the main heating fuel, 51 used portable appliances, and

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13. The major manufacturer of oil heaters reported a strong seasonal demand during the colder months, most frequently to replace open fireplaces. The term "oil heater" in this discussion refers to a fixed, oil-burning heater. Movable, oil-filled radiators were classified as "portable heating equipment".

14. An Australia-wide survey on home-heating (Australian Consumers Association, 1978a) found that, of 2,171 respondents, the most popular form of energy used for heating was electricity, followed in descending order, by oil, solid fuel, kerosene and gas. The most popular applicance was the portable electric radiator.

15. Reverse cycle room air conditioners can provide 1.7 to 3 times as much heat as a resistance type of heater for the same cost. This is because they are heat pumps which extract heat from the outside air, even in cold weather, and pass it into the house (ETSA, 1977b).

32 fixed electrical appliances (including 16 with reverse-cycle heating)[16].

Most householders used only one method of fixed heating. Fifty-six per cent of houses in the southwestern suburbs and 77 per cent in Salisbury East used gas, solid fuel or liquid fuel as the sole supply. The heater was nearly always in the living room. Electricity, for radiant or reverse-cycle heating, was the sole method in seven per cent and two per cent respectively.

Other householders used more than one method of fixed heating. Figure 7.3 shows that gas heating, and to a lesser extent, solid and liquid fuel systems were often supplemented by other methods of heating. For example, 12 per cent of the sampled dwellings in Salisbury East had gas space-heaters in the living room as well as room air conditioners either in the living room or some other location[17]. Four per cent of the sampled houses in the southwestern suburbs and one per cent in Salisbury East had fixed heating in five rooms or the whole house, either

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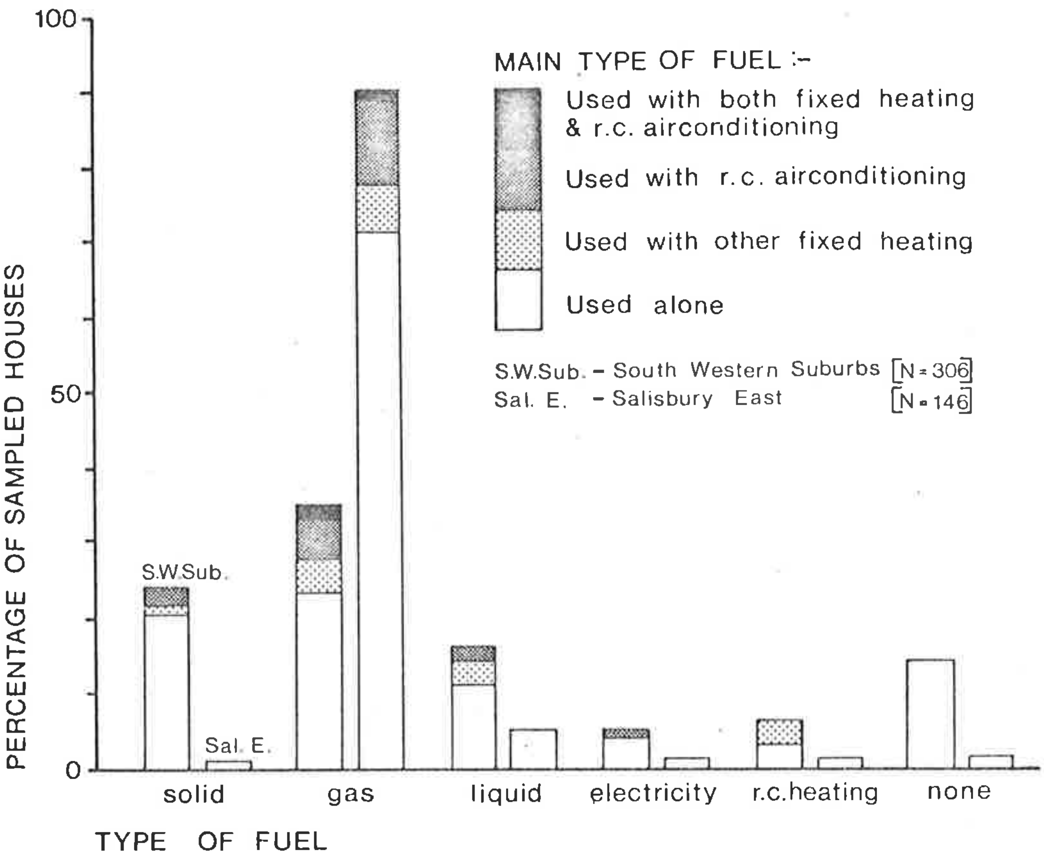
16. Comparable data from the Electricity Trust's "Domestic Consumer Survey" showed that electricity was used as the main type of heating in 40 per cent of the surveyed houses in 1975, gas in 21 per cent, oil in 20 per cent, wood in 8 per cent and kerosene in 11 per cent. Trends showed electricity, kerosene and wood decreasing as main types of house-heating, with gas and oil increasing. The differences in results between the two surveys can best be explained in terms of the nature of the samples, the method of data-collection and the wording of questions. For example, the high percentage of gas-heating in the Salisbury East houses resulted largely from the installation of gas space heaters during construction and their inclusion in the purchase-price. Furthermore, although both surveys asked house-holders to describe heating equipment possessed, this survey differentiated between "fixed" and "portable" and the Electricity Trust survey between "main type" and "supplementary" forms of heating.

17. The Electricity Trust of South Australia survey shows that 32 per cent of sampled houses in 1975 used electricity for supplementary heating, with gas, wood and kerosene of minor use.



SOURCE : Household Survey

FIG. 7·3 COMBINED METHODS OF FIXED HEATING USED IN SAMPLED HOUSES fully-ducted air conditioning, open fireplaces in each room or various combinations of radiation, convection and reverse-cycle heating[18]. Australia-wide, the Australian Consumers Association (1978a) found that most people used at least two, if not three, different types of heating, with the portable electric radiator (the open bar type, used in 63 per cent of respondents' houses) most often used to supplement other types of heating arrangement.

In this study, fourteen per cent of sampled houses in the southwestern suburbs used no fixed heating, relying instead on portable electric radiators or fan heaters, kerosene heaters, or both. In a third of these houses with no fixed heating, one electric radiator was the sole piece of heating or cooling equipment. Table 7.04 shows the dominance of portable electric radiators in all sampled houses, with 32 to 38 per cent of sampled houses using at least one, and 21 to 41 per cent using two or more electric radiators[19]. Kerosene heaters were less popular.

Table 7.04 also shows a lower rate of ownership of portable heating appliances among householders of Salisbury East. This was probably due to the presence of a gas or oil (fixed) space-heater in 95 per cent of the sampled houses of Salisbury East. In general, the high proportion

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18. For example, one house in Clarence Park (a southwestern suburb) had open fireplaces in three rooms, a gas space-heater in the living room, a reverse-cycle air conditioner in the kitchen-dining room, and a strip heater in the bathroom.

19. The Electricity Trust of South Australia survey showed that 83 per cent of all consumers possessed a small radiator in 1975, and 51 per cent a larger radiator. The average number of radiators per consumer was 1.27. However, the survey notes a decline in the number of radiators possessed since 1972, and suggests that this was probably associated with the increasing use of oil and gas space heaters.

TABLE 7.04

PORTABLE HEATING EQUIPMENT USED IN SAMPLED HOUSES

Type of Equipment and Number	Percentage of sampled houses	
	Southwestern Suburbs (N = 306)	Salisbury East (N=146)
Electric radiators		
One	38	32
Two	29	16
Three or more	12	5
Subtotal	79	53
Kerosene heaters		
One	11	4
Two or three	3	1
Subtotal	14	5
Other types of portable heating	2	1
Total[a]	86	56

Source: Householder's Questionnaire (Question 12).

Chi-square (original data) = 7.89, df = 5, s = .20

a. Eight per cent of southwestern suburbs households and three per cent of Salisbury East used both electric and kerosene portable heaters.

of fixed and portable heating in the sampled houses suggests that provision for winter warmth was of high priority among Adelaide householders during 1974 and 1975. The implications of this pattern of heating equipment for householders' evaluations of the comfort of their houses are discussed later in this chapter.

Cooling and Air Conditioning

Previous Research. In Australia, comfort by cooling in summer has received much more attention than winter warming, even though, climatically and economically, warming is just as important (Ashton, 1964, 1). This perhaps occurs because warming is simpler; it occurs naturally from exercise, increased clothing or from the use of relatively simple appliances. Cooling is less straightforward. Air circulating fans can do much to improve daytime comfort (Williamson and Coldicutt, 1974,3) and are particularly useful for significant temperature reduction at night. by careful placement near an open window, they can be used to assist the thermal mass to store "coolth" (lack of heat). Ceiling and attic fans are widely used in central and Northern Australia (Weston, 1952). Evaporative coolers (fixed or portable) are best suited to a hot-dry environment where the wet-bulb temperature is substantially lower than the dry-bulb temperature (CEBS, NSB 75,1971): this type of temperature regime occurs frequently in South Australia and inland centres of other states (Paynter, 1964). The rock bed (regenerative) air conditioner, developed in the late 1960's by the Division of Mechanical Engineering (CSIRO, 1973) is now reported (CSIRO, 1979) to be making a comeback after earlier setbacks.

There are numerous overseas publications of a general and specific nature on air conditioning (such as Harris, 1959; American Society of Heating and Ventilating Engineers, 1959; Sherratt, 1969; Faber and Kell, 1971; Institution of Heating and Ventilating Engineers, 1971) and a smaller number for Australian conditions (such as Sheridan et al., 1963, Whelan, 1978) . Although air conditioning has been shown to be highly desirable in Central and Northern Australia on psychological and sociological grounds (Damm, 1961; Drysdale, 1962) for physiological and health reasons (Macpherson, 1956; Macfarlane, 1961), costs are high (Woodhead and Scanes, 1972; Prior, 1962) and its justification in temperate regions is more difficult. Despite its increasing popularity in industrial, commercial and entertainment premises, not everyone prefers it. For example, Wong (1967) shows that Sydney office workers attributed an increase in respiratory ailments to air conditioning in offices and that a quarter of the respondents said they would prefer to work in non-air conditioned premises. Other authors warn against the dangers of continual exposure to increasingly high, constant level temperatures in terms of occupational boredom (Gerlach, 1974) and further reduction in the width of the subjectively-tolerated comfort zone (Wyon, 1974). Further disadvantages of air conditioning include the capital and operating costs and the noise of many packaged units, particularly when the fan setting is "high" (commonly used to maximise cooling)[20].

Nevertheless, the percentage of homes with air conditioning has risen rapidly in the 1970's[21]. It has been paralleled by increasing criticism of its energy consumption by such authors as Broinowski (1967)

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20. Research by the CSIRO Division of Mechanical Engineering (CSIRO 1972, 1978a) has been directed at means of reducing the noise level of certain types of room air conditioners, while recent legislation was passed in South Australia regarding the effect of exterior noise from air conditioners (in terms of neighbour disturbance).

21. Coldicutt and White (1977, 24) suggest that air conditioner sales are increasing by over ten percent annually; data collected by the Electricity Trust of South Australia (in Domestic Consumer Surveys) support this. In an earlier paper, White (1975, 19) argues that,

    "on no rational economic grounds can the installation of domestic air conditioning be justified for Melbourne, Canberra or Adelaide, and even in Sydney. With a thermally efficient house and emphasis on ventilation control, the percentage of occasions when summer comfort conditions are exceeded makes the provision of air conditioning uneconomic".

Hirst and Moyers (1973), Marshall (1973), Ballantyne (1975b) and Constance (1976). They argue that wasteful use of energy for air conditioning (and for space heating) can be minimised by:

(i) design to utilise solar energy when it is desired and to reject it when it is not required;

(ii) the use of thermal insulation (preferably in conjunction with thermal capacity);

(iii) greater control of ventilation rates; and

(iv) the use of fans to increase air-flow past the body.

Others advocate energy-savings by more appropriate clothing levels (Burberry, 1976b; Lammers et al., 1978) and stress the need for consumer information on the insulating value of garments (Nevins et al., 1974).

Cooling and Air Conditioning in the Sampled Houses. Although very high temperatures are relatively infrequent, and heat waves usually of short duration in Adelaide, most sampled householders had one or more artificial aids to air cooling. Seventy-nine per cent of households in the southwestern suburbs and 65 per cent of households in Salisbury East owned one or more portable fans (Table 7.05)[22]. About a third of the houses in each sample area had exhaust fans installed in kitchen, bathroom or both, though these were more often used to reduce moisture and odours than for the effect on temperatures.

Tables 7.06 and 7.07 show that approximately forty per cent of sampled houses in both areas had some form of air conditioning, with reverse cycle and portable evaporative air coolers predominating, mainly for one

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22. This is much higher than the Electricity Trust of South Australia's Survey figure of 41 per cent of consumers with electric fans in 1976.

TABLE 7.05

PORTABLE FANS AND EXHAUST FANS USED IN SAMPLED HOUSES

Type and number of fans	Percentage of sampled houses	
	Southwestern Suburbs (N = 306)	Salisbury East (N = 146)
Desk fans (portable)		
One	56	51
Two	17	11
Three or four	6	3
Total with desk fans	79	65
Chi-square (original data) = 1.61, df = 2, s = .50		
Exhaust fans (fixed)		
Kitchen	23	19
Bathroom	3	-
Kitchen and bathroom	11	12
Total with exhaust fans	37	31
Chi-square (original data) = 7.33, df = 2, s = .05		

Source: Householder's Questionnaire (Question 12).

TABLE 7.06

PRESENCE OF AIR CONDITIONING IN SAMPLED HOUSES

Proportion of house with air conditioning	Percentage of sampled houses	
	Southwestern Suburbs	Salisbury East
Whole house	3	3
Half house	6	8
One or two rooms (fixed)	19	14
Evaporative air cooler (portable)	10	14
None	62	60
Total	100 N = 306	100 N = 146

Source: Householder's Questionnaire (Question 12).

Chi-square (original data) = 4.51, df = 4, s = .50

or two rooms[23]. Whole house air conditioning was found in seven to ten per cent of the air conditioned houses or three per cent of the total sample in each area. Fully ducted systems are far more expensive than half-house systems, and refrigerated systems more expensive than evaporative cooling[24]. The least expensive air conditioning appliance is the portable evaporative cooler, used in 10 to 14 per cent of the sampled houses. It provides a cheap to operate method of reducing air temperature in one room at a time, but is criticized on noise-level, the amount of air movement, and the increase in humidity resulting from the operating mechanism (Australian Consumers Association, 1972b, 1978e). Nevertheless, portable evaporative air coolers were reported (in an air conditioning firm interview, April, 1975) to have higher sales than room air conditioners, mainly from "impulse-buying" during heat waves.

The many differences between the sampled households of the southwestern suburbs and those of Salisbury East have been continually highlighted in this and the previous chapters, whether discussing orientation, shading from the garden or the nature of heating appliances. Thus, it is of special interest that the nature of air

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23. Room air conditioners were first introduced into Australia in the mid-1950's, with popular use for domestic buildings a decade later. In the mid-1970's, there were approximately 35 brands of room air conditioners available, some Australian-made and some imported. Most were sold for installation in existing homes, usually the living-dining room, followed by bedrooms. The primary aim in buying the equipment was for cooling. (Information from air conditioning firm interviews, March, 1975).

24. For whole house air conditioning, evaporative cooling is approximately half the capital cost of refrigerated cooling, and one sixth the running cost. Air conditioning manufacturers and retailers report increasing sales, during the 1970's, of two horsepower units to heat and cool half the house at one time, and of evaporative cooling combined with gas space heating.

TABLE 7.07

TYPE AND ZONE OF AIR CONDITIONING USED IN SAMPLED HOUSES

Type and zone of equipment		Percentage of air conditioned houses: Southwestern Suburbs	Percentage of air conditioned houses: Salisbury East
Reverse cycle:	One or two rooms	32	17
	half house	11	14
	whole house	3	3
Subtotal		47	34
Evaporative cooling:	one or two rooms	13	10
	half house	3	4
	whole house	4	5
Subtotal		20	19
Refrigerated:	one or two rooms	5	9
	half house	2	2
Subtotal		7	11
Portable evaporative air cooler:			
	one or two rooms	26	36
Total		100	100
		n = 116	n = 58

Source: Householder's Questionnaire (Question 12).

Chi-square (original data, subtotals excluded) = 3.49, df = 8, s = .95

conditioning is so similar in the two sample areas (Table 7.07)[25].

There was a significant tendency for householders of modern homes to possess air conditioning. Of the 174 air conditioned dwellings in both sample areas, 126 houses (72 per cent) had been constructed since 1950 and 62 (36 per cent) since 1965. Furthermore, as Table 7.08 shows, there was a strong relationship between the possession of air conditioning equipment and the householder's stated attitude to air conditioning. Householders in air conditioned houses were more likely to consider air conditioning to be necessary or desirable throughout the whole house or in certain rooms. Residents of houses without air conditioning were more likely to have a negative attitude, regarding air conditioning as too expensive, not worthwhile, or undesirable for health reasons.

Five per cent of sampled housholders in the southwestern suburbs, and 15 per cent in Salisbury East, stated they planned to install air conditioning in their houses in the future. The Electricity Trust's consumer survey of 1976 found a similar result, with ten per cent of the

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25. The only comparable data on the possession of air conditioning in dwellings of South Australia were collected by the Electricity Trust of South Australia. The Trust's surveys showed a progressive increase in the percentage of domestic consumers with air conditioners, from ten per cent in 1969, to 22 per cent in 1972, 44 per cent in 1975, and 51 per cent in 1976. These figures agree closely with the findings of this survey. Data on the type and size of units are less directly comparable, due to the nature of the questions asked. Nevertheless, the Domestic Consumer Survey of the Electricity Trust showed reverse cycle systems in over half the houses surveyed in 1975, evaporative systems in a quarter and refrigerated in one fifth of the houses with air conditioning. Electricity consumers may not have included portable evaporative air coolers in their statements, which probably accounts for the lower frequency of evaporative cooling in the Trust's survey. Size of air conditioning units were comparable in the two surveys, showing the prevalence of medium-capacity units designed to air condition two or three rooms.

TABLE 7.08

RELATIONSHIP BETWEEN POSSESSION OF AND HOUSEHOLDERS' STATED ATTITUDES TOWARDS AIR CONDITIONING

Stated attitude towards air conditioning[a]	Percentage of houses	
	With air conditioning (n = 174)	Without air conditioning (n = 278)
Necessary throughout whole house	17	11
Desirable throughout whole house	40	28
Necessary in certain rooms	32	17
Desirable in certain rooms	16	18
Too expensive to install and run	24	38
Not worthwhile for Adelaide's climate	10	32
Not desirable for health reasons	3	11
Other statement	3	10

Source: Householder's Questionnaire (Question 16).

Chi-square (original data) = 67.12, df = 7, s = .001

a. Includes multiple responses.

consumer sample stating they planned to install air conditioning during the following summer.

Table 7.09 shows that most sampled houses used a single method of cooling, predominantly portable electric fans. Approximately one fifth of householders owned more than one air cooling appliance, whereas one sixth of sampled houses reported no cooling equipment in the house. In general, Adelaide householders seemed to have spent less money in the past on cooling equipment, than on heating systems, although this will be reversed if the upward trend in the purchase of domestic air conditioning units continues.

TABLE 7.09

COMBINED METHOD OF PORTABLE AND FIXED COOLING EQUIPMENT USED IN SAMPLED HOUSES[a]

Equipment	Percentage of sampled houses	
	Soutwestern Suburbs	Salisbury East
Desk fan (portable)	49	43
Evaporative air cooler (portable)	2	4
Air conditioning (fixed)	5	12
Desk fan and PEC	8	10
Desk fan and air conditioning	22	12
No cooling equipment	13	18
Total	100	100
	N = 306	N = 146

Source: Householder's Questionnaire (Question 12).

Chi-square (original data) = 16.76, df = 5, s = .01

a. Excludes exhaust fans (fixed).

The pattern of heating and cooling equipment in the sampled houses has been described above with little or no reference to many factors of direct or indirect influence, of which the following are examples.

(i) The extent to which heating systems have been installed during construction of a house, and included in the purchase price. Fireplaces were common in older houses and oil or gas space heaters common in homes built during the 1960's and early 1970's. Their presence influenced both the amount of portable or supplementary heating equipment needed and the householders' evaluations of the comfort of their houses.

(ii) The relative costs of different methods of artificial heating and cooling. For example, the choice of fuels and range of equipment is far greater for heating appliances than for air cooling. The range in capital cost is outlined later in this chapter: running costs are discussed in Chapter 8, on energy consumption.

(iii) People's attitudes to, and perception of, their local climate. The direct influence of particular weather (such as a heat wave or cold, rainy period) on consumer spending for heating and cooling appliances is well recognized. Such weather extremes are also likely to have a long term effect in determining general attitudes to discomfort in winter and in summer. Particular aspects of Adelaide's climate (such as hot, summer nights or cold, southerly winds) may be sufficiently disliked to affect an individual's whole attitude to summer and/or winter, and thus their comfort-related behaviour.

(iv) Householders' attitudes to and assessments of the physical comfort of their dwellings. Householders' views on the nature of indoor comfort are likely to vary. Some may consider indoor comfort to result primarily from the design and structure of the dwelling, whereas others (like the respondent quoted at the beginning of the chapter) may place more emphasis on the type of heating and cooling equipment in the house or on their thermal management skills. The comfort-related behaviour and assessments of householders are likely to vary accordingly.

These last two factors provide the main focus for the remainder of this chapter. An outline of the sampled householders' attitudes to Adelaide's climate is followed by a description of their responses to summer and winter discomfort and a discussion of their assessments of the physical comfort of their dwellings.

Comfort-related Attitudes, Assessments and Behaviour of Householders

Stated Attitudes to Adelaide's Climate

Since 70 per cent of the heads of households in the Salisbury East sample were born in the United Kingdom and 77 per cent of household heads in the southwestern suburbs sample were Australian-born, one could expect a distinctive or different perception of Adelaide's climate (and thus knowledge of ways to overcome discomfort). However, the two groups of householders described and generally evaluated Adelaide's climate in similar ways (Table 7.10). Although some described the climate only in terms of its temperature or changeability, well over 60 per cent of householders in both sample areas demonstrated their favourable attitude by using such evaluative terms as "perfect", "very pleasant" or "quite comfortable". Householders who regarded Adelaide's climate as "unpredictable", "too cold in winter" or "not as good as it used to be" were in the minority.

Only in stated dislikes was there a significant and unexpected difference between the two sample groups. A higher percentage of southwestern suburbs householders disliked high temperatures, heat-waves and other weather-extremes, than did the Salisbury East householders. This latter group seemed equally concerned with Adelaide's winter features (low temperatures, long wet spells, winter itself) as they were with summer conditions (high temperature, high humidity and hot north winds). It is interesting to note that, after temperature, the feature most frequently commented on, and disliked by both groups, was short-term changeability, which was a dominant feature of Adelaide's weather in the few months or weeks prior to interviewing[26]. Obviously, attitudes to long-term climate are influenced by recent weather.

Apart from a significant tendency for householders who self-administered the questionnaire to have a more unfavourable attitude towards Adelaide's climate, and a slight tendency for elderly, retired respondents to have a highly favourable attitude, there were no systematic relationships between the "general attitude to Adelaide's climate" and other variables. In terms of comfort-related attitudes, assessments and behaviour of householders, their stated attitudes to Adelaide's climate seem to have played a minor or negligible role.

Householders' Assessments of Comfort of Own Homes

The respondents were asked to evaluate the physical comfort of their own houses in two separate ways. The first was an evaluation on a five-point scale (very satisfied to very dissatisfied) of various

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26. For example, Australia, Bureau of Meteorology Monthly Weather Review, (South Australia,) April, 1975, p. 4:

> There were marked day to day fluctuations in both maximum and minimum temperatures during the first week. A pronounced warm spell occurred from the 13th to 18th April, and was largely off-set by a cold spell on the 22nd to 25th days while for the remainder of the period temperatures were generally close to average.

TABLE 7.10

HOUSEHOLDERS' STATED ATTITUDES TO ADELAIDE'S CLIMATE

Description and Evaluation		Percentage of Sampled Householders: Southwestern Suburbs (N = 306)	Percentage of Sampled Householders: Salisbury East (N = 146)
Features mentioned in description			
temperature only (e.g. "hot")		13	17
humidity or precipitation or combination of temperature, humidity, precipitation		8	10
wind		6	12
changeable (short or long term)		16	17
seasonal nature		4	5
other (e.g. Mediterranean, healthy)		4	2

Chi-square (original data) = 5.65, df = 5, s = .50

Description and Evaluation		Southwestern Suburbs	Salisbury East
General evaluation			
very good		14	16
good or favourable		27	23
mild or pleasant or moderate		23	28
reasonable		15	9
unfavourable		3	2

Chi-square (original data) = 7.85, df = 4, s = .20

Description and Evaluation		Southwestern Suburbs	Salisbury East
Main dislikes			
summer features:	high temperature	23	18
	heat waves	10	5
	high humidity	7	10
	hot, north winds (with dust)	6	10
	other summer aspects	7	6
winter features:	low temperatures	6	6
	long wet spells	6	10
	winter in general	7	10
other features:	weather extremes	6	1
	cold, or all wind	8	8
	changeability	12	21
	miscellaneous (e.g. air pollution)	8	2
No dislikes		14	3

Chi-square (original data) = 29.50, df = 12, s = .001

Source: Householder's Questionnaire (Question 18).

comfort features of the house. The second was a description of any rooms or parts of the house considered uncomfortable in certain types of weather, giving reasons for the discomfort and possible means of overcoming the perceived discomfort.

Level of Satisfaction with Comfort Features

The degree of householder satisfaction varied from one feature to another and between the two groups of householders (Figure 7.4). The greatest source of satisfaction in both samples was provided by features associated with windows, namely the amount of daylight indoors, size and placement of windows and indoor air movement in summer. Outdoor living areas were also rated satisfactory, by four-fifths of the respondents.

The least satisfactory features for both groups were associated with warm or hot weather, namely room temperatures indoors in summer, the amount of shade on the house, and the cooling ability of the house after a heat wave. The winter comfort features of room temperatures and lack of draught remained items rated moderately satisfactory.

Nearly all the modern houses of Salisbury East were built with large windows with good-sized openings, so that the high level of satisfaction with daylighting and summer air movement was not surprising. Nevertheless, the large windows, combined with 600 mm wide eaves, poor or mediocre orientation, uninsulated ceilings and lack of established gardens, must have contributed to a comparatively high degree of dissatisfaction with summer room temperatures and with the amount of shade on the house (50 per cent, and 40 per cent dissatisfied, respectively). Their dissatisfaction seemed to result in considerable house modification to improve summer comfort (discussed later in this

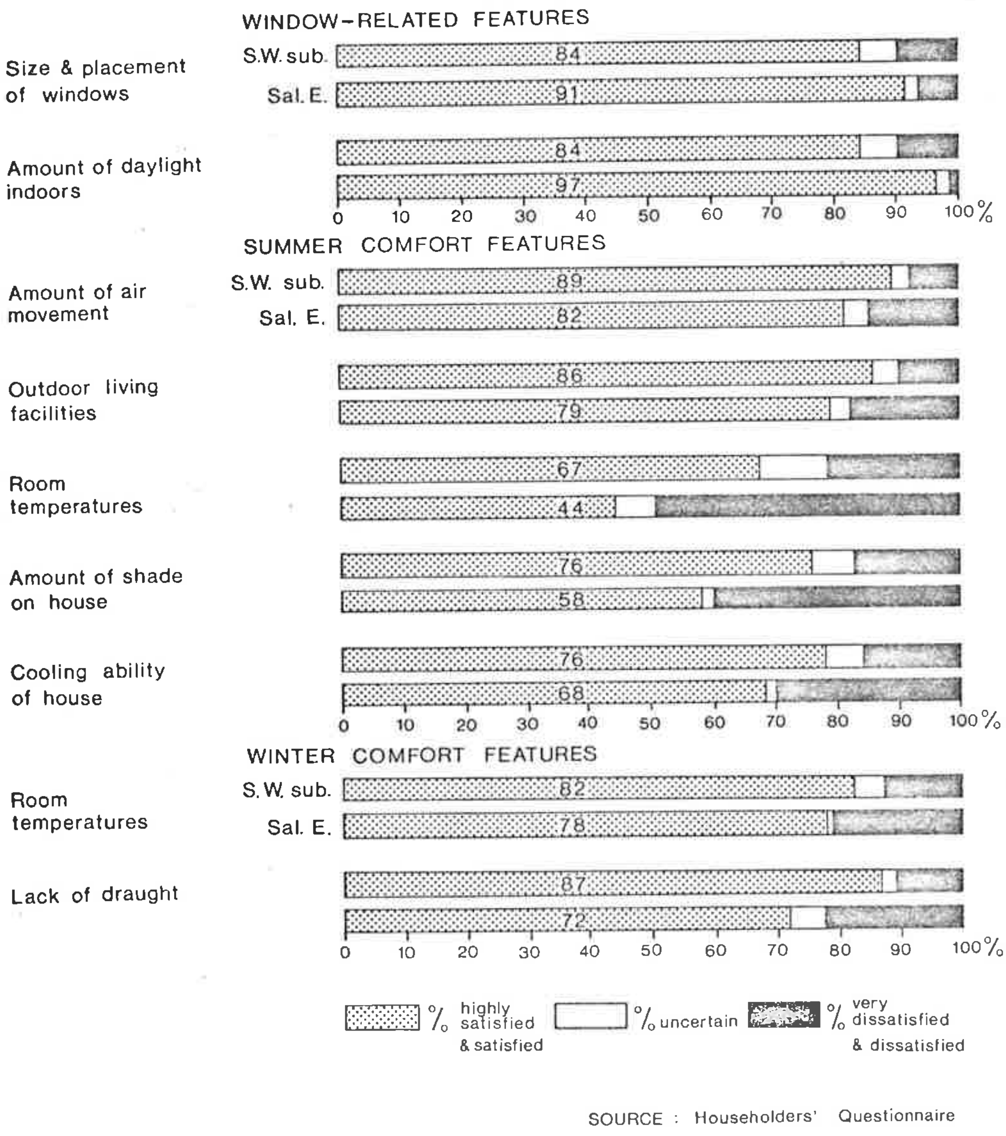

FIG. 7·4 STATED LEVEL OF SATISFACTION WITH COMFORT FEATURES OF HOUSES chapter). Since three-quarters of the household heads were recently arrived migrants from the United Kingdom, acclimatisation problems may help to account for this level of summer discomfort and for an apparent disparity in the evaluation of the cooling ability of the house and summer air movement. Thirty per cent of householders were dissatisfied with the cooling ability of the house after a heat wave, yet only 15 per cent with the amount of air movement indoors in summer. Although 85 per cent were satisfied with air movement in summer, 22 per cent of householders in Salisbury East expressed dissatisfaction with winter air movement in the form of draughts. Since most houses had a gas space-heater installed during construction, room temperatures in winter were considered satisfactory by almost 80 per cent of sampled householders in the Salisbury East area.

Figure 7.4 shows that, for householders of the southwestern suburbs, summer-time conditions caused relatively little concern. Most of these householders were Australian born, and had lived in their older-style houses (with established gardens) for many years.

With the exception of window-related features (their small size and poor placement causing some dissatisfaction with the amount of daylight indoors) the householders of the southwestern suburbs generally rated their houses as "comfortable". Table 7.11 shows that 43 per cent were completely satisfied with the nine selected comfort features of their houses, and an additional 22 per cent expressed minor dissatisfaction. In contrast, sixty per cent of the respondents living in the new housing of Salisbury East expressed moderate to severe dissatisfaction with the

TABLE 7.11

HOUSEHOLDERS' STATED LEVELS OF SATISFACTION WITH SELECTED HOUSE-COMFORT FEATURES

Level of satisfaction with nine features	Percentage of sampled houses	
	Southwestern Suburbs	Salisbury East
Very high (very satisfied, most features)	5	3
High (very satisfied or satisfied, all features)	15	10
Moderately high (satisfied, all features)	23	11
Moderate (minor dissatisfaction)	22	17
Low to moderate (dissatisfied, two features)	18	21
Low (dissatisfied, three or four features)	11	31
Very low (dissatisfied, most features)	7	8
Total	100	100
	N = 306	N = 146

Source: Householder's Questionnaire (Question 14)

Chi-square (original data) = 33.62, df = 6, s = .0001

comfort of their houses. Several of the more important contributing factors, such as house style and age, period of residence, occupation and age of household head and method of questionnaire completion are discussed later in this chapter[27].

27. The effect of "method of questionnaire completion" on householders' assessments of the comfort of their houses is discussed in Appendix IV, pp. 422-425.

The level of satisfaction in this study is lower than that of other house-evaluation studies overseas and within Australia[28]. Such studies suggest that, once a dwelling has been chosen, householders tend to rationalize the decision, or adjust in some way. Stimson (1973, 19) asked Adelaide respondents to rate on a five-point scale their level of satisfaction with their present place of residence. The vast majority were well satisfied, though Stimson queries whether it is due to people achieving or modifying the object of their aspirations[29]. Furthermore, the relatively high socio-economic level of Australians enables considerable expenditure on consumer durables and the ability (if only in financial terms) to provide for personal physical comfort.

Few other house-satisfaction studies specify comfort related features as separate items, so that comparative data are sparse. One exception is provided by the study of Sanoff (1972) in which respondents rated 17 attributes in their own dwellings. Results showed that 38 per cent were dissatisfied with the temperature of their home, 23 per cent with

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28. For example: "88 per cent of the households say they are satisfied with their dwelling unit" (National Coop. Highway Research Program, 1959, 19); "Residents generally rate their dwellings highly. They also highly rate each individual feature of them" (Troy, 1972, 8); and "...the vast majority of people expressed high levels of satisfaction with their present place of residence" (Stimson, 1973, 19).

29. Stimson uses the behavioural approach to analysing behaviour in a spatial system, where the decision maker (in the residential location decision) is seen as having a goal of satisfaction when there is some measure of equality between his achievements and his aspirations. If the stable equilibrium is upset by the appearance of "stressors," the decision-maker resolves his dissatisfaction by either modifying his aspirations or achievements <u>in situ</u>, leading to a decision to stay, or starts to look for a new location. In this framework, house discomfort can be regarded as a "stressor," and house modifications as achievements <u>in situ</u> aimed to restore the goal of satisfaction.

cross-ventilation and 10 per cent with "morning sunlight". An Australian Home Journal (1972) survey showed that one-third of respondents expressed dissatisfaction with the windows of their houses, complaining that they were poorly positioned for maximum light or for a particular room, badly fitted or too small.

Other North American and British studies document dissatisfaction with heating systems and heating costs (Rossi, 1955; University of Edinburgh, 1966; Lowrie, 1975; Townsend and Colesby, 1975; Murphy, 1976) which seems to suggest, as in this study, that householder evaluation of room temperature is a major indicator of comfort. A survey run by the Australian Consumers Association (1978a) shows that householder satisfaction with their heating arrangements depended more on whether their house was insulated than on the form of heating they had. Nevertheless, the people most satisfied with their type of heating were those who owned gas space heaters, fixed oil heaters and moveable oil-filled electric heaters. The least satisfied were those who owned reverse cycle air conditioners, claiming, perhaps erroneously, that they were too expensive to run as a main source of heat.

Weather-induced Discomfort in Rooms or Parts of the House

After assessing the whole house on comfort-related features, householders were asked to describe weather-induced discomfort in rooms or parts of their house. Their replies, shown in Tables 7.12 to 7.17 can be used to indicate the general attitude to, and knowledge of, summer and winter discomfort in one's own house and methods of reducing it.

The general pattern shown in Table 7.12 is the comparatively high degree of discomfort in the Salisbury East houses, and the prevalence of one or two uncomfortable rooms in almost half the sampled houses from both areas. Two hundred and fifty-four householders (92 in the Salisbury East area, 162 in the southwestern suburbs) described one or more rooms of their houses as "uncomfortable" in certain types of weather. In each sample area approximately half of these "uncomfortable" rooms were bedrooms, and one third kitchens or living rooms (Table 7.13). These rooms were most frequently uncomfortable

TABLE 7.12

ROOMS OR PARTS OF HOUSE UNCOMFORTABLE

IN CERTAIN TYPES OF WEATHER

	Percentage of sampled houses	
Part of House	Southwestern Suburbs	Salisbury East
One room	36	27
Two rooms	14	19
Three rooms	3	14
Four rooms	1	3
Five rooms or whole house	4	6
Other parts of house, e.g. passage	2	1
None, or not answered	40	31
Total	100	100
	N = 306	N = 146

Source: Householder's Questionnaire (Question 15)

Chi-square (original data) = 30.63, df = 6, s = .0001

during hot weather, especially heat waves, or hot nights in the case of bedrooms. Cold weather also caused discomfort, often for sleepouts, bathrooms or bedrooms located away from living-room heating. When asked for reasons, householders often mentioned the direction the room faced, or other causes related to the design and structure of the house (Table 7.14). According to the householders, north or west-facing rooms helped to create summer discomfort in almost half the "uncomfortable" rooms, whereas south-facing rooms were associated with winter discomfort. Other reasons suggested by householders included the nature and size of windows, the nature of roof or walls, the size or position of the room, or lack of outside shading. Table 7.15 shows that householders suggested such remedies as outside awnings or other structural shading features (verandah, carport, wider eaves), air conditioning and heating (especially for Salisbury East householders), and trees or other vegetation (especially for southwestern suburbs householders).

The differing responses from the two groups of householders can largely be explained in terms of the design and structure of the houses, and the nature of the occupants. Table 7.13 shows, for example, that there was a wide variety of "uncomfortable" rooms in the houses of the southwestern suburbs (including sleepouts, sunrooms, rumpus and other rooms) whereas nine-tenths of the "uncomfortable" rooms in the Salisbury East sampled houses were bedrooms, kitchens or living rooms. Furthermore, a higher proportion of Salisbury East householders were concerned at the discomfort of all three bedrooms in both hot and cold weather. Various reasons were offered for the discomfort during summer (such as the size of the windows, the orientation of the room or the lack of air circulation) but a consistent reason for the winter discomfort was the layout of the house, and the distance of the bedrooms

TABLE 7.13

DETAILS OF ROOMS DESCRIBED BY HOUSEHOLDER AS UNCOMFORTABLE IN CERTAIN TYPES OF WEATHER

Nature of room and of weather		Percentage of 'uncomfortable' rooms: Southwestern Suburbs (n = 210)	Percentage of 'uncomfortable' rooms: Salisbury East (n = 167)
Room:	kitchen	19	25
	living room	10	10
	main bedroom	16	18
	other bedrooms	27	36
	rumpus or family	7	3
	sleepout, sunroom, or dining room	10	2
	bathroom or laundry	8	5
	other	3	1
Weather:	hot/heat waves	62	56
	summer	10	7
	cold/wet/windy/damp	13	24
	winter	8	9
	all year round	7	4

Source: Householder's Questionnaire (Question 15): compiled from 210 'uncomfortable' rooms in 162 houses of the southwestern suburbs and 167 'uncomfortable' rooms in 92 houses of Salisbury East.

Chi-square (original data) = 25.59, df = 12, s = .01

TABLE 7.14

STATED REASONS FOR DISCOMFORT IN ROOMS DESCRIBED BY HOUSEHOLDER AS UNCOMFORTABLE IN CERTAIN TYPES OF WEATHER

Reasons		Percentage of 'uncomfortable' rooms	
		Southwestern Suburbs (n = 210)	Salisbury East (n = 167)
Direction of room:	north	27	11
	south	11	14
	east	7	4
	west	23	22
	other or general	7	14
	not mentioned as reason	25	35
Design or structural[a]:	nature of windows	20	6
	nature of roof or lack of insulation	10	1
	lack of cross-ventilation	10	9
	nature of walls	5	2
	size or position[b] of room	6	10
	lack of outside shading	3	5
	type of activity in room	3	5
	other design or structural	7	10
	no other cause suggested	48	54
No reason suggested		-	5

Source: Householder's Questionnaire (Question 15).

Chi-square (original data) = 65.18, df = 14, s = .001

a. Multiple reasons included.

b. This includes many statements about the position of the room relative to the fixed heating equipment.

TABLE 7.15

REMEDIES SUGGESTED BY HOUSEHOLDERS FOR DISCOMFORT IN PARTICULAR ROOMS DURING CERTAIN TYPES OF WEATHER

Solution[a]	Percentage of "uncomfortable" rooms	
	Southwestern Suburbs (n = 210)	Salisbury East (n = 167)
Outside awnings	30	31
Trees or other vegetation	18	2
Air conditioning	17	28
Verandah, carport, wider eaves	8	21
Heating	9	28
Change windows	9	5
Ceiling insulation	9	8
Fan or water cooler	6	2
Other structural or design	7	4
Avoid use of room	3	1
None suggested or practicable	13	5

Source: Householder's Questionnaire (Question 15)

Chi-square (original data) = 72.10, df = 10, s = .001

a. Includes multiple responses.

from the living room space-heater. Some householders, recently arrived from the United Kingdom (where most houses have some form of supplementary heating in the bedrooms) considered that a better method of heating the house should have been provided by the builder. Thus "additional heating" was suggested as a remedy to winter discomfort for 28 per cent of the "uncomfortable" rooms in the houses of Salisbury East (Table 7.15).

The older style of housing in the southwestern suburbs probably accounts for the higher percentage of householder's comments about the nature of windows (louvred, too small, facing the wrong way) and the nature of the roof (galvanised iron, uninsulated) as causes of discomfort (Table 7.14) and the subsequent desire to change the windows or insulate the ceiling (Table 7.15). In general, the remedies suggested by householders of the southwestern suburbs tended to be "energy-saving" (adding outside awnings, growing trees or other vegetation, adding a verandah or carport or insulating the ceiling). In contrast, remedies suggested by householders in the Salisbury East sampled houses were almost evenly divided between energy-saving procedures and energy-consuming devices such as air conditioning and room heating. A sample of householders' statements about "uncomfortable" rooms in their houses are shown in Table 7.16.

Eight to ten householders in each sample area described the whole house as "uncomfortable", mainly in hot weather, but sometimes in cold weather or all year through. Stated reasons were varied, including orientation, house design and structural features, with generally more expensive solutions suggested, such as complete air conditioning and/or central heating, insulation and major structural changes. For one low-income, migrant householder, living alone in an uninsulated cement brick house, with a large open-plan living area containing two walls of glass (or "french doors"), no carpets and no fixed heating, the winter months were almost unbearable. Only a minority of householders were able to specify the multiple-cause and complex nature of discomfort in their own homes, and suggest practicable means of reducing it. Most of the statements shown in Table 7.16 were obtained from this minority group of householders. Despite wide variation among the interviewed

TABLE 7.16

SAMPLE OF HOUSEHOLDERS' STATEMENTS ABOUT "UNCOMFORTABLE" ROOMS IN THEIR HOUSES

Room or Part of House Stated as Uncomfortable (Location of House)	Type of Weather	Householder's Suggestions	
		As reason for Discomfort	For Improving Situation
Kitchen (Southwest Suburbs)	Summer	Two west-facing windows (with no awnings), plus cooking	Verandah across back of house, and awnings
Kitchen (Southwest Suburbs)	All year	Galvanised iron lean-to added to back of house	Replace galvanised iron with brick walls, and tile over roof
Kitchen-dine (Salisbury East)	Very cold	Faces south, so no winter sun	Extra heating
Lounge-dining room (Salisbury East)	Hot	Lounge - sun in morning, dining room - sun in afternoon	Outside awnings, air conditioning
Living room (Salisbury East)	Cold, windy	Layout of room - no doors to exclude heat - very draughty	Add doors to living room
Main bedroom (Southwest Suburbs)	Hot	Faces north, and poor cross-ventilation	Shift window?
Main bedroom (Salisbury East)	Summer	Large windows to west	Less glass, awnings, insulation
Main bedroom (Salisbury East)	Cold	Design of house - too far from heater	Supplementary heating
Second bedroom (Southwest Suburbs)	Hot	North-west corner of house, window faces west	Outside blinds and plant trees
Third bedroom (Salisbury East)	Cold	Faces south	Don't know - and has to sleep two children
Spare bedroom (Southwest Suburbs)	Hot	No cross-ventilation - opens onto sleepout and carport	Nothing? except fans or air conditioning
Family room (Salisbury East)	Hot	Large windows and sun all day	Solchek on window
Sleepout (Southwest Suburbs)	Cold and hot	Louvred windows to east, unlined wall	Change windows, and supplementary heating
Dining room (Southwest Suburbs)	Hot summer days	Opens from sunroom	Avoid use or air conditioning
Bathroom (Salisbury East)	Cold	Faces south	Heating (should be installed by builder)
Laundry (Southwest Suburbs)	Cold	Rear exit unprotected from rain and bad weather	Verandah

Source: Compiled from responses to Question 15, Householder's Questionnaire.

householders, the general level of understanding of, and knowledge about weather induced house comfort appeared to be low.

House-modification by the Present Householder

In order to place comfort-improving features in the context of all major expenditure on houses, to ascertain differences (if any) between summer and winter discomfort as a cause of house-modification, and to indicate the householders' general levels of satisfaction with their houses, respondents were asked to state all major changes to the house since moving in. Table 7.17 shows the many ways in which houses were modified, especially in the longer-occupied dwellings of the southwestern suburbs. Major structural changes included the addition of extra space (23 per cent of sampled houses), remodelling the kitchen, bathroom and other plumbing areas (41 per cent) or the erection of carport, verandah or garage (66 per cent). Garden development, roof painting and other outdoor changes were listed by 68 per cent of householders in the southwestern suburbs, while 41 per cent described indoor changes (such as redecorating or carpentry).

Many of the modifications had a direct or indirect effect on indoor comfort. Approximately one-third of householders of the southwestern suburbs had added outside awnings, some form of air conditioning and ceiling insulation, and one-fifth had changed the method of room heating. However, most householders of the southwestern suburbs had occupied their houses for five to thirty years, so that such additions and modifications have probably been a gradual process. In contrast, the Salisbury East householders had occupied their houses for no more than five years before the questionnaire was administered, so that the comparatively high degree of house modification and additions is of

TABLE 7.17

MODIFICATIONS MADE TO HOUSES BY HOUSEHOLDERS SINCE TAKING UP RESIDENCE

Nature of change to house[a]	Percentage of sampled houses	
	Southwestern Suburbs (N = 306)	Salisbury East (N = 146)
Inside:		
room or rooms added	23	3
room(s) extended or layout altered	22	3
renovations of kitchen, bathroom, laundry, W.C., HWS, (incl. plumbing)	41	3
other changes	41	26
Outside:		
addition of carport	16	20
garage	34	14
shed or workshop	7	17
verandah	16	17
porch or patio	4	15
swimming pool	3	9
other changes to block, garden or house exterior	68	32
Comfort features installed:		
air conditioning	29	28
ceiling insulation	28	51
space-heating	21	3
outside awnings	36	31
other	2	1
No changes since moving into house	11	14
No answer to this question	2	3

Source: Householder's Questionnaire (Question 10).

Chi-square (original data, inside changes) = 34.69, df = 3, s = .0001
(original data, outside changes) = 72.52, df = 7, s = .0001
(original data, comfort features) = 37.01, df = 6, s = .0001

a. Multiple responses included.

special significance. In less than five years, nearly half the Salisbury East householders had added a carport, garage, shed or workshop, 32 per cent a verandah or patio, as well as other changes inside the house (26 per cent) and outdoors (32 per cent). Fifty per cent added ceiling insulation, 31 per cent outside awnings, and 28 per cent air conditioning. This greater degree of modification in a shorter time is almost certainly due to the general nature of the housing and to the type of family in the Salisbury East sampled houses, as well as to particular factors to be discussed later. In both sample areas, the relatively high level of house modification to overcome discomfort soon after moving into the house suggests the idea of a belated discovery, at least in some people, of the fundamental need for the house to fulfil its basic purpose of shelter by being climatically suitable and physically comfortable.

Future House Modifications. Householders were also asked to describe the features of the house (and its immediate environment) that they would like to change or improve next. Responses again differed between the two samples, with more major changes to room size, layout and modernisation wanted in the older houses of the southwestern suburbs, and more additions in the newer houses of Salisbury East (Table 7.18). Approximately one in six Salisbury East householders listed a verandah, carport, patio or air conditioning in their future plans, each of which has some effect on physical comfort, especially during the summer months. In general, householders of the southwestern suburbs seemed to be more satisfied with their houses, as indicated by the 26 per cent who desired no future changes.

TABLE 7.18

MODIFICATIONS TO HOUSES DESIRED BY HOUSEHOLDERS

Nature of change[a]	Percentage of sampled houses	
	Southwestern Suburbs (N = 306)	Salisbury East (N = 146)
Inside:		
room or rooms added	13	12
room(s) extended or layout altered	14	9
renovation of kitchen, bathroom, laundry, W.C., HWS, (incl. plumbing)	14	3
other changes desired	20	8
Outside:		
addition of carport	5	22
garage	2	3
shed or workshop	2	5
verandah	6	22
porch or patio	3	15
swimming pool	1	2
Other changes to block, garden or house exterior	28	28
Comfort features desired:		
air conditioning	5	15
ceiling insulation	5	7
space-heating	2	1
outside awnings	2	4
other	1	1
Local environment (buildings, roads, etc)	8	9
Too many to list/change house	7	1
No changes desired	26	11
No answer to this question	5	5

Source: Householder's Questionnaire (Question 11)

Chi-square (original data, inside changes) = 8.42, df = 3, s = .05
(original data, outside changes) =32.00, df = 6, s = .0001
(original data, comfort features) = 6.84, df = 6, s = .50

a. Includes multiple responses.

<u>The "Capital Cost" of Comfort.</u> Thermal insulation, heating, ventilating and cooling equipment, window protection and some outdoor living facilities are conventional methods used by householders to improve house-comfort. These items vary widely in cost, ranging from a few dollars for a bamboo-cane outside blind or portable radiator, to $2,300 for reverse-cycle air conditioning with individual controls for each room of the house. As a general rule, householder comfort, especially in terms of personal control over the internal environment, is related to the capital cost of the items concerned[30]. For example, a wall-mounted "Seasonmaker," costing approximately $900, designed to provide gas heating, evaporative cooling and ventilation for "five squares" (an average-sized living-dining-kitchen area) permits more "total comfort" than the cheapest forms of heating, cooling and ventilation equipment such as the portable radiator and desk fan. Thus the cost of various house-modifications to improve comfort in a house can be calculated, and the total expenditure used as a measure or index of the potential comfort of the house[31].

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30. Capital costs were chosen for ease of calculation: other costs show wider variation (such as the difference in running costs between evaporative and refrigerative cooling, or the maintenance/replacement costs of bamboo, canvas and aluminium outside awnings).

31. The cost of house improvements was used successfuly by Brealey (1972b), investigating the nature and extent of problems of living in six remote communities throughout tropical Australia. Respondents were asked to play the "Home Improvement Game," involving the spending of $5,000 in pseudo-money on a number of options in order to upgrade a basic house to suit there own preferences. The highest ranked comfort feature (ranked seventh, overall, in the ordered frequency distribution of options) was "evaporative cooling", for the whole house, costing $1,000. Brealey (1974) reports an enthusiastic response to this type of questionnaire, and suggests the possibility of using it for other places.

The items used for estimating the "cost" of comfort are listed in Table 7.19 at mid-1977 prices[32]. Any expenditure, after moving in, by the present or previous householder was included. Table 7.20 shows that the total expenditure of the two groups of householders was very similar, despite significant differences in period of residence, nature of houses and occupations of household-heads. Nevertheless, when expenditure on "energy-saving" devices (ceiling insulation, outside awnings, reflective film on windows or verandah) was calculated separately from expenditure on "energy-consuming" equipment (fans, air conditioning, space-heating, portable heaters) significant differences between the two groups of sampled households did occur (Table 7.21). It can be seen that a higher proportion of Salisbury East householders had invested in energy-saving devices for their houses: ceiling insulation and outside awnings were the main item of expenditure for 23 and 21 per cent of householders, respectively. For householders of the south-

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32. No data were collected, in the Householder's Questionnaire, on the date of purchase of these items and equipment. Investigation of the comparative cost of two items, namely ceiling insulation (50 mm rockwool batts) and heating systems (oil space heater) in 1960, 1970, 1974 and 1977 revealed in increase in costs similar to that of the average weekly earnings per employed male unit, as in the Table below:

YEAR	COST OF SUPPLY AND INSTALLATION: Oil Heater into Existing Fireplace (excludes oil tank)[a]		COST OF SUPPLY AND INSTALLATION: 50 mm rockwool batts in ceiling[b]		AVERAGE WEEKLY EARNINGS PER EMPLOYED MALE UNIT (South Australia)[c]	
	Actual Cost ($)	Percentage of 1977 Cost	Actual Cost ($)	Percentage of 1977 Cost	Actual Earnings ($)	Percentage of 1977 Earnings
1960	165	35	129	45	43.40	24
1970	251	53	150	53	78.20	43
1974	286	60	235	83	138.60	77
1977	475	100	284	100	179.50	100

Source: a. Personal Communication, J.H. Vast, Vulcan Australia Ltd, 31st August, 1977.

b. Personal Communication, F.G. Pearce, Bradford Insulation (S.A.) Pty Ltd, 30th August, 1977.

c. South Australian Year Books, 1969, 1975; Australian Bureau of Statistics, "Average Weekly Earnings" March Quarter 1978.

TABLE 7.19

TYPICAL COSTS OF COMFORT-IMPROVING FEATURES, ADELAIDE HOUSES, 1977

Item	Type and Size		Approximate cost (installed)
Thermal insulation (ceiling)	rockwool 50 mm batts	Average-sized house	$ 285
	fibreglass 50 mm batts		$ 300
	cellulosic 75 mm loose-fill	(100 m^2 of ceiling above living/sleeping areas)	$ 295
			$ 300
	aluminium foil		$ 200
Air conditioning	evaporative	portable	$ 200
		fixed one room	$ 400
		half house	$ 700
		whole house	$1,550
	reverse cycle (if refrigerated cooling only, slightly cheaper)	one room	$ 500
		half house) average size	$1,100
		split system) average size	$1,600
		whole house) average size	$2,300
Fans	exhaust (fixed)		$ 20
	desk (portable)		$ 40
Heaters	portable radiator	small	$ 10
		large	$ 50
	fixed radiator		$ 50
	space-heater (fixed)	oil	$ 475
		gas	$ 430
		slow combustion	$ 250
Outside awnings (windows)	bamboo	small (0.9 m x 1.5 m)	$ 4
		medium (1.8 m x 1.5 m)	$ 8
		large (3.0 m x 1.5 m)	$ 12
	canvas	small	$ 80
		medium	$ 110
		large	$ 150
	aluminium	small	$ 90
		medium	$ 130
		large	$ 200
Solar control film (windows)	reflective	small	$ 30
		medium	$ 55
		large	$ 92
Verandah	metal	small (6.1 m x 1.5 m)	$ 200
		medium (9.1 m x 1.5 m)	$ 300
		large (12.2 m x 1.5 m)	$ 400

Source: Manufacturers and retailers, Adelaide, 1977.

TABLE 7.20

HOUSEHOLDERS' TOTAL EXPENDITURE ON SELECTED FEATURES TO IMPROVE HOUSE-COMFORT

Expenditure[a]	Percentage of sampled households	
	Southwestern Suburbs	Salisbury East
More than $2,500	2	1
$2,000 to $2,499	4	4
$1,500 to $1,999	7	5
$1,000 to $1,499	20	16
$500 to $999	27	27
Less than $500	41	47
Total	100	100
	N = 306	N = 146

Source: Householder's Questionnaire, and costs detailed in Table 7.19

Chi-square (original data) = 1.24, df = 5, s = .90

a. Additional expenditure by present or previous householder, after moving into house

western suburbs, outside awnings were also an important item of expenditure (the main item for 31 per cent of householders) but air conditioning and heating equipment (fixed or portable) were the most costly items for an additional 23 per cent each. Thus, for almost half of the householders from the southwestern suburbs, energy-consuming devices had taken precedence. In both areas, approximately one-fifth of householders had spent money only on energy-consuming appliances, particularly portable heaters and fans.

TABLE 7.21

PERCENTAGE RATIO OF HOUSEHOLDERS' EXPENDITURE ON ENERGY-SAVING DEVICES TO EXPENDITURE ON ENERGY-CONSUMING EQUIPMENT

Percentage Ratio of Expenditure Energy saving: energy consuming	Percentage of sampled households Southwestern suburbs	 Salisbury East
100:1 (i.e. all energy-saving)	2	4
90:10	4	14
80:20	14	12
70:30	6	15
60:40	12	8
50:50	10	6
40:60	10	6
30:70	8	8
20:80	4	5
10:90	6	1
1:100 (i.e. all energy consuming)	22	18
No spending or not known	2	3
Total	100	100
	N = 306	N = 146

Source: Householder's Questionnaire and costs detailed in Table 7.11

Chi-square (original data) = 34.24, df = 11, s = .001

Factors Related to and Affecting the Physical Comfort of the Sampled Houses

Having described the comfort of the sampled dwellings; some of the factors of direct or indirect influence can now be considered. Those of possible importance include factors relating to the physical structure of the house (its style and age, size, designer-builder, orientation, equipment and appliances) and factors relating to the structure and characteristics of households (the size of the household, occupation, age, place of birth of the household head and the years of residence).

Factors Related to the Physical Structure of the House

House Style and Age. The nature of the housing appears to be a major factor contributing to the different levels of satisfaction expressed by the two groups of sampled householders. When data from both samples are combined, and householders asked to describe weather-induced discomfort in rooms or parts of their houses, those living in older houses were far more likely to specify one or two rooms, or none at all. As Table 7.22 shows, the number of "uncomfortable" rooms increased as the age of housing decreased: two thirds of the houses with major discomfort had been built since 1966.

This higher level of satisfaction with housing of older style and age may have been due to a combination of features, or related to particular feature of design and structure, such as verandahs. The value of incorporating verandahs in the design of a house has been a continuing, but unresolved issue in Adelaide (Allman[33], 1953,31; Marshall, 1955,28-29; Broinowski, 1962b,150; Chappel, 1973a,16[34]). Table 7.23

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33. Ruth Allman was women's editor of the Chronicle, and her perceptive article on the value of verandahs on country houses (in response to a reader's enquiry) provoked a long series of letters from South Australian country women on the topic. Although some letters highlighted the disadvantages, most women were in favour of at least one, well-placed and well-planned verandah on their houses.

34. This study indicates the continued popularity. For example, 17 per cent of Salisbury East householders had already added a verandah to their newly constructed houses, while 22 per cent planned to add one in the future. When asked to describe their idea of "the house best suited to Adelaide's climate," 35 per cent of all respondents incorporated verandahs in their outlines.

TABLE 7.22

HOUSE STYLE AND AGE BY HOUSEHOLDER'S STATEMENT OF WEATHER-INDUCED DISCOMFORT IN HOUSE

House Style and Age	Sample size	Number of rooms stated as uncomfortable (Percentage of houses)		
		None	One or two	Three or more
Symmetrical Front and Early Villas, 1850-1905	35	12	6	-
Later Villas, Bungalows and Tudor, 1905-1945	69	13	19	9
Austerity, 1946-1952	66	18	14	5
S.A.H.T., L-shape, Conventional, 1952-1965	126	29	29	18
New, 1966-1974	156	29	31	68
Total	452	100 n = 56	100 n = 204	100 n = 56

Source: Householder's Questionnaire (Question 15) and House Details Form (Item 1).

Kendall's tau_c (original data) = .1559, s = .0001

TABLE 7.23

PRESENCE OF VERANDAHS ON HOUSE BY HOUSEHOLDER' EVALUATION OF HOUSE COMFORT

Number of Verandahs	Householder's Evaluation of House Comfort				
	High	Moderate to high	Moderate	Low to Moderate	Low
Two	14	11	13	8	7
One	43	41	38	32	31
None	42	48	50	60	63
Total	100 n = 79	100 n = 81	100 n = 96	100 n = 84	100 n = 112

Source: Householder's Questionnaire (Question 14) and House Details Form (Item 14).

Kendall's tau_c (original data) = .13001, s - .0008 (a negative tau indicates that the householder's evaluation of house comfort increases as the number of verandahs increases) shows that the householders' evaluations of the comfort of their houses gradually increased as the number of verandahs on the house increased. Part of this relationship is indirect, since verandahs are more likely to occur on certain older styles of houses, but at least some of the householders' assessments of climatic suitability and comfort must be attributed to the presence or absence of verandahs.

Householders' expenditures on comfort-related modifications were also related to the style and age of their houses. Table 7.24 shows that highest total expenditure occurred in houses built between 1947 and 1965, fairly evenly divided between energy-saving and energy-consuming equipment. Householders in "new" houses (built after 1966) had the second-highest average expenditure on energy-saving equipment, particularly ceiling insulation and outside awnings. The effect of this expenditure on energy-saving and energy-consuming equipment on the householders' evaluations of the comfort of their houses is shown in Table 7.25. The average total expenditure of householders who were fully satisfied (with the comfort of their houses) was almost double that of householders who were dissatisfied. These data generally support the hypothesized relationship between affluence and comfort.

<u>The Size of the House.</u> Table 7.26 shows that larger houses tended to be occupied by larger-sized households with more children, and moderate to high income. Although there was no systematic relationship between the size of the house and the householders' evaluations of the comfort of their houses, there was some tendency for expenditure on energy-saving and energy-consuming equipment to increase as the size of the house increased (Table 7.26).

TABLE 7.24

HOUSEHOLDER'S EXPENDITURE ON ENERGY-CONSUMING AND ENERGY-SAVING EQUIPMENT AS A FUNCTION OF HOUSE STYLE AND AGE

House Style and Age	Sample size	Average Expenditure ($) on Equipment		
		Energy-Saving	Energy-Consuming	Total
Symmetrical Front and Early Villas, 1850-1905	35	240	259	499
Later Villas, Bungalows and Tudor, 1905-1945	69	261	277	538
Austerity, 1946-1952	66	421	417	838
S.A.H.T., L-shape, Conventional, 1952-1965	126	499	527	1,026
New, 1966-1974	156	422	315	757
Total	452	412	379	792

Source: Household Data.

TABLE 7.25

HOUSEHOLDER'S EXPENDITURE ON ENERGY-SAVING AND ENERGY-CONSUMING EQUIPMENT AS A FUNCTION OF THEIR EVALUATIONS OF HOUSE-COMFORT

Householder's Evaluation of Comfort	Sample size	Average Expenditure on Equipment ($)		
		Energy-Saving	Energy-Consuming	Total
High or very high	79	553	563	1,116
Moderate to high	81	423	407	830
Moderate	96	438	331	769
Low to moderate	84	375	365	740
Low	112	307	281	588
Total	452	412	379	792

Source: Householder's Questionnaire (Questions 10 to 14).

TABLE 7.26

AVERAGE NUMBER OF PERSONS, AVERAGE NUMBER OF CHILDREN AND AVERAGE HOUSEHOLD INCOME AS A FUNCTION OF HOUSE SIZE

Number of main rooms	Sample size	Size of Household: Average number of persons	Size of Household: Average number of children	Average Household Income[a] (1974)	Average Expenditure on Comfort Equipment
Four	25	2.0	.1	$3,702	$ 610
Five	177	3.2	1.1	$6,414	$ 820
Six	161	3.6	1.4	$6,747	$ 750
Seven	57	3.9	1.5	$7,335	$ 810
Eight or more	32	4.1	1.4	$10,019	$1,035
Total	452	3.5	1.2	$6,754	$ 792

Source: Household Data.

a. Household Income was taken as the joint annual wage of the household head and second adult using average annual incomes of 1973-74 provided by the Australian Bureau of Statistics (1974) and by the Department of Social Security. Incomes varied, during 1974-75, from $1,700 for an old-age pensioner (living alone) to $21,650 for a solicitor and his teacher-wife.

The Designer-Builder of the House. There was a slight tendency for householders living in houses designed by an individual, by the South Australian Housing Trust or by a small commercial firm to be better satisfied with the comfort-features of the house (Table 7.27). Several explanations can be offered. First, it is possible that greater care and attention is paid to house-design and construction by individuals, and small firms and by the South Australian Housing Trust. Second, personal knowledge of or contact with the builder may increase the likelihood of rationalization (even if that builder happens to be an institution). Third, this relationship (of Table 7.27) may reflect householder satisfaction /dissatisfaction with design and construction features of the house, rather than the designer.

<u>Orientation.</u> Although orientation is stressed as the fundamental principle of climatic design, its full effect as a determining factor in this study was masked by the high percentage of houses facing north, south, east or west in the southwestern suburbs sample area, and houses facing north-east, south-east, south-west and north-west in Salisbury East[35]. This was primarily due to the street layout. For example, of the 116 north-facing houses in the combined sample, 108 were located in the southwestern suburbs (and likely to be of older style and age) whereas 60 of the 75 houses facing southwest or southeast were located in Salisbury East (and all constructed after 1970). Thus the variable "orientation" was, in effect, reflecting house-style and age, rather than the direction the house faced. In Table 7.28, for example, householders in houses facing north or south were more highly satisfied than those living in houses facing other directions. It is not clear whether this satisfaction resulted from the style, age and environment of the house, from its orientation or from both. There was no significant relationship between orientation and the presence of air conditioning or outside awnings[36], or between orientation and the householder's expenditure on house comfort.

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35. Orientation of the sampled houses is shown in Table 6.01, p. 159.

36. Table 6.18 (p. 184) shows a non-significant relationship between the presence of outside awnings and the direction of the front of the house (both sample areas).

TABLE 7.27

HOUSEHOLDER'S EVALUATION OF HOUSE COMFORT BY DESIGN-METHOD OF HOUSE

Householder's Evaluation of House Comfort	Design-Method of House				
	Owner, previous owner, architect	S.A.H.T.	Commercial builder (small)	Commercial builder (large)	Not known
	(percentage of sampled houses)				
High or very high	29	24	11	16	15
Moderate to high	19	13	27	11	24
Moderate	39	20	32	16	19
Low to moderate	6	20	8	20	24
Low or very low	8	24	22	38	19
Total	100 n = 52	100 n = 55	100 n = 37	100 n = 152	100 n = 155

Source: Householder's Questionnaire (Questions 3 and 14).

Chi-square (original data) = 56.27, df = 16, s = .000

TABLE 7.28

RELATIONSHIP BETWEEN ORIENTATION OF FRONT OF HOUSE AND HOUSEHOLDER'S EVALUATION OF HOUSE COMFORT

Orientation	Householder's Evaluation (Percentage of houses)				
	High	Moderate to high	Moderate	Low to Moderate	Low
North	25	28	29	26	21
South	25	31	25	13	17
West and East	22	25	18	23	14
Northwest and Northeast	15	7	16	12	27
Southwest and Southeast	13	9	13	26	21
Total	100 n = 79	100 n = 81	100 n = 96	100 n = 84	100 n = 112

Source: Householder's Questionnaire (Question 14) and House Details Form (Item 4).

Chi-square (original data) = 36.9801, df = 16, s = .0021

Equipment and Appliances. The presence of insulation and of mechanical methods of heating and cooling can either enhance the good effects or counteract the bad effects of house design and structure. Table 7.29 shows the relationship between the presence or ownership of ceiling insulation, air conditioning and space-heating and the householders' assessments of the overall comfort of their houses. There was a significant tendency for householders of insulated houses to be more highly satisfied. The presence of air conditioning had a lesser effect on the householders' evaluations, whereas the presence of space-heating was inversely related to respondent satisfaction. In other words, respondents in space-heated houses (predominantly of modern construction) were more inclined to be dissatisfied with the overall comfort of their houses. Table 7.29 also shows that the average annual income of the household was higher for houses with ceiling insulation, air conditioning or space-heating than for houses without. This suggests a link between affluence and comfort and, since air conditioning and space-heating consume energy, between affluence and household energy consumption.

Factors Related to the Structure and Characteristics of Households

Size of Household. The relationship between the size of household and the householder's evaluation of house comfort and the household's use of energy was far more obvious. Since smaller households tended to occupy the older houses of the southwestern suburbs[37], their occupants were

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37. The higher level of householder satisfaction in housing of older style and age is shown in Table 7.22, p. 274.

TABLE 7.29

RELATIONSHIP BETWEEN HOUSEHOLDER'S EVALUATION OF COMFORT AND PRESENCE OF CEILING INSULATION, AIR CONDITIONING AND SPACE HEATING

	Percentage of sampled houses with					
Householder's evaluation of comfort	Ceiling insulation		Air conditioning		Space-heating	
	Present	Absent	Present	Absent	Present	Absent
High	21	15	24	14	18	17
Moderately high	19	17	18	18	13	25
Moderate	25	18	18	23	21	22
Low to moderate	18	19	21	17	20	17
Low	17	31	20	28	29	19
Total	100	100	100	100	100	100
	n = 210	n = 242	n = 174	n = 273	n = 261	n = 191
Mean annual household income ($)	6,998	6,541	6,835	6,716	7,308	5,997

Source: Householder's Questionnaire (Questions 12 and 13).

Chi-square (original data, ceiling insulation) = 14.56, df = 4, s = .006

Chi-square (original data, air conditioning) = 10.88, df = 4, s = .028

Chi-square (original data, space-heating) = 13.910, df = 4, s = .008

generally more satisfied with the comfort of their houses. This significant tendency for householder evaluation of house comfort to increase as the size of the household decreased is shown in Table 7.30. One of the reasons for the highly satisfied one and two person household was their age and number of years they had lived in the house: many were over 65 years old, or approaching retirement, and had been resident in the area for 15 years or more.

TABLE 7.30

RELATIONSHIP BETWEEN NUMBER OF PERSONS IN HOUSEHOLD AND HOUSEHOLDER'S EVALUATION OF COMFORT OF HOUSE

Number of persons in house	Householder's Evaluation				
	High	Moderate to high	Moderate	Low to Moderate	Low
	(Percentage of Households)				
One or two	38	53	33	26	18
Three	24	25	14	17	23
Four	18	12	30	24	34
Five	15	6	15	18	11
Six or more	5	4	8	16	14
Total	100	100	100	100	100
	n = 79	n = 81	n = 96	n = 84	n = 112

Source: Householder's Questionnaire (Questions 7 and 14).

Kendall's tau_c (original data) = .177, s = .0000

Occupation of Head of Household. Despite a slight tendency for households whose head was in a moderate to high status occupation to occupy houses best suited to Adelaide's climate (see Table 6.35), the households whose head was in lower-status occupations, or non-earning[38], tended to be more highly satisfied with the comfort features of their houses (Table 7.31). This was despite lower average expenditure by household heads in craft or trade or non-earning occupations on equipment and appliances to overcome discomfort in the

38. This was partly a function of the age of the household head, since 89 per cent of the non-earning heads were 60 years or older.

house[39]. Table 7.32 shows that the average expenditure ranged from $1,035 by household heads in managerial or administrative occupations to $695 by household heads who were retired, housewives or unemployed.

Age of Head of Household. Age of household head did, however, influence the householders' evaluations of the comfort of their houses. Table 7.33 shows that householders under 40 years of age were far more likely to describe one or more rooms as "uncomfortable" in certain types of weather than were householders aged over 60 years.

Place of Birth of the Head of the Household. The contrast in percentages of Australian-born household heads in the southwestern suburbs sample area and in the Salisbury East area has already been emphasized. However, household heads born in Australia were generally more satisfied with the comfort of their houses than were household heads from other countries (Table 7.34). Since their attitude to Adelaide's climate was similar (discussed earlier in this chapter) and the knowledge of design-for-climate principles of Australian and British-born household heads only slightly better than that of household heads from other countries, one can only assume that it was the house style, its features and environment which exerted greater influence on householder comfort than did the ethnicity of the household.

Nature and Duration of Occupancy. Household comfort and energy consumption are likely to be influenced by the household's equity in the house, and by the number of years of residence. However, since none of the Salisbury East householders and only eight per cent of those in the

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39. See Table 7.19 and accompanying text for method of calculation of these expenditures.

TABLE 7.31

OCCUPATIONS OF HEADS OF HOUSEHOLD BY HOUSEHOLDER'S EVALUATION OF HOUSE COMFORT

Occupation of Head	Householder's Evaluation (Percentage of households)				
	High	Moderate to high	Moderate	Low to Moderate	Low
Professional	12	14	15	13	19
Administrative, managerial	10	13	15	7	7
Sales, service, clerical	18	19	18	22	26
Craftsmen, tradesmen	35	19	30	43	41
Non-earning	25	36	22	15	8
Total	100 n = 77	100 n = 80	100 n = 94	100 n = 83	100 n = 105

Source: Householder's Questionnaire (Questions 8 and 14).

Kendall's tau_c (original data) = .0939, s = .0065 (A negative tau indicates that the evaluation of the house increased as the occupation-status of the household head decreased.)

TABLE 7.32

AVERAGE HOUSEHOLD INCOME AND EXPENDITURE ON ENERGY-SAVING AND ENERGY-CONSUMING EQUIPMENT AS A FUNCTION OF OCCUPATION OF THE HOUSEHOLD HEAD

Occupation of Household Head	Estimated Average Household Income[a] ($)	Average Expenditure on Equipment ($)		
		Energy-saving	Energy-consuming	Total
Professional	11,144	401	384	785
Administrative/managerial	10,922	479	553	1,032
Sales, service, clerical	7,054	473	341	814
Craftsmen, Tradesmen	7,042	400	373	773
Non-earning	1,429	350	342	692

Source: Household Data.

a. See footnote, Table 7.26 for method of calculation of household incomes.

TABLE 7.33

HOUSEHOLDER'S STATEMENT OF WEATHER-INDUCED DISCOMFORT IN HOUSE BY AGE OF HEAD OF HOUSEHOLD

Number of rooms uncomfortable	Age of head (percentage)				
	29 years or less	30-39 years	40-49 years	50-59 years	60 years or more
Three rooms or more	18	17	19	8	-
One or two rooms	52	47	42	47	41
None	30	36	39	45	60
Total	100 n = 67	100 n = 78	100 n = 117	100 n = 85	100 n = 89

Source: Householder's Questionnaire (Questions 8 and 15).

Chi-square (original data) = 30.320, df = 8, s = .0002

Kendall's tau_c (original data) = .1986, s = .0000

TABLE 7.34

HOUSEHOLDER'S EVALUATION OF HOUSE COMFORT BY PLACE OF BIRTH OF HEAD OF HOUSEHOLD

Householder's Evaluation	Place of birth (percentage)			
	Australia	United Kingdom	Italy, Greece	Other
High	21	12	12	7
Moderately high	23	12	6	13
Moderate	23	17	35	19
Low to moderate	16	22	18	32
Low	18	38	29	29
Total	100 n = 264	100 n = 137	100 n = 17	100 n = 31

Source: Householder's Questionnaire (Questions 8 and 14).

southwestern suburbs were renting their houses, it is difficult to assess the effect of the nature of occupancy of the dwelling. Nevertheless, householders of rented houses lived in houses with lower climatic suitability scores, were generally less satisfied with the comfort of their houses, had spent an average of $350 less on equipment and appliances to overcome discomfort, and used 22 per cent less energy than owner-buyers of their houses. The estimated average annual household income in 1975 was $1,135 lower than that of non-rental households.

The period of residence in the house was related both to the assessment of comfort by the householder and to the expenditure on energy-saving and energy-consuming equipment. Table 7.35 shows that the householders most satisfied with the comfort of their houses were those who had moved in before 1959 (thus occupying the same house for fifteen years or more). The least satisfied were those who had moved in after 1970, and these were also the group with lowest average expenditure on energy-saving and energy-consuming equipment, but with highest average household income (Table 7.36).

Conclusion

The various measures of comfort described in this chapter have demonstrated householders' concern for and involvement in the physical comfort of their own homes. In both sample areas there was a relatively high level of weather-induced discomfort and subsequent house-modification to ameliorate conditions. The "most highly satisfied" and "comfortable" householder tended to live in a house of

TABLE 7.35

HOUSEHOLDER'S EVALUATION OF HOUSE COMFORT BY YEAR OF MOVING INTO HOUSE

Householder's Evaluation	Year of Moving in (Percentage of households)				
	Before 1950	1950 to 1959	1960 to 1966	1970 to 1972	1973 to 1975
High or very high	17	25	18	13	14
Moderately high	39	26	16	13	12
Moderate	27	19	23	20	19
Low to moderate	15	12	22	24	20
Low	2	19	23	30	35
Total	100 n = 41	100 n = 92	100 n = 97	100 n = 106	100 n = 104

Source: Householder's Questionnaire (Questions 3 and 14).

Kendall's tau_c (original data) = .1838, s = .0000

TABLE 7.36

AVERAGE HOUSEHOLD INCOME AND EXPENDITURE ON ENERGY-SAVING AND ENERGY-CONSUMING EQUIPMENT AS A FUNCTION OF YEARS OF RESIDENCE

Year of Moving into House	Estimated Average Household Income ($)	Average Expenditure ($) on Equipment		
		Energy-saving	Energy-consuming	Total
Before 1950	3,970	289	338	627
1950-59	6,502	476	484	960
1960-69	6,350	454	472	926
1970-72	8,021	437	308	745
1973-75	7,481	352	293	645

Source: Household Hata.

older style, with verandahs and an insulated ceiling, facing north or south, and above average in size. The head of the household tended to be Australian-born, aged over 60 years and retired. The household had usually occupied the house for many years so that the number of people remaining in the dwelling tended to be small, and expenditure on such comfort-related items as outside awnings, ceiling insulation or air conditioning had often been completed.

Since the nature of housing and the type of householder differed in the two sample areas, there were many significant differences in comfort-related behaviour and assessments. Summer conditions were the major cause of dissatisfaction and house-modification in the Salisbury East sample area[40]. In the southwestern suburbs, however, past and anticipated house modification indicated a desire to overcome both summer and winter discomfort. Only in two respects, namely the nature of air conditioning in the sampled houses and the householders' stated attitudes to Adelaide's climate, were there no significant differences between the two sample areas.

It would be tempting to interpret the expressed dissatisfaction and remedial actions of the sampled householders as an indicator of change in their attitudes towards the role of climatic suitability and comfort. In other words, only after the house has been selected and occupied for a year or more, does the experience of discomfort prompt householders to realize the importance of the "climate factor" and the need to design and construct houses to be thermally efficient from the outset. For a

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40. Although many of the "uncomfortable" rooms described by the householders of Salisbury East were due to lack of heating, relatively little additional heating had been installed.

small minority of householders, there did seem to be some change in attitude, and considerable learning from an "uncomfortable" house. For others, however, discomfort was tolerated, avoided or overcome (by physical alteration to the dwelling) without any associated change in knowledge or understanding. For example, firms selling such products as thermal insulation, heating and cooling equipment, sunshades and verandahs reported that many of their sales to householders were impulsive (such as the high number of room air conditioners purchased during heat waves) or transacted for non-comfort reasons (such as the selection of outside awnings for colour and appearance, rather than to keep the sun off the glass). Furthermore, they suggested, the equipment was often not operated efficiently (evaporative cooling, for example, relies on complete air changes, but some householders still keep all doors and windows firmly closed). Nevertheless, rather than consider climatic suitability and potential comfort during the design, construction and purchase of a house, most householders preferred to rely on relatively costly rectification procedures and/or energy consuming appliances in order to achieve the desired level of indoor comfort.

CHAPTER 8

ENERGY CONSUMPTION IN THE SAMPLED HOUSEHOLDS

Residential dwellings use approximately fourteen per cent of the primary energy consumed within Australia (NCDC, 1977). Until recently, however, relatively little research has been undertaken to investigate patterns of energy use in the home[1]. Studies of household energy use are important not only for making recommendations for ways of reducing the amount of energy used (Smallternatives, 1977; Wheeler, 1977) but also because it is in the home where people develop their patterns of, and attitudes towards, the use of energy (Crossley, 1977a). In this chapter the general nature of energy consumption in the sampled households is discussed, followed by an attempt to build an explanatory model of household energy use.

As explained in Chapter 3, data on the consumption of electricity, gas and heating oil in the sampled households were obtained (retrospectively) for two years, 1974-1975. Data were collected from the energy-supply organizations listed in Table 8.01 for electricity (452 households), gas (334 households) and heating oil (53 households). The primary energy equivalent for each household was calculated using the conversion factors suggested by Ballantyne (1977,22) which were verified by the Electricity Trust of South Australia, the South Australian Gas Company and the South Australian office of the Shell Company of Australia.

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1. Two surveys of household energy use, started in 1978, are still under way. One, of households in South Australia, at the request of the South Australian Energy Council, by the Australian Bureau of Statistics; the other, of "Energy Requirements, Energy Use and User Satisfaction in Houses", financed by the Australian Housing Research Council in Melbourne. Preliminary results of the former survey became available in September, 1979 (Australian Bureau of Statistics, South Australian Office, 1979).

TABLE 8.01

SUPPLY METHOD OF ELECTRICITY, GAS AND HEATING OIL TO DOMESTIC CONSUMERS OF ADELAIDE

Type of Fuel	Name of Organization(s)	Meter-reading or delivery schedule (domestic)	Domestic Tariffs[a]
Electricity	Electricity Trust of South Australia (E.T.S.A)	Meters read quarterly, approximately every 90 days.	'M' or General Purpose used for home heating/cooling, cooking, lighting, refrigeration of food and other uses 'J' or "Off-peak" for storage hot water systems
Gas	South Australian Gas Company (S.A.Gas Co.)	Meters read -monthly, approximately every 60 days.	'111' for Cooking and General Use ('114' Pensioners) '112' Storage Hot Water and Other Uses (45 Litre Capacity and Over) ('115' Pensioners) '113' Space-Heating and Other Uses (Input 26 MJ/h or greater) ('116' Pensioners)
Heating Oil	Ampol Petroleum Ltd BP Australia Ltd Caltex Oil (Aust) Pty Ltd ESSO Australia Ltd Mobil Oil Aust Ltd Shell Co of Australia Ltd	Oil-tank delivery every few weeks during the colder months (April to September) depending on consumer consumption, and, for Shell, "heating degree days"	One tariff, regardless of consumption or type of customer

Source: Energy supply authorities.

a. 'M', 'J', '111' - '116' are accounting codes used by E.T.S.A. and S.A. Gas Co.

Thus

Primary-energy equivalent (GJ) = (kWh of electricity X.014) + (MJ of gas X.00125) + (litres of heating oil X.045)

where GJ = Gigajoule (a unit of energy equal to 10^9 joules)

kWh = kilowatt hour (the commonly used unit of electrical energy, equal to 1000 watt hours).

MJ = megajoule (a unit of energy equal to 10^6 J)

Average Annual Consumption of Energy by the Households

Primary Energy Equivalent

For the 452 households, the primary-energy equivalent varied from 9.99 GJ to 263.51 GJ, with a mean value of 91.96 GJ[2]. This total was influenced particularly by the nature of equipment used for room-heating and by the type of hot-water system. Households with oil-burning heaters, followed by those with reverse-cycle and other fixed electrical heating tended to have the highest average annual energy consumption; households with open fireplaces and kerosene heaters had the lowest. These differences were accentuated by the omission of data on the consumption of solid fuel and of kerosene in the calculation of household energy consumption[3]. Nevertheless, even if such data were

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2. For United Kingdom households, Desson (1976) utilised average 1973 fuel prices and estimated the annual fuel purchase per household. Desson explains (1976, 3) that the average household energy purchase was 85.3 GJ per year compared with 82.9 GJ per year derived from Department of Energy statistics (U.K.). Both figures are slightly lower than the mean obtained in this study.

3. Kerosene and solid fuel were the main heating fuels in 11 and 60 houses, respectively. Thus, for 16 per cent of the sampled households, energy data were incomplete. All but one of these households were in the southwestern suburbs sample area.

available, it is still likely that households using solid fuel and kerosene for room heating would use less total energy than households using other types of fuel and equipment[4].

On the basis of the type of fuel used for room heating, hot water and other uses, the type of "energy-mix" in each household could be specified. For example, a household using a gas fire or gas space-heater[5] for room heating, electricity for hot water, and gas or electricity for other purposes was classified as a "gas-electric" house. The distribution of the seven types of "energy-mix" households in the two sample areas is shown in Table 8.02. The heterogeneous nature of housing in the southwestern suburbs is reflected in the mixture of types, whereas the Salisbury East sample area is dominated by "mainly gas" households (using electricity only for lighting, refrigeration and portable appliances). Table 8.02 also shows that average annual energy

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4. Adelaide householders using solid fuel tend to obtain it (at no cost) from their gardens and other local sources or purchase sacks of briquettes or tonne loads of mallee roots as needed. Kerosene is usually bought in small quantities. Both systems involve more labour than required for gas, oil or electricity. The Australian Bureau of Statistics (1978) Household Expenditure Survey 1975-76 shows that, for 269 sampled households in Adelaide, average weekly expenditure on fuel and power (for the home) was \$3.45. Of this total, \$3.05 (88 per cent) was spent on electricity, mains gas and heating oil whereas 30 cents (12 per cent) was spent on LP gas, kerosene and paraffin, and other fuels.

5. In this discussion, the term "space-heating" is used to describe a fixed room heater, using gas, oil, solid fuel or electricity as the heat-source, and electricity for convection, and effectively heating one or more rooms. Small electric radiators (fixed or portable), kerosene heaters, open fireplaces using solid fuel, and radiant gas fires are excluded.

TABLE 8.02

AVERAGE ANNUAL ENERGY CONSUMPTION BY "ENERGY-MIX" OF HOUSEHOLD

Type of Energy-Mix	Type of Fuel Used for			Number of houses of this type			Average annual consumption of household, primary-energy equivalent (GJ)[b]
	Room Heating (type of appliance)	Hot Water[a]	Cooking, lighting and other appliances	Southwestern Suburbs	Salisbury East	Total	
Natural gas	Gas (fire or space-(heater)	Gas	Gas/Electricity	90	131	221	89.0
Gas-electric	Gas (fire or space-heater)	Electricity	Gas/electricity	18	3	21	116.8
All-electric	Electricity (reverse cycle heating, fixed or portable heaters)	Electricity	Electricity	55	4	59	99.8
Electric-other	Electricity (as above)	Gas	Gas/Electricity	28	3	31	77.9
Oil-other	Oil heater	Gas or electricity	Gas/electricity	44	4	48	131.1
Solid fuel-other	Solid fuel (slow combustion or open fireplace)	Gas or electricity	Gas/electricity	60	1	61	71.6
Kerosene-other	Kerosene (fixed or portable)	Gas or electricity	Gas/electricity	11	-	11	45.0
Total				306	146	452	92.0

Source: Householder's Questionnaire (Question 12), and tariff data from Electricity Trust of South Australia, and South Australian Gas Company.

a. Hot water systems include storage, instantaneous, bath or sink heaters.

b. Primary-energy equivalent (GJ) = (kWh of electricity x .014) + (MJ of gas x .00125) + (litres of heating oil x .045) consumption was highest for "oil-other" houses, followed by "gas-electric" and "all-electric" households: consumption in "mainly-gas" households was closest to average, while consumption in "electric-other", "solid fuel-other" and "kerosene-other" was below average.

Electricity

The average annual electricity consumption for two years for the sampled houses is shown in Table 8.03, with comparative figures from other sources listed below. Consumption in the sampled houses of Adelaide is similar to that of all residential consumers of South Australia, but lower than the average consumption in the households located in the colder climates of Canberra, New Zealand and North America. A steady increase in the average annual consumption of electricity is occurring in most countries: in the United States, for example, the average annual electricity consumption per wired household has increased from 1,800 kWh in 1950, to 3,820 kWh in 1960, and 7,000 kWh in 1970 (Tansil and Moyers, 1974, 375).

In order to investigate further the pattern of annual electricity consumption of the sampled households, the annual general domestic consumption of each household in the sample area was ranked and placed into categories used by the Electricity Trust to describe domestic consumption patterns in South Australia as a whole. These categories, and the percentage of households with their annual consumption occurring within the categories, are shown in Table 8.04. The main difference in the consumption pattern shown in Table 8.04 is between domestic consumers of least electricity (under 1,2000 kWh annually). Within the sample area, 98 per cent of dwellings were detached, all were occupied

TABLE 8.03

AVERAGE ANNUAL ELECTRICITY CONSUMPTION OF VARIOUS HOUSEHOLD GROUPS

Sample location	Number of consumers in sample	Year of calculation	Average annual consumption per household: Secondary energy (kWh)	Average annual consumption per household: Primary-energy equivalent (GJ)
Adelaide - combined samples (southwestern suburbs and Salisbury East)	452	1974	4,180	58.52
	452	1975	4,292	60.09
South Australia - all residential consumers served by ETSA	405,678	1974	4,284	59.98
	417,996	1975	4,559	63.83
Canberra - typical Government house:	12	1976	7,985	111.79
average detached house	not known	1976	8,500	119.00
New Zealand - stratified random selection of domestic consumers (North and South Islands)	2,000	1971/72	7,908	110.71
	2,000	1972/73	7,821	109.49
United States of America - town houses in Twin Rivers, New Jersey	248	1973	16,670	226.7

Source: Electricity Trust of South Australia records and Annual Report, 1976; NCDC (1977) and Tone Wheeler (Personal Communication, 15 May, 1978) for Canberra figures ; Blakeley and Cook (1974) for New Zealand statistics; Grot and Socolow (1974) for data on Twin Rivers, New Jersey.

and no flats or home units were included. Table 8.04 shows that sixty per cent of the sampled households of this study used between 1,200 and 3,600 kWh of electricity annually, for purposes other than water heating. In contrast, flats and home units constitute approximately ten per cent of the 343,273 domestic consumers supplied directly by the Electricity Trust in 1976. Furthermore, the Electricity Trust's categorization (of Table 8.04) included vacant properties and holiday homes, which would contribute to the 17 per cent of domestic consumers with annual consumptions below 1,200 kWh. Apart from this difference in consumers of least electricity, the pattern of annual electricity consumption of the sampled households in 1975 is relatively similar to that of domestic consumers of South Australia in 1976.

Gas

The South Australian Gas Company offers various tariffs according to the nature of appliances and of the householder. For example, a house with a gas cooker, gas fire and gas storage hot-water service (of 45 litre capacity and over) would be placed on tariff '112' (Storage Hot Water, Other)[6]. Table 8.05 shows that the distribution of gas tariffs among the sampled households of the southwestern suburbs is similar to the distribution among the LGA population, and among all Adelaide's domestic gas consumers. Approximately 40 per cent of consumers used the "Cooking and General Use" tariff, 35 per cent the "Storage Hot Water" tariff and 25 per cent the "Space-Heating" tariff. In contrast, the Salisbury East sampled households were atypical of their LGA and of Adelaide, in that 98 per cent used the "Space-Heating" tariff. This primarily resulted from the age and style of the houses, and the inclusion of gas space-heaters during construction.

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6. For pensioner householders a cheaper tariff ('115') would be used.

TABLE 8.04

ANNUAL ELECTRICITY CONSUMPTION OF SAMPLED HOUSEHOLDS AND OF ALL ADELAIDE DOMESTIC CONSUMERS

Annual Electricity Consumption ('M' tariff in kWh)	Percentage of households	
	Sampled houses of Adelaide (1975)	Domestic consumers of South Australia[a] (1976)
Over 9,600	1	3
8,400 to 9,599	2	2
7,200 to 8,399	2	4
6,000 to 7,199	4	5
4,800 to 5,999	8	9
3,600 to 4,799	17	19
2,400 to 3,599	29	21
1,200 to 2,399	31	20
Under 1,200	6	17
Total	100	100
	N = 452	N = 343,273

Source: Electricity Trust of South Australia records.

Chi-square (original data) = 14.924, df = 8, s = .05

a. includes all domestic consumers supplied directly by the Electricity Trust in the State: excluded are areas of the State supplied indirectly by the Trust, any consumers connected to tariffs other than 'M' or 'J', and dwellings with changing tenants.

As expected, the average annual consumption of gas increased as the number of gas-consuming appliances increased. The average use per bill for households on the "Cooking and General Use" tariffs was 12,496 MJ, increasing to 26,357 MJ for households on the "Storage Hot Water, Other

TABLE 8.05

GAS TARIFFS OF SAMPLED HOUSEHOLDS AND OF THE POPULATION OF L.G.A.'S AND THE ADELAIDE STATISTICAL DIVISION (HOUSES WITH GAS ONLY)

Metropolitan Tariff (Domestic)[a]	Southwestern Suburbs (1974)		Salisbury East (1975)		Adelaide (1975)
	Percentage of sampled households	Percentage of L.G.A. Population[b]	Percentage of sampled households	Percentage of L.G.A. Population[c]	Percentage of Population of all L.G.A.'s
'111' (Cooking and General Use)	33	35	-	22	33
'112' (Storage Hot Water, Other)	32	32	2	36	30
'113' (Space-Heating, Other)	18	16	96	39	21
'114' (Pensioners - Cooking)	6	9	-	1	8
'115' (Pensioners - Storage Hot Water)	10	6	-	2	6
'116' (Pensioners - Space Heating)	2	1	2	1	1
Other	-	1	-	0.3	1
Total	100 n = 199	100 N = 38,463	100 n = 135	100 N = 12,512	100 N = 177,375

Source: S.A. Gas Company data.

a. '111' - '116' are accounting codes used by S.A.Gas Co.

b. L.G.A. Population of Brighton, Marion, Mitcham and Unley.

c. L.G.A. of Salisbury.

Uses" tariffs, and to 42,612 MJ for households on "Space-Heating, Other" tariffs. A similar increase occurred among all metropolitan gas consumers on these tariffs (South Australian Gas Company, unpublished data).

Heating Oil

The annual consumption of heating oil in sampled households varied from 100 to 2,078 litres, with an average of 939 litres. This was lower than the average household consumption estimated by two heating oil companies of approximately 1,200 to 1,500 litres annually. This higher average estimate for Adelaide as a whole may have resulted from the greater frequency of householders with oil-burning heaters and oil-fired furnaces in the foothills and hills suburbs.

Gas and Electricity in the Same Household

Seventy-four per cent of the sampled households used both gas and electricity. In their study of townhouses in New Jersey, Grot and Socolow (1974,488) were surprised to find a total lack of correlation between winter gas and winter electric consumption in the same unit. In a scatterplot of 152 units, the coefficient of correlation was 0.24 which, they suggest, resulted from two contradictory "explanations": first, those who are profligate with one energy source will be profligate with another; second, more heat generated by electricity means less heat generated by gas, since both are operating.

Both explanations can be offered in this study, where the coefficient of correlation between winter gas and winter electricity in the same household was -.046 (significance .204), and, for annual gas and electricity consumption in the same household -.053 (significance .167). The complete lack of correlation is an indicator of the unpredictable nature of household energy use.

Percentage of Annual Energy Consumed for Various Purposes by the Household

The most detailed study of energy use in Australia (Institution of Engineers, 1977) shows that there is a fairly constant amount of energy consumed per capita for hot water, light, power and cooking, and that the amount of energy consumed for space heating is positively correlated very closely with the coldness of the climate. Thus, for the temperate cities of Australia, the highest proportion of primary energy is used for space-heating, followed in equal parts by water heating and other energy needs such as lighting, cooking, refrigeration. Their study suggests that, for Adelaide, these ratios are 46:27:27, whereas the severe winters of Canberra and Hobart change the ratio to 60:20:20. For South Australia as a whole, 31 per cent of domestic energy is used for space heating or cooling, 37 per cent for water heating, and 32 per cent for other uses: these percentages are close to the national averages of 26, 39 and 35 respectively.

In this study, the actual amounts of total energy used for space-heating, hot water and other requirements were known only for a small minority of households, such as those using oil for space-heating, off-peak electricity (the 'J' tariff) for a storage hot water system, and electricity (the 'M' tariff) for other purposes such as cooking, lighting and refrigeration of food. Nevertheless, for each type of "energy-mix" in the household, it was possible to predict ratios of energy consumption according to the type of fuel used for room heating, hot water and other purposes and compare these ratios to actual measurements. This enabled the validity of the ratio suggested for Adelaide by the Institution of Engineers (1977,218) to be tested, namely that 46 per cent of household energy is used for space-heating, 27 per cent for water heating and 27 per cent for other needs. For example, in a "mainly gas" house, in which gas is used for room heating, hot water and cooking, and electricity for all other needs, the household's gas consumption should be (46 + 27) per cent (or more) of the total household energy, with electricity the remaining 27 per cent (or less). In the 221 "mainly gas" households of this sample, the mean ratio of gas consumption to electricity consumption was 56:44. This suggests that, either the general ratios are incorrect[7], or that these householders are using a disproportionately high amount of electricity. (It should be remembered that, in many houses electric heating is likely to be used on occasions even though the main heating is by gas or oil and, furthermore, 40 per cent had some form of air conditioning). The expected and measured findings for the various types of "energy-mix" of household are shown in Table 8.06.

A close agreement between the expected and actual ratios of energy consumption occurred in the group of households using electricity for all or most purposes, the "all-electric" and "electric-other" house. This indicates that the percentages of annual consumption used for various purposes within the household, suggested in the Institution of Engineers Report (1977, 218), apply best to the "all-electric" and

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7. A recent article on the cost of running household appliances in Adelaide (Townsend, 1979) suggests that in a "mainly gas" home, gas for space-heating costs approximately $3.60 per week, for a fast recovery hot water service $1.80 per week and for cooking an average of 80c per week. All other appliances (excluding lights) cost approximately $3 per week to operate. This suggests ratios, for a "mainly gas" home (including lightings) of 36:18:45 for space heating, hot water and other uses. The ratios are close to the findings of this study.

TABLE 8.06

PERCENTAGE OF ANNUAL CONSUMPTION USED FOR VARIOUS PURPOSES WITHIN THE HOUSEHOLD: EXPECTED AND ACTUAL FINDINGS BY "ENERGY-MIX" OF HOUSEHOLD

Type of "Energy-Mix" in Household	Number of Houses	Expected percentage used for various purposes	Findings: expected	Findings: actual
All houses	452	46% of total energy used for space-heating, 27% for water heating, 27% other needs.	-	-
Mainly gas	221	Gas (for room heating and hot water and cooking) 75% (or more) of total; electricity 25% (or less).	Gas:electricity 75:25	56:44
Gas-electric	21	Gas (for room heating, some cooking) 45-50% of total; electricity (for water heating and other needs) 50-55%.	Gas:electricity 47:53	20:80
All-electric	59	'M' tariff consumption (for room heating and other needs) approximately 70% of total; 'J' tariff consumption (for hot water) 30%.	'M' tariff:'J' tariff 70:30	67:33
Electric-other	31	Electricity (for most room heating and other needs) approximately 70% of total; other fuels (for hot water, some cooking) 30%.	Electricity:other fuels 70:30	71:29
Oil-other	48	Oil (for room heating) 46% of total; other fuels 54%.	Oil:other fuels 46:54	34:66
Solid fuel-other	61	Solid fuel not known; average use of gas and electricity lower than mean for all houses.	Household energy (GJ) <92.0	72.1
Kerosene-other	11	Kerosene not known; average use of gas and electricity likely to be lower than mean for all houses.	<92.0	45.0

Source: Derived from energy data.

"electric-other" houses. For other types of "energy-mix" households in Adelaide, the percentage of annual consumption used for space-heating appeared to be lower than the suggested 47 per cent. Without intricate, separate metering of the household's use of energy for particular purposes, it is not possible to specify the actual percentage used solely for space-heating.

Seasonal Pattern of Energy Use

The heating or cooling required to maintain a comfortable indoor temperature in a building depends partly on its design, structure and size, and partly on the external climate and fluctuations in the weather. Maunder (1970) cites many studies which clearly indicate the significant effect of weather and climatic conditions on the consumption of electricity, gas and heating oil. These studies show temperature to be the most important weather element affecting energy consumption, although wind speeds, cloud cover, length of daylight and rainfall have notable multiplier effects. People change their energy-related behaviour according to the weather and climate, such as increasing their winter-time consumption of hot foods and drinks, and of hot water for baths and for laundry[8].

In this study the seasonal pattern of electricity and gas consumption was investigated in order to evaluate the effect of seasonal weather, and to determine the most important meteorological variable related to seasonal energy use. The quarterly electricity and bi-monthly gas consumption (over a two-year period) for each household was tested for

8. Long term climatic changes also affect fuel requirements. By using a method of "degree months" Manley (1957) was able to show considerable seasonal variation in interior heating requirements in Britain since 1700.

linear correlation with seven meteorological variables calculated for the same period as the meter readings. Five of these meteorological variables (detailed in Table 8.07) were related to air temperature, the remaining two were rainfall and degree days [9]. Their monthly values during 1974 and 1975 are shown in Appendix V, p. 431.

The direction of the coefficient's signs differed for gas and electricity. The seasonal consumption of households using gas always showed a negative correlation with temperature data, and positive with rainfall and degree days, indicating a higher gas consumption during the colder, wetter months of the year. Electricity users were far less uniform. Only 58 per cent of households had quarterly consumptions which indicated more electricity being used during the winter months. Of the remainder, the electricity consumption of 19 per cent of households showed a positive correlation with temperature data, and negative with rainfall and degree days, indicating that more electricity was being used during the summer months.

The tendency for Adelaide consumers to be using increasing amounts of electricity during the summer months is related to the ownership and operation of air conditioning. It is part of a national and world-wide trend, associated with increasing affluence, increasing consumer spending and an increasing expectation of higher thermal comfort standards (Ballantyne, 1975). Until 1976 the maximum load on the Electricity Trust of South Australia's interconnected system had always

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9. "Degree days" are defined on p. 17. Calculations (for Adelaide) by Shell Oil, Birkenhead, South Australia using a base-temperature of 18.3°C (65°F) and adding 1.67° for a daily minimum of 4 mm of rain. Daily maximum and minimum temperatures measured at the Adelaide Bureau of Meterorology were used to calculate the departure of the mean temperature from 18.3°C. The annual totals for 1974 and 1975 were 1,074 and 1,028 heating degree days respectively.

TABLE 8.07

SUMMARY OF CORRELATIONS BETWEEN HOUSEHOLD ELECTRICITY AND GAS CONSUMPTION AND SEVEN METEOROLOGICAL VARIABLES (WINTER MAXIMUM USERS ONLY)

Meteorological Variable		Total number of houses recording a negative correlation with temperature data, positive with rainfall and degree days	Number of houses with correlation 0.8 or more (and significance 0.05 or less)	Houses with correlation 0.8 as percentage of total
Mean 0900 temperature (°C)	Electricity	315	108	34
	Gas	325	204	63
Mean 1500 temperature (°C)	Electricity	314	104	33
	Gas	325	205	63
Mean daily maximum temperature (°C)	Electricity	307	105	34
	Gas	325	207	64
Mean daily minimum temperature (°C)	Electricity	307	78	25
	Gas	325	202	62
Mean quarterly or bi-monthly temperature (°C)	Electricity	313	103	33
	Gas	325	207	64
Rainfall (mm)	Electricity	320	85	27
	Gas	325	28	9
Degree-days	Electricity	324	122	38
	Gas	325	194	60

Source: Calculated, using Pearson's 'r', from data provided by the Electricity Trust of South Australia, South Australian Gas Company, Bureau of Meteorology (Adelaide) and Shell Oil (Birkenhead, S.A.).

occurred during the early evenings of the winter months. This position was reversed, for the first time, in the summer months of 1976-77, reflecting the marked increase in the number and operation of domestic air conditioners discussed in Chapter 7. Approximately 24 per cent of sampled householders owned some form of fixed air conditioning, with a further 11 per cent owning a portable evaporative air cooler. Operation of these appliances would account for the 19 per cent of households using more electricity during the summer months.

Twenty-three per cent of sampled households used electricity in an ill-defined or irregular seasonal pattern during 1974-75. This irregular seasonal use of electricity helps to explain the generally low level of correlation between the quarterly readings and the selected meteorological variables. A correlation coefficient of 0.8 or more (and a significance level of 0.05 or less) was chosen to indicate a strong linear relationship between the electricity or gas consumption figures and meteorological conditions. Table 8.07 shows that, for winter-maximum users only, the number of sampled households in which quarterly electricity consumption showed a high level of correlation with the selected meteorological data used was only twenty to thirty per cent of the total. The meteorological variable providing the highest number of correlations greater or equal to 0.8 with quarterly electricity consumption was degree-days.

Correlation coefficients between gas consumption and meteorological data were generally higher. The number of sampled households in which bi-monthly gas consumption showed a high level of correlation with the selected meteorological data was usually 60 per cent or more of the total. The meteorological variables providing the highest number of correlations greater or equal to 0.8 were the mean daily maximum, and mean bi-monthly temperature. For both electricity and gas consumption, rainfall data provided the lowest levels of correlation. Thus, for both electricity and gas, seasonal consumption was not closely related to seasonal meteorological phenomena for one third to half of the sampled households[10].

The lack of close correlation results partly from the quarterly or bi-monthly interval between meter readings, and partly from the varied nature of equipment consuming energy on one tariff. In an attempt to counteract this latter feature, a separate analysis of Salisbury East households on the gas space-heating tariff ('113') did reveal an average correlation coefficient of .896 with degree days. The South Australian Gas Company recognizes the importance of meteorological data by using degree-day calculations in its estimates of load requirements. Both the Gas Company and the Electricity Trust of South Australia obtain specially designed "load" forecasts from the Bureau of Meteorology, Adelaide, four times daily[11].

The small number of oil-heated houses, and the lack of detailed delivery data from the five heating oil companies involved, precluded an analysis of the effect of meteorological conditions on heating oil consumption. Only one Adelaide oil company uses heating degree days in its predictive calculations of customer requirements. There seems to be

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10. This differs from the finding of Grot and Socolow (1974) who, in their study of energy use in town houses in New Jersey, found that "The correlation coefficient between the average consumption of gas in the split-level town houses and the monthly degree days (adjusted for actual dates of meter reading) is 0.997, calculated from 12 months of data."

11. The Electricity Trust also graphs the relationship between the official (dry bulb) air temperature and electricity load, from which an outdoor temperature of 27°C is suggested as the "trigger" for the first operation of air conditioning systems in the home.

sufficient evidence from this study to indicate that daily temperatures and degree days should be incorporated in the estimation of all household energy requirements in Adelaide.

An Operational Model of Household Energy Consumption in Adelaide

The preceding discussion has suggested some of the reasons for the variation in household energy consumption. An attempt is now made to build an explanatory model of household energy consumption, using regression analysis to construct a causal system. Such an approach is based on the assumption that there are a number of recognized factors which normally account for the variance in household energy consumption, and that these can be measured and evaluated for a particular group of sampled houses. Nevertheless, the development of a theoretical framework for relating an essentially qualitative phenomena (life style) to one that, while partly qualitative, can still be quantified (energy use), should be approached with caution.

Analytical techniques used in previous studies of household energy use have ranged from the descriptive, bi-variate techniques of Newman and Day (1975) and the United States, Federal Energy Administration (1976), to factor analysis used in the attitude surveys of Phillips (1976) and Crossley (1978) and to the simple regression used by Grot and Socolow (1974)[12]. In a New Zealand study (New Zealand Department of

12. Although the authors called it multiple regression, it seemed to be an attempt to select nearly identical subsets of households to demonstrate a reduction in the variability of gas and electric consumption. Even after the effects of five design/structural features were "factored out," considerable variation in energy consumption remained.

Statistics, 1976) multiple regression techniques were used in the preliminary analysis to isolate several variables (that is, household and dwelling characteristics) which directly influenced the electricity consumption for portable appliances, lights and heaters. An analytical tool "Automatic Interaction Detection" (A.I.D.) was used to further analyse the data, particularly the effect of ceiling insulation on energy consumption of the household[13].

The Dependent (or Criterion) Variable - Household Energy Consumption

The nature of the dependent variable, household energy consumption was constrained by the data available. The closest approximation was the average "primary-energy equivalent", calculated (using the method described at the beginning of this chapter) from the annual totals of electricity, gas and heating oil. Of necessity, the average annual total was selected, due to computation difficulties resulting from quarterly and bi-monthly meter readings for electricity and gas, respectively, and irregular heating oil deliveries.

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13. A.I.D. (originally developed by the University of Michigan) sequentially identifies and segregates subgroups of the data, in order to select the set of subgroups which will maximise the reduction in the prediction error of the dependent variable relative to the number of groups. Thus, A.I.D. can be used to measure the extent to which the variation in dependent variable is explained, identify the main factors influencing a particular dependent variable, and indicate the direction of the effect tht different categories of these factors have on that dependent variable. However, the sample size must be sufficiently large to be divided into a mutually exclusive series of subgroups through a series of binary "splits," while retaining credibility and stability within the subgroup. In the New Zealand survey, a sample of 1,323 houses was "split" into 19 groups (the result of which did reveal the anticipated higher electricity consumption in an uninsulated dwelling).

In developing an operational model it is often impossible to obtain suitable measures for some effects even though they can be specified. In the case of other factors the effect is exogenous to the system so it cannot be explicitly included in the model. This seems an appropriate stage of the discussion to unearth some of these effects which are commonly referred to as predetermined factors.

Predetermined Influences on Household Energy Use

Theoretically Adelaide householders can select from any of the five major fuels (electricity, gas, solid fuel, oil, kerosene) for heating, and electricity or gas for hot water and cooking[14]. In practice, however, most householders use one or two types of fuel. One factor influencing choice is the geographic availability of the fuel. Natural gas, for example, is not available in the foothill suburbs of Adelaide, nor in certain sections of the Adelaide Plains. Some householders can easily gather firewood from the local area: others prefer to purchase their fuel in advance (by using heating oil, kerosene, briquettes or mallee roots) rather than pay bi-monthly metered gas or quarterly electricity accounts. The overwhelming influence, however, results from the installation of major energy-consuming appliances (the hot water service and room heating equipment) during construction of the house. Only a small percentage of householders have any influence on the design of their houses. For most, the major appliances are there when the householder buys or rents the dwelling: alterations are often difficult or expensive to implement.

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14. Although readily available in Adelaide, none of the sampled houses used solar hot water systems.

The basic level of household energy use for heating (and for cooling) is determined by the structure of the dwelling itself and by the climate. Previous research (Institution of Engineers, 1977, 218) has shown that, for the temperate cities of Australia, the amount of energy consumed for space heating can be positively correlated with the coldness of the climate (coldness as measured by degree days to the base 18.3°C). Since domestic energy costs for cooking, lighting, hot water and appliances are assumed to be relatively constant throughout Australia, the percentage of the annual energy-bill used for winter space heating is partly predetermined[15]. Similarly, the broad requirements for summer cooling can be estimated from the nature and extent of hot weather in Adelaide.

Energy consumption is also influenced by the general design and construction of a building, by such factors as its' size and shape, its' relationship to other buildings (whether it is detached, semi-detached or terraced), the number of storeys, and the nature and insulation of the roof, wall and floor material. Despite some variation in plan-shapes, amount of glass and other design features, Adelaide house-structure is relatively homeogeneous - predominantly one-storey, detached, averaging 110 square meters of heavy-weight construction, with a tiled roof, timber floor and no insulation incorporated while being built. This relative homogeneity reduces the range in energy consumption which can be attributed to the structure alone.

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15. The effect of the "coldness of the climate" on annual electricity consumption can be seen in Table 8.03.

The Independent Variables

The selection of the explanatory variables was influenced by theoretical considerations as well as by surveys related to household energy consumption[16]. Conceptual or empirical bases for the relationship between each determinant and household energy consumption are discussed, prior to developing a causal system for the sampled houses in Adelaide. The variables under consideration can be divided into two groups; those related to the structure of the house and those related to the nature of the household.

Variables Related to the Structure of the House. There is general agreement that household energy consumption (particularly for space-heating) is related to the size of the dwelling, building design and aspect, the type of fuel, percentage of dwelling heated, the quantity of insulation and the chosen operating mode for heating (Ballantyne, 1975a; Walsh, 1976a; Coldicutt, 1977; NCDC, 1977; Lacey, 1978). The effect of the size of the dwelling, structural features of the house, major appliances and equipment, and the "measured" climatic suitability of dwellings on total average annual consumption of the sampled households is discussed below.

(i) Size of the dwelling: Table 8.08 shows that the average household energy consumption increased steadily as the number of main rooms increased, to the extent that the total energy used in houses with eight or more rooms was double that used in four-roomed houses, with a similar

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16. For example, O'Brien (1973) calculated up to 40 per cent reduction in heating load in houses insulated with 50 mm of mineral wool, whereas Blakeley and Cook (1974) showed that insulated houses of New Zealand used, on average, more electricity than uninsulated houses.

increase in the annual use of electricity[17]. Average annual use of gas was highest for six-roomed houses, influenced by the high number of gas space heaters in the sampled houses of Salisbury East, most of which had five or six main rooms. Nevertheless, a variable to describe the number of main rooms in the house was an obvious regressor to include.

TABLE 8.08

ANNUAL ENERGY CONSUMPTION AS A FUNCTION OF HOUSE SIZE

Number of main rooms	Sample size	Average Annual Consumption: Electricity (kWh)	Gas (MJ)	Primary-Energy Equivalent (GJ)
Four	25	2,779	12,075	54.6
Five	177	3,606	23,735	83.4
Six	161	4,147	26,055	93.2
Seven	57	5,597	19,812	109.0
Eight or more	32	6,880	23,981	132.0
All houses	452	4,236	23,439	92.0

Source: Household and Energy Consumption Data.

(ii) The structural features of the house: Evidence of the effect of house structure on household energy consumption is provided by the studies of Grot and Socolow (1974)[18], Williamson and Coldicutt

17. Other studies which illustrate the effect of house size on energy consumption include that of Grot and Socolow (1974) who demonstrate that the average winter gas consumption (in their sample of 400 townhouses) increased as the number of bedrooms increased and Crossley's (1978) finding of a statistically significant association between three behavioural indices (such as the total cost of household energy supplies for the preceding twelve months) and the number of rooms in the house.

18. In their study of the energy consumption of 400 townhouses, Grot and Socolow (1974) discuss the effect of such structural features as "Thermopane"(double glazed) windows, architectural style, orientation and the presence of an "end wall".

(1974)[19] and Newman and Day (1975)[20]. In this study, as Table 8.09 shows, energy consumption was related to many structural features. The average annual primary-energy equivalent was highest for houses with brick veneer walls, tiled roofs, medium- sized windows, wider eaves and complex plan-shapes, whereas least annual energy was consumed in houses with stone walls, galvanised iron roofs, small windows, no eaves, and L-shape or square plan-shapes. Individually, these five variables explained less than five per cent of the variance in household energy consumption (R^2 = .05) and, furthermore, multicollinearity was inevitable. An attempt to combine several attributes into one variable "House style and age" yielded considerable increase in the level of explanation (R^2 = .213)[21]. Table 8.10 shows that highest average annual electricity consumption occurred in houses built between 1947 and 1965 (including Austerity, L-shape, S.A.H.T., and Conventional styles).

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19. Williamson and Coldicutt (1974) developed a computer program to calculate the thermal performance of a typical project house in Melbourne and a modified thermally improved version. The improved house needed only one-third the annual heating requirement of the typical house, and could achieve summer comfort by the use of exhaust and internal fans only (rather than by the use of evaporative cooling or reverse cycle air conditioning).

20. Newman and Day (1975) stress that most of the structural features which affect energy consumption in typical American households (such as a row house compared to a detached dwelling, the square feet of floor space, the type of roof and foundation, the openings in the building, the type of windows and the extent of weather-stripping and insulation) are determined at the time of construction, and may be difficult and expensive to change.

21. The use of multiple regression for explanatory purposes means that most of the formal assumptions of the linear regression model still have to be met (Poole and O'Farrell, 1971, 148-149) but that the objective is to maximise the amount of variation in the dependent variable accounted for by the independent variable set (maximising R^2) subject to significant regression coefficients. Thus the net effect of each independent variable on the dependent variable, when all the other independent variables are held constant, can be stated in terms of its "contribution to R^2".

TABLE 8.09

ANNUAL ENERGY CONSUMPTION OF HOUSEHOLD AS A FUNCTION OF STRUCTURAL FEATURES OF THE HOUSE

Feature of House	Sample size	Average Annual Consumption		
		Electricity (kWh)	Gas (MJ)	Primary-Energy Equivalent (GJ)
Material of outer walls:				
Brick veneer	27	3,970	33,580	99.7
Brick cavity	303	4,017	25,909	91.6
Brick and stone	70	4,924	15,960	93.3
Stone	26	4,762	14,279	86.5
Other	26	4,685	13,423	90.3
Material of roof:				
Tiles	340	4,336	25,872	96.7
Galvanised iron, other	112	3,930	16,052	77.7
Ratio window to wall:				
High	128	3,634	36,159	95.8
Medium	177	4,900	20,256	98.8
Mixture	24	3,951	19,590	89.0
Low	123	3,962	15,534	78.7
Width of eaves:				
>3 ft wide	28	5,183	18,796	95.7
1½-3 ft wide	263	4,034	29,075	95.1
<1½ ft wide	147	4,517	14,700	87.8
None	14	3,172	18,601	69.4
Shape of House:				
Complex, other	57	5,145	26,898	108.9
Elongated	63	3,778	32,811	95.1
L-shape	52	4,311	21,305	87.4
Square	280	4,140	21,022	88.6

Source: Household and Energy Consumption Data.

Households living in the "Symmetrical Front" style of house and villas built before 1905 were relatively high users of both electricity and gas, and thus total energy (the primary-energy equivalent). Average annual use of gas was highest among households living in new houses (built after 1966) but the total energy use (gas, electricity and oil) was highest in houses built between 1952 and 1965. In the regression analysis, however, most of this explanatory power of "House style and age" was lost once other variables were included in the regression equation, particularly those relating to the major appliances of the house, the number of occupants and the household income.

Thus "House style and age" - a variable based on the material of outer walls, roof material, size of windows, width of eaves, other shading features, the shape, age and general architectural style of the house - was not included in the model, once other, less complex variables could be used. The variable "Year of Construction" was also rejected since it encompassed only some of the structural features considered important[22].

(iii) Major appliances and equipment: Newman and Day (1975,xxiv) stress that architectural design, the furnace and the water heater were the most energy related features of the typical American household. Their

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22. The relationships do, however, suggest the possibility of deriving a spatial pattern or map of Adelaide showing levels of household energy use. In their New Zealand study, Blakeley and Cook (1974, 12) were able to show that total electricity consumption was higher in urban areas than in rural ones.

TABLE 8.10

ANNUAL ENERGY CONSUMPTION OF HOUSEHOLD AS A FUNCTION OF HOUSE STYLE AND AGE

House Style and Age	Sample Size	Average number of persons	Average Annual Consumption		
			Electricity (kWh)	Gas (MJ)	Primary-Energy Equivalent (GJ)
Symmetrical Front and Early Villas, 1850-1905	35	3.5	4,857	19,610	93.0
Later Villas, Bungalows and Tudor, 1905-1945	69	2.8	3,638	14,302	72.4
Austerity, 1946-1952	66	3.0	4,971	9,956	91.4
S.A.H.T., L-Shape, Conventional, 1952-1965	126	3.3	5,084	17,784	97.9
New, 1966-1974	156	4.0	3,364	38,612	95.8
Total	452		4,236	23,439	92.0

Source: Household and Energy Consumption Data.

study, and others, demonstrate the importance of the type of fuel[23] and the number and nature of appliances[24]. Nevertheless, Newman and Day, (1975,xxiv) caution that the judgement of energy use based on the number of major appliances in a house is only right because the presence or absence of major appliances is a key indicator of total energy consumption and is linked chiefly with income. Crossley (1978) also stressed the link between the number of people in the household, the expenditure on energy, the number of energy-using appliances available for use by the household, the total power rating of these appliances and household income.

Of the major appliances and equipment affecting energy use in the sampled households, four are discussed below.

* Main method of room heating: Figure 8.1 shows how the annual consumption of secondary energy was related to the main method of room heating in the house. High electricity consumption occurred in houses with reverse-cycle heating, fixed or portable electric heating[25] or

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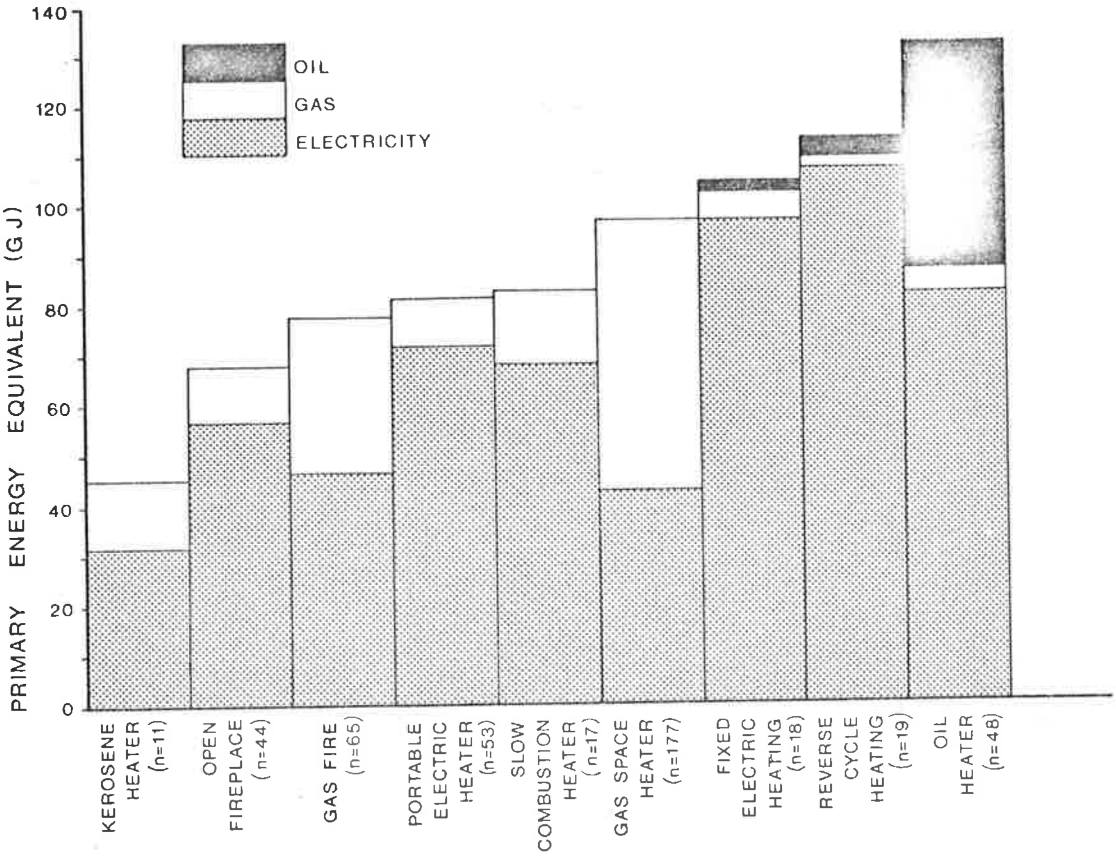
23. All other things being equal, an electrically heated home requires about twice as much fuel per unit of heat as a gas or oil heated home (Newman and Day, 1975, 35).

24. In New Zealand houses, Blakeley and Cook (1974, 11) show that the use of electricity was increased by the number of heaters (fixed and portable) and by the possession of particular appliances, notably clothes dryers. Maadah and Maddox (1976, 237) calculate the energy usage of almost every type of appliance, and conclude, "In the typical American home of 1,500 square feet and a family of four persons ... home heating and cooling, water heating and refrigeration of foods account for 80% of home energy use".

25. Since, for the same consumption of electricity, reverse-cycle heating provides at least twice as much heat as any element type of heater, the sampled households using reverse-cycle heating as the main method for rooms must have, presumably, been heating larger volumes of air, for longer periods and/or living at higher indoor temperatures.



SOURCE : Household and Energy Data

FIG. 8·1 ANNUAL CONSUMPTION OF ELECTRICITY, GAS AND HEATING OIL OF SAMPLED HOUSEHOLDS, CLASSIFIED BY MAIN ROOM-HEATING EQUIPMENT (N=452) oil-burning heaters, whereas houses with gas space-heaters or gas fires had the expected high annual gas consumption, and houses with oil heaters the expected high oil consumption. Lowest annual electricity consumption occurred in households using kerosene heaters, and lowest gas consumption in households using oil or reverse-cycle heating.

Thus, as Table 8.11 shows, combined energy consumption of the three fuels was highest in houses using oil as the main heating fuel; electrically-heated and gas-heated houses were closest to average, whereas those houses using solid fuel or kerosene used least energy. Households with space-heating (of any type) used slightly less electricity, but an additional 17,000 MJ of gas and 26 GJ of primary-energy equivalent than those households with no space-heating; about a third of the sampled houses had gas space-heaters.

* Hot water systems: Electrical storage hot water services were high users of energy in this survey and in others (see Newman and Day, 1975, 53). It is widely accepted that the amount of hot water used varies with the number of people in the household and the nature of appliances, such as automatic washing machines. No data were collected in this survey on the possession and use of water-using appliances, or the demand on the hot water supply by baths, showers and laundering of clothes. Nevertheless, Table 8.11 indicates that the presence of a storage hot water system (especially if electric) is an important contributor to total household energy consumption.

* Air conditioning: Electricity consumption is increased by the operation of an air conditioning unit. Table 8.12 shows that households with (fixed) air conditioning used, on average, 1,700 kWh more electricity but 3,000 MJ less gas annually, and thus only an additional

TABLE 8.11

ANNUAL ENERGY CONSUMPTION OF HOUSEHOLD AS A FUNCTION OF MAJOR APPLIANCES OF THE HOUSE

Major Appliance	Sample size	Average Annual Consumption		
		Electricity (kWh)	Gas (MJ)	Primary-Energy Equivalent (GJ)
Main Room Heating Fuel:				
Gas	242	3,225	38,014	91.4
Electricity	90	6,160	5,727	92.3
Oil	48	5,968	3,785	131.0
Solid Fuel	61	4,389	9,492	71.6
Kerosene	11	2,313	10,819	45.0
Space-heating:				
Present	261	4,141	30,469	103.0
Absent	191	4,365	13,833	76.9
Type of Hot Water Service:				
Storage electric	106	7,634	4,690	123.0
Storage gas	255	2,980	36,728	87.8
Other or none	91	3,795	8,042	67.4

Source: Household and Energy Consumption Data.

13 GJ of primary-energy equivalent than households with no air conditioning.

*Ceiling insulation: Theoretically, ceiling insulation is regarded as a means of reducing household energy consumption. However, Table 8.12 shows that households living in insulated houses used 17 per cent more electricity, 9 per cent more gas and 12 per cent (11 GJ) more primary-

TABLE 8.12

ANNUAL ENERGY CONSUMPTION OF HOUSEHOLD AS A FUNCTION OF FIXED AIR CONDITIONING AND CEILING INSULATION

Feature of House	Sample size	Average Annual Consumption		
		Electricity (kWh)	Gas (MJ)	Primary-Energy Equivalent (GJ)
Reverse-cycle air conditioning	81	5,644	20,138	105.2
Refrigerated, evaporative air conditioning	43	4,303	23,264	94.2
No air conditioning	328	3,883	24,180	88.4
Insulated ceiling	210	4,584	24,490	97.7
No ceiling insulation	242	3,933	22,527	86.9

Source: Household and Energy Consumption Data.

energy equivalent than households living in uninsulated houses[26].

The problem arose as to which of these many variables to include in the regression model, remembering that independence needed to be maximised, without sacrificing variables of conceptual relevance (Blalock, 1963). If, for example, the variable "energy-mix" of the

26. The fact that the supposed "energy-saving" feature of ceiling insulation was not evident in this study reflects the findings of two surveys in New Zealand. Blakely and Cook (1974) attribute the higher use of energy in the insulated houses of their study to the heating of more rooms than in uninsulated houses. Phillips (1976) suggests a link between high income earners, the presence of insulation in the roof of their dwellings, and a tendency to have higher ownership rates for various consumer durables (such as a deep freeze or automatic washing machine) as well as the habit of heating the whole house, rather than individual rooms. The relationship between ceiling insulation and household energy consumption in this study is discussed elsewhere (Kerby, 1977a, 1979).

household had been selected (see Table 8.02), a variable based on the type of fuel used for room and hot water heating, this would imply the presence of space-heating or a storage hot water system for some types of "energy-mix" but not for others. The variable "Main type of room-heating equipment" (see Figure 8.1) seemed too complex, with its nine categories. Some high inter-correlations seemed inevitable.

The best solution seemed to be inclusion, initially, of type of heating fuel, the presence of space-heating and the type of storage hot water service. Therefore, seven "dummy variables" were created to describe the use of gas, electricity, oil and solid fuel as the main type of heating fuel, the presence of a space-heater (regardless of the type of fuel), and the presence of a gas or electric storage hot water service[27]. Variables indicating the presence of fixed air conditioning and of ceiling insulation were included on a trial basis.

Because the distribution pattern of these major appliances and of ceiling insulation in the sampled households of the southwestern suburbs was so different from the distribution in Salisbury East, it soon became apparent that the development of separate operational models would be necessary. To attempt to collectively analyse households from the two sample areas would have violated two of the basic assumptions of the linear regression model, that of normality, and that of homoscedasticity (Poole and O'Farrell, 1971).

(iv) <u>"Measured" climatic suitability of dwellings:</u> An index of climatic suitability was developed, and each sampled house given a summer, winter

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27. The creation of dummy variables for the purpose of including nominal variables in a multiple regression procedure is a recognized procedure described in detail in Nie et al. (1975, 374-378). The newly created dichotomous variables were assigned the arbitrary scores of 1 if present, 0 if absent.

and overall "score" (See Chapter 6). These variables were included in the regression model on a trial basis, but explained less than three per cent of the variance in household energy consumption (Overall climatic suitability score, $R^2 = .024$). This was partly because the "score" was based on such items as ceiling insulation or other structural features, and partly because there was a non-linear relationship between the overall climatic suitability score and annual household energy consumption. The climatic suitability scores were, therefore, not included in the model.

Variables Related to the Nature of the Household. Most previous studies of energy use patterns stress the importance of household characteristics such as the number and ages of persons in the dwellings, their occupations, ethnicity and attitudes (Blakeley and Cook, 1974; Newman and Day, 1976; Crossley, 1978).

(i) Number and ages of occupants: Several surveys (Blakeley and Cook, 1974,12; Newman and Day, 1976,xxv; Australian Bureau of Statistics, 1977; Crossley, 1978) demonstrate that total household energy consumption increases as the number of occupants of dwellings increases, although the rate of increase tends to become smaller with an increasing number of occupants[28]. Grot and Socolow (1974), however, found that family size and family income were inversely correlated and that there was no statistically significant correlation with either winter gas or winter electric consumption and either family income or family size.

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28. This is demonstrated by the Household Expenditure Survey (Australian Bureau of Statistics, 1977). Average weekly expenditure by Adelaide householders on fuel and power (for the home) increased from \$1.76 in a one-person household, to \$2.57 for two adults (no children), \$3.48 for a household containing two adults and two children, to \$3.92 for a household containing three adults and one child or more.

In this study, household energy use was related to the number of persons in the household, the age of the head of the household and the number and ages of the children. The four variables were strongly interrelated, since all are associated with the stage of the life-cycle. When family earning power is at its peak, children are usually still at home; household size is greatest then, and so is energy consumption. Table 8.13 indicates that this peak tended to be reached when the household head was aged 40 to 49 years, with two or more children, some of whom were in their teen-age years. Average annual gas consumption, however, was highest in the four-person household whose head was aged 30 to 39 years (which reflected the dominance of gas appliances in the sampled houses of Salisbury East).

The variable "Household size" was selected as an indicator of stage in the life-cycle, age of the household head, number and ages of children[29]. In preliminary regression analyses, the explanatory power of variables describing age of the household head, number or ages of children was always undermined if "Household size" was also included.

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29. Crossley (1978) explains the relationship (in his Brisbane survey) between energy-related behaviour and such variables as the age of the respondent, number of rooms in the house and household income, in terms of the number of people. He calculated his energy-behavioural indices on a per capita basis, on the premise that the energy attributable to a child frequently equals that of an adult, and that of a very young child may exceed that of an adult. Similarly, the New Zealand Department of Statistics (1976) show that the number of occupants tended to dominate the power of other variables in explaining the variation in electricity consumption.

TABLE 8.13

ANNUAL ENERGY CONSUMPTION OF HOUSEHOLD AS A FUNCTION OF HOUSEHOLD CHARACTERISTICS

Household Characteristic	Sample size	Average Annual Consumption		
		Electricity (kWh)	Gas (MJ)	Primary-Energy Equivalent (GJ)
Number of persons in the household:				
One	30	3,145	4,554	55.9
Two	117	3,974	14,083	77.8
Three	92	4,395	20,862	91.3
Four	111	3,764	34,033	96.5
Five	58	5,176	28,217	111.6
Six or more	44	5,293	33,559	118.2
Age of the head of the household:				
Under 29 years	83	3,650	24,620	85.0
30-39	78	3,939	32,590	99.9
40-49	117	4,777	30,712	107.3
50-59	85	5,078	17,419	97.4
60 years or older	89	3,526	10,507	66.1
Number of children under 18 years:				
None	196	3,996	13,550	77.2
One	86	4,381	24,801	97.5
Two	88	3,909	36,979	100.7
Three or more	82	5,006	31,116	112.0
Ages of children:				
None	201	3,973	14,276	77.7
Under 9 years	106	3,849	30,760	97.7
10-17 years	94	4,967	29,335	106.4
5 -18 years	51	4,726	33,469	109.8

Source: Household and Energy Consumption Data.

(ii) Household income. One of the most recurrent themes throughout all previous studies has been the relationship between energy use and income[30]. As Newman and Day (1975, xxiii) state so clearly:

> The main findings .... show, without doubt, that the more money you have the more energy you use at home and in your automobile. This is regardless of any other condition - climate: how and how far you commute to work; the size of your house; your age; number of people in your household; and whether or not your house is protected from the weather by insulation, for instance. Paradoxically also, the better off you are, the more likely you are to have equipment that saves energy as well as a house and equipment that uses a great deal of energy.

Since data were obtained on occupations of all adults in the sampled households, it was possible to ascertain the relationship between several indicators of household income and household energy use. Table 8.14 shows that most energy was used in households with a head in an administrative, managerial or professional occupation, with three or more wage-earners, or with an average annual income exceeding $15,000. Least energy was used in households whose head was in a non-earning occupation, with an annual income below $3,000. Thus, an almost two-fold increase in energy consumption was associated with a five-fold increase in household income[31].

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30. In their survey of New Zealand houses, Blakeley and Cook (1974, 13) found that total energy consumption increased with increasing income of the household head and in general with increasing income of the household as a whole. Crossley (1978) found that the higher the educational level attained by the nominated head of the household, the larger were the household energy bills. Households in which the nominated head followed a professional or administrative occupation also tended to score highly on the energy-related behavioural indices.

31. The Australian Bureau of Statistics' (1977) Household Expenditure Survey showed a steady increase in the expenditure on fuel and power from $2.04 if average weekly income was under $80, to $3.07 for weekly income $140 to $200, to $3.85 if weekly income was $340 or more (indicating a two-fold increase in household fuel expenditure for a four-fold increase in income).

TABLE 8.14

ANNUAL ENERGY CONSUMPTION OF THE HOUSEHOLD AS A FUNCTION OF OCCUPATION OCCUPATION AND INCOME CHARACTERISTICS

Occupation or Income Characteristic	Sample size	Average Annual Consumption		
		Electricity (kWh)	Gas (MJ)	Primary-Energy Equivalent (GJ)
Occupation of the head of the household[a]:				
Professional	65	4,699	23,246	97.7
Administrative, managerial	45	5,279	27,980	114.3
Sales, service, clerical	91	4,274	25,518	93.4
Craftsmen, tradesmen, transport	149	4,261	26,909	97.4
Non-earning	89	3,398	11,703	65.1
Number of wage-earners in household:				
Three or more	30	5,509	19,166	101.4
Two	113	4,246	24,073	94.1
One	216	4,364	27,754	98.8
None	80	3,518	10,664	65.4
Average annual income of household[b] ($):				
Less than $3,000	95	3,508	14,753	70.6
$ 3,001- 6,000	105	4,209	25,615	92.9
$ 6,001- 9,000	107	4,105	26,929	94.1
$ 9,001-12,000	98	4,686	26,267	103.2
$12,001-15,000	26	4,512	19,723	89.3
$15,001 or more	21	5,880	25,478	124.0

Source: Household and Energy Consumption Data.

a. Excludes 13 households for which occupations were unknown.

b. See footnote, Table 7.26, for method of calculation of 'household income'.

One survey which found no correlation between energy use and income was that of Grot and Socolow (1974), who explained their findings in terms of the inverse correlation between family size and family income: a two-person household was more likely to have two-wage-earning adults, than a three or four person household, where young children needed home care by one adult. A similar, unexpected pattern in energy patterns seems apparent in this study, in which households with two wage-earners used slightly less total energy than households with one (94.1 GJ compared to 98.8 GJ). Furthermore, households where the joint annual income (of two adults) was between $12,000 and $15,000 had an unexpectedly low total energy consumption (89.3 GJ). Of the 26 households in this income group, 19 had two wage-earning adults, four households had three wage-earners, and nearly all other members of the household were school-age children. In eight households all members were wage-earning, whereas only two households had a single wage-earning adult, with housewife and children at home. This suggests that, in 24 of these households, the dwelling was unoccupied during working hours, so that use of heating and other appliances was intermittent, and energy consumption lower[32]. However, the majority of households with

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32. The effect of the intermittent occupation of dwellings on domestic energy consumption for 7,000 dwellings in the United Kindgom was investigated by Desson (1976). By using occupation patterns inferred from data on employment status in the Family Expenditure Survey (of 1973) a model was constructed which estimated that intermittent heating might occur in 41 to 61 per cent of households in the domestic sector. The model indicates that the two-fold increase in household fuel expenditure for by a ten-fold increase in income could be partly accounted for a trend of increasing intermittent heating with increase in income. However, Desson (1976, 5) found that there was a discontinuity in fuel expenditure at the $100 per week income level, and thus it was assumed that the "households in the over $100 per week income group already practise continuous heating (or have extensive pre-heating) and have optimised their heating standards".

incomes over $15,000 also had two or three wage-earning adults, yet average energy consumption was the highest of any group. One can only assume that continuous heating (and some cooling) was practised, regardless of the diurnal nature of occupation.

Despite the relatively weak (and uneven) relationship between energy consumption and income, the variable "Household income" was selected for inclusion in the regression model, rather than rely on the more difficult categorization and ranking of occupations (Darke and Darke, 1969; Vanneman, 1977).

(iii) Ethnicity of the household and years of residence: Living habits, household income, thermal management of the house, the ownership and use of appliances are likely to be affected by the household's prior experiences with local conditions and their length of experience with a particular house. One attempt to measure these differences is the ethnicity of the household, as indicated by the place of birth of the household head. This was particularly useful in this survey, where thirty per cent of the household heads were born in the United Kingdom. Table 8.15 shows that the household whose head was born in Greece or Italy used least energy, and the household whose head came from the United Kingdom used most. The ethnicity of the household was included in the regression analysis by the creation of dummy variables for an Australian-born household head and a household head born in the United Kingdom. (The numbers of household-heads born in other countries were too small to be of significance).

Average energy consumption was generally higher for households who had moved in since 1960, than for households resident for fifteen years or more (Table 8.16). However, the uneven nature of the relationship meant that the inclusion of a variable "Year of moving into house" yielded no significant increase in the level of explanation.

(iv) Comfort of the dwellings: In order to test the relationship between energy consumption and indoor comfort, a variable describing householders' assessments of the comfort of their dwellings (see Table 7.11) was included in the regression model on a trial basis. However, analysis of a scattergram showed a curvilinear relationship between these householders' evaluations and the energy consumption of the household[33] and thus very little explanatory power (R^2 = .002). The householder's expenditure on energy consuming and/or energy saving equipment was also included and, initially, resulted in considerable increase in the level of explanation (R^2 = .061). However, when "Householder's capital expenditure on comfort" was included with variables describing major appliances and equipment, the explanatory power was reduced by the over-riding effects of variables describing the main type of heating fuel, the presence of space-heating, air conditioning and ceiling insulation. Variables describing the comfort of dwellings were, therefore, excluded from the model.

Regression Procedure

Stepwise procedures were used to structure the relationships because, of the various regresion techniques available, they are recommended for selecting "explanatory" equations (Hauser, 1974,150) and are well suited

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33. This relationship is also shown in Table 9.03. It appeared to result from both highly satisfied and highly dissatisfied householders using more energy.

TABLE 8.15

ANNUAL ENERGY CONSUMPTION OF HOUSEHOLD AS A FUNCTION OF BIRTH-PLACE OF THE HOUSEHOLD HEAD

Place of Birth of Head of Household[a]	Sample size	Average Annual Consumption Electricity (kWh)	Gas (MJ)	Primary-Energy Equivalent (GJ)
Australia	264	4,514	18,631	90.0
United Kingdom	137	3,699	35,406	98.6
Greece, Italy	17	4,418	15,623	80.3
Other	31	4,107	16,246	85.9

Source: Household and Energy Consumption Data.

a. Excludes three households for whom the place of birth of the head was unknown.

TABLE 8.16

ANNUAL ENERGY CONSUMPTION OF HOUSEHOLD AS A FUNCTION OF YEARS OF RESIDENCE

Year of Moving into House	Sample size	Average Annual Consumption Electricity (kWh)	Gas (MJ)	Primary-Energy Equivalent (GJ)
Before 1950	53	3,615	14,643	70.7
1950-59	92	4,951	13,521	91.4
1960-69	97	4,782	19,874	95.5
1970-72	106	3,744	31,910	93.1
1973-75	104	3,910	31,387	98.7

Source: Household and Energy Consumption Data.

to handling sizeable sets of independent variables (Draper and Smith, 1966, 171). Apart from its value as a search procedure (identifying which independent variables have the strongest relationship with the dependent variable) hierarchical inclusion permits examination of changes in regression coefficients at each step, which can lead to substantially greater understanding of the nature of interrelationships among the variables. Various stepwise procedures are available, but the commonest is forward selection which adds independent variables to the multiple regression equation on the basis of their partial correlation with the dependent variable, so that at each step in the analysis the remaining independent variable with the highest partial correlation is included[34].

For the multiple regression model to be valid, the independent variables must be linearly independent [35] (Poole and O'Farrell, 1971; Blalock, 1963). An examination of the zero-order correlation matrix for the sampled households of the southwestern suburbs (Table 8.17) revealed low to moderate intercorrelations. The highest pairwise correlations (.510 between "Space-heating" and "Oil as main heating fuel"), -.543 between "Electric hot water service" and "Gas hot water service", and

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34. The SPSS Subprogram REGRESSION was used (Nie et al., 1975, 320-365).

35. Other critical assumptions relate to the linearity of variables, homoscedasticity and serial independence. (As a rule, some relaxation of the normality, measurement error and zero-disturbance-mean assumptions is tolerated). The linearity of relationships was examined through the use of scatterplots for some independent variables and revealed no abnormalities. For others nominal variables, included in the regression by the use of "dummies", linearity was assumed. The requirement tht all the 'Y' arrays have the same variance (homoscedasticity), and that the values of μ were independent of each other (serial independence) were evaluated by direct examination of the plot of residuals from regression, and associated measures (such as the Durbin Watson Statistic).

TABLE 8.17

MATRIX OF ZERO-ORDER COEFFICIENTS-HOUSEHOLD ENERGY CONSUMPTION (Southwestern Suburbs)

AND THE INDEPENDENT VARIABLES (N = 306)

	HHENERGY	HOUSESIZE	ELHWS	GASHWS	SPACEH	GASHEAT	ELECHEAT	OILHEAT	SOLIDF	SIZEHH	HHINC	AUSTHEAD	UKHEAD
HHENERGY	1.000	.375	.488	-.153	.414	-.003	-.028	.378	-.209	.375	.290	-.005	.068
HOUSESIZE		1.000	.173	-.103	.125	.000	-.043	.141	-.020	.295	.262	.043	-.059
ELHWS			1.000	-.543	.155	-.259	.178	.289	-.082	-.009	.038	-.033	.008
GASHWS				1.000	.076	.466	-.313	-.198	-.046	.123	.123	.080	-.025
SPACEH					1.000	.009	-.249	.510	-.110	.058	.163	.029	.047
GASHEAT						1.000	-.451	-.303	-.365	.203	.104	.082	-.068
ELECHEAT							1.000	-.250	-.301	-.111	-.073	-.170	.061
OILHEAT								1.000	-.202	-.042	.079	-.040	.064
SOLIDF									1.000	-.062	-.051	.096	-.014
SIZEHH										1.000	.255	-.055	-.077
HHINC											1.000	-.110	.059
AUSTHEAD												1.000	-.577
UKHEAD													1.000

Variables:
HHENERGY = Annual Household Energy Consumption
HOUSESIZE = House Size (number of main rooms)
ELHWS = Electric hot water service
GASHWS = Gas hot water service
SPACEH = Spaceheating
GASHEAT = Gas as main heating fuel
ELECHEAT = Electricity as main heating fuel
OILHEAT = Oil as main heating fuel
SOLIDF = Solid fuel as main heating fuel
SIZEHH = Size of household (number of persons)
HHINC = Household income
AUSTHEAD = Australian-born head of household
UKHEAD = U.K.-born head of household

.577 between "Australian-born head of household" and "U.K.-born head of household") were well below the value of 0.8 suggested by Hauser (1974,152) as evidence of serious collinearity. Conceptually, it was important to retain all categories of these nominal variables.

In the more homogeneous housing of Salisbury East, different problems arose. Several pairs of variables were highly correlated; particularly "Electric hot water service" and "Gas hot water service" (-.954), "Electric hot water service" and "Gas as main heating fuel"(-.670), and "Gas as main heating fuel" and "Electricity as main heating fuel" (-.750). Therefore, it was decided, due to low numbers of houses with other than a gas space-heater and gas storage hot water system to eliminate variables describing other types of fuel for room heating and hot water. Furthermore, since the correlation between "Australian-born head of household" and U.K.-born head of household" was -.909 (since almost all household heads not born in the United Kingdom were born in Australia) it was decided to eliminate the latter variable from the list of independent variables. This left only one moderately-correlated pair, "Gas hot water service" and "Gas as main heating fuel" (r = .728): both were retained, however, since it was considered important to determine which of the two gas appliances contributed most to total household energy consumption. Partly to compensate for these changes, the variables "Ceiling insulation" and "Fixed air conditioning" were included in the set of independent variables[36]. The revised matrix of zero-order correlation coefficients is shown in Table 8.18.

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36. Earlier regression equations for the southwestern suburbs included "Ceiling insulation" and "Fixed air conditioning" (with variables describing house size, household size, household income, and type of heating fuel and hot water system) but no statistically significant regression coefficient emerged.

TABLE 8.18

MATRIX OF ZERO-ORDER COEFFICIENTS - HOUSEHOLD ENERGY CONSUMPTION (Salisbury East) AND THE INDEPENDENT VARIABLES[a] (N = 146)

	HHENERGY	HOUSESIZE	GASHWS	SPACEH	GASHEAT	AIRCOND	INSUL	SIZEHH	HHINC	UKHEAD
HHENERGY	1.000	.444	-.339	-.378	-.445	-.028	-.024	.381	.196	.115
HOUSESIZE		1.000	-.073	-.180	-.132	-.082	.037	.254	.187	-.067
GASHWS			1.000	.492	.728	.060	-.106	.022	-.024	.112
SPACEH				1.000	.629	.110	-.009	-.094	.069	-.068
GASHEAT					1.000	.117	-.106	-.019	-.097	.112
AIRCOND						1.000	.246	-.109	-.065	-.131
INSUL							1.000	.017	.010	-.023
SIZEHH								1.000	.025	.109
HHINC									1.000	.140
UKHEAD										1.000

Source: Regression Analysis of Household Energy Data.

a. Variables
HHENERGY = Annual household energy consumption
HOUSESIZE= House size (number of main rooms)
GASHWS = Gas hot water system
SPACEH = Space-heating
GASHEAT = Gas as main heating fuel
AIRCOND = (Fixed) air conditioning
INSUL = Ceiling insulation
SIZEHH = Size of household
HHINC = Household Income
UKHEAD = U.K.-born head of household

The framework of relationships having been presented, the hypothesised determinants of household energy use, for the two groups of sampled households in Adelaide, can be set out formally:

HHENERGY (South-western Suburbs) $= a + b_1 HOUSESIZE_i + b_2 ELHWS_i - b_3 GASHWS_i + b_4 SPACEH_i - b_5 GASHEAT_i - b_6 ELECHEAT_i + b_7 OILHEAT_i - b_8 SOLIDF_i + b_9 SIZEHH_i + b_{10} HHINC_i - b_{11} AUSTHEAD_i + b_{12} UKHEAD_i + e$

HHENERGY (Salisbury East) $= a + b_1 HOUSESIZE_i - b_2 GASHWS_i - b_3 SPACEH_i - b_4 GASHEAT_i - b_5 AIRCOND_i - b_6 INSUL_i + b_7 SIZEHH_i + b_8 HHINC_i + b_9 UKHEAD_i + e$

where HHENERGY = Annual household energy consumption

HOUSESIZE = House size (number of main rooms)

ELHWS = Storage electric hot water system

GASHWS = Storage gas hot water system

SPACEH = Space-heating

GASHEAT = Gas as main room heating fuel

ELECHEAT = Electricity as main room heating fuel

OILHEAT = Oil as main room heating fuel

SOLIDF = Solid fuel as main room heating fuel

AIRCOND = Fixed air conditioning

INSUL = Ceiling insulation

SIZEHH = Size of household (number of persons)

HHINC = Household income

AUSTHEAD = Australian-born head of household

UKHEAD = U.K.-born head of household

and $a, b_1 \ldots b_{12}$ are empirically derived constants

i = 1, 2, ..., 146/306

e = error term.

Regression Equations for Household Energy Consumption in Adelaide

Southwestern suburbs. The best estimate of 'Y' is an equation comprising the following variables (the standardised regression coefficients, β_1's, are given in parentheses below the regressor):

HHENERGY (South western Suburbs) = −2.195 + 36.989 ELHWS (.381) + 8.432 SIZEHH (.286) + 21.425 SPACEH (.233) + 6.685 HOUSESIZE (.166) − 11.650 SOLIDF (.103) + .001 HHINC (.108)

R^2 = .55

df = 304

HHENERGY = Annual household energy consumption

ELHWS = Electric hot water service

SIZEHH = Size of household (number of persons)

SPACEH = Space-heating

HOUSESIZE = House size (number of main rooms)

SOLIDF = Solid fuel as main heating fuel

HHINC = Household income

The analysis was terminated at step seven by which stage 55 per cent of the total variance in household energy consumption was accounted for (the remaining four regressors only yield a two per cent improvement in R^2). Table 8.19 lists the stepwise regression equations to step seven and indicates that all R^2 and all but one of the β's "Oil as main heating fuel" were significantly different from zero at the 99 per cent level.

In the seven variable equation six regressors are positively related to household energy use and one ("solid fuel as main heating fuel") negatively related. Examination of the main effects operative in the household energy use patterns in the sampled households of the southwestern suburbs showed, rather surprisingly, the dominance of so few factors (namely the major appliances of the house, the size of the dwelling and the number of persons in the household).

Table 8.19 shows that "Size of household" and "Space-heating" were the regressors that produced the greatest change in household energy consumption. The behaviour of "Size of household" in the model was a reflection of its general role in magnifying the effects of all other regressors: between steps one and two, following the entry of "Size of household", the partial coefficients of "House size", "Gas hot water service", "Electricity as main heating fuel", and "Household income" were reduced by a third, and "Gas as main heating fuel" by a half. The partial coefficients of "Space-heating", however, was increased slightly, resulting in its inclusion in step two. It has been shown previously that the size of the household and the presence of space-heating were almost unrelated (Table 8.17), but that larger households with space-heaters were higher users of total energy. The introduction of "Space-heating" effectively reduced the partials of other appliance-related variables, so that three of them ("Gas hot water service", "Gas as main heating fuel" and "Electricity as main heating fuel") were not taken into the model. The two heating-fuel variables that were taken into the model ("Solid fuel" at step five and "Oil" at step seven) represent the household groups of lowest and highest annual energy consumption (Figure 8.1 and Table 8.11). Although the partial co-effieient of "House size" was reduced by the entry of "Size of household" on step two, it remained sufficiently high to be included on step four but had little effect on the remaining partials, except to reduce that of "Household income" and delay its entry until step six.

TABLE 8.19

STEPWISE REGRESSION OF HOUSEHOLD ENERGY CONSUMPTION (Southwestern Suburbs) ON SEVEN INDEPENDENT VARIABLES

Step	Variable	R	R^2	α		b	β	Partial Variable	Partial Correlation Coefficient
1.	ELHWS	.4875	.24*	75.1191		47.2213	.4875*	HOUSESIZE	.3564
								GASHWS	.1523
								SPACEH	.3924
								GASHEAT	.1466
								ELECHEAT	-.1344
								OILHEAT	.2841
								SOLIDF	-.1938
								SIZEHH	.4340
								HHINC	.3119
								AUSTHEAD	.0129
								UKHEAD	.0740
2.	SIZEHH	.6175	.38*	39.7839		11.1613	.3790*		
					ELHWS	47.5454	.49087*		
								HOUSESIZE	.2625
								GASHWS	.1023
								SPACEH	.4073
								GASHEAT	.0643
								ELECHEAT	-.0960
								OILHEAT	.3356
								SOLIDF	-.1852
								HHINC	.2309
								AUSTHEAD	.0412
								UKHEAD	.1198
3.	SPACEH	.6957	.48*	31.4044			.3249*		
					ELHWS	42.6366	.4402*		
					SIZEHH	10.5934	.3597*		
								HOUSESIZE	.2498
								GASHWS	.0291
								GASHEAT	.0525
								ELECHEAT	.0207
								OILHEAT	.1686
								SOLIDF	-.1610
								HHINC	.1884
								AUSTHEAD	.0281
								UKHEAD	.1084
4.	HOUSESIZE	.7184	.52*	-6.6213			.1918*		
					ELHWS	39.6222	.4091*		
					SIZEHH	8.9437	.3037*		
					SPACEH	28.3735	.3091*		
								GASHWS	.0495
								GASHEAT	.0594
								ELECHEAT	.0271
								OILHEAT	.1533
								SOLIDF	-.1721
								HHINC	.1487
								AUSTHEAD	.0118
								UKHEAD	.1236
5.	SOLIDF	.7283	.53*	-3.2082		-13.6487	-.1209*		
					ELHWS	38.7824	.4004*		
					SIZEHH	8.7170	.2960*		
					SPACEH	27.2836	.2972*		
					HOUSESIZE	7.8587	.1946*		
								GASHWS	.0358
								GASHEAT	-.0096
								ELECHEAT	-.0346
								OILHEAT	.1281
								HHINC	.1468
								AUSTHEAD	.0284
								UKHEAD	.1233
6.	HHINC	.7352	.54*	-3.2357		.0011	.1072†		
					ELHWS	38.947	.4021*		
					SIZEHH	8.1205	.2757*		
					SPACEH	26.0218	.2835*		
					HOUSESIZE	7.0254	.1740*		
					SOLIDF	-13.3704	-.1185*		
								GASHWS	.0168
								GASHEAT	-.0193
								ELECHEAT	-.0321
								OILHEAT	.1306
								AUSTHEAD	.0466
								UKHEAD	.1125
7.	OILHEAT	.7405	.55*	-2.1953			.1084*		
					ELHWS	36.9389	.3814*		
					SIZEHH	8.4317	.2863*		
					SPACEH	21.4245	.2334*		
					HOUSESIZE	6.6846	.1655*		
					SOLIDF	-11.6499	-.1032*		
					HHINC	.0011	.1079*		
								GASHWS	.0406
								GASHEAT	.0376
								ELECHEAT	.0082
								AUSTHEAD	.0541
								UKHEAD	.1077

R = Correlation Coefficient
R^2 = Multiple Correlation Coefficient
α = Y intercept (constant)
b = (Unstandardised) regression coefficient
β = Standardised regression coefficient
* = Significant at .01 level
† = Significant at .05 level
F, t distributions

ELHWS = Electric hot water service
HOUSESIZE = House size
GASHWS = Gas hot water service
SPACEH = Spaceheating
GASHEAT = Gas as main heating fuel
ELECHEAT = Electricity as main heating fuel
OILHEAT = Oil as main heating fuel
SOLIDF = Solid fuel as main heating fuel
SIZEHH = Size of household
HHINC = Household income
AUSTHEAD = Australian-born head of household
UKHEAD = U.K.-born head of household

The variables excluded from the model of household energy use (South-western suburbs), namely "Gas hot water service", "Gas as main heating fuel", "Electricity as main heating fuel", "Australian-born head of household" and "U.K.-born head of household" appear to be relatively unimportant determinants. Partials of "Gas as main heating fuel" and "Gas hot water service" were reduced by "Size of household" and by "Space-heating", with which they are positively correlated. The role of "Electricity as main heating fuel" was partly taken over by "Electric hot water service" (just over half the electrically-heated houses also had an electric hot water service) and further reduced by "Size of household" (three-quarters of the households using electricity for heating contained one or two persons, or over five persons). The ethnicity of the household head remained unimportant in relation to other household characteristics.

Salisbury East. The best estimate of 'Y' is an equation comprising the following variables:

HHENERGY (Salisbury East) = 35.436 − 43.541 GASHEAT (.426) + 11.193 HOUSESIZE (.336) + 6.596 SIZEHH (.280) + 10.856 UKHEAD (.168) + 6.598 AIRCOND (.102)

$R^2 = .46$

df = 144

where HHENERGY = Annual household energy consumption

GASHEAT = Gas as main heating fuel

HOUSESIZE = House size (number of main rooms)

SIZEHH = Size of household (number of persons)

UKHEAD = U.K.-born head of household

AIRCOND = Fixed air conditioning.

The analysis was terminated at step five by which stage 46 per cent of the total variance in household energy consumption is accounted for (the remaining two regressors only yield a two per cent improvement in R^2). Table 8.20 lists the stepwise regression equations to step five and indicates that all R^2 and all but one of the β 's "Fixed air conditioning" were significantly different from zero at the 99 per cent level. Examination of the regression coefficients and the partial correlation coefficient showed that the nature of major appliances (in this case "Gas as main heating fuel") continued to explain most of the variance in household energy consumption, that "Gas as main heating fuel" was a negative regressor (that is, total energy use is reduced by the use of gas for room heating). Once "Gas as main heating fuel" had entered, the explanatory power of "Space-heating" and "Gas hot water service" (with which the heating fuel variable had correlations of .629 and .728, respectively) was virtually removed. The entry of "House size" on step two had little effect on "Size of household", reflecting the relative homogeneity of the sample, but reduced the partial of "Household income", so that it did not enter the equation. In the absence of a number of variables describing major appliances and fuels, the ethnicity of the household head was a relatively important determinant, entering at step four. The entry of "Fixed air conditioning" at step five increased the value of "Ceiling insulation", but did not produce a statistically significant regression coefficient. Other excluded variables, "Household income", "Gas hot water service" and "Space-heating", were not important determinants of household energy consumption once "Gas as main heating fuel" and "House size" were included.

TABLE 8.20

STEPWISE REGRESSION OF HOUSEHOLD ENERGY CONSUMPTION (Salisbury East)

ON FIVE INDEPENDENT VARIABLES

Step	Variable	R	R^2	α		b	β	Partial Variable	Partial Correlation Coefficient
1.	GASHEAT	.4450	.20*	138.2750		-45.4767	-.4499*		
								HOUSESIZE	.4338
								GASHWS	-.0241
								SPACEH	-.1415
								AIRCOND	.0271
								INSUL	-.0799
								SIZEHH	.4154
								HHINC	.1709
								UKHEAD	.1853
2.	HOUSESIZE	.5907	.35*	57.3813		13.0449	.319*		
					GASHEAT	-40.1874	-.3932*		
								GASHWS	-.0432
								SPACEH	-.0973
								AIRCOND	.0628
								INSUL	.1000
								SIZEHH	.3505
								HHINC	.1063
								UKHEAD	.2316
3.	SIZEHH	.6549	.43*	45.0292		6.8939	.2924*		
					GASHEAT	-40.6221	-.3974*		
					HOUSESIZE	10.5561	.3171*		
								GASHWS	-.0635
								SPACEH	-.0755
								AIRCOND	.1026
								INSUL	-.1102
								HHINC	.1221
								UKHEAD	.2003
4.	UKHEAD	.6721	45*	38.4490		9.9304	.1539*		
					GASHEAT	-42.2470	-.4133*		
					HOUSESIZE	11.0040	.3306*		
					SIZEHH	6.4102	.2719*		
								GASHWS	-.0733
								SPACEH	-.0758
								AIRCOND	.1347
								INSUL	-.1102
								HHINC	.0912
5.	AIRCOND	.6759	.46*	35.4358		6.5893	.1021		
					GASHEAT	-43.5406	-.4260*		
					HOUSESIZE	11.1928	.3363*		
					SIZEHH	6.5964	.2798*		
					UKHEAD	10.8555	.1682*		
								GASHWS	-.0705
								SPACEH	-.0808
								INSUL	-.1530
								HHINC	.0951

R = Correlation Coefficient

R^2 = Multiple Correlation Coefficient

α = Y intercept (constant)

b = (Unstandardised) regression coefficient

β = Standardised regression coefficient

* = Significant at .01 level (F, t distributions)

GASHEAT = Gas as main heating fuel

HOUSESIZE = House size (no. of main rooms)

GASHWS = Gas hot water service

SPACEH = Spaceheating

AIRCOND = Fixed air conditioning

INSUL = Ceiling insulation

SIZEHH = Size of household (no. of persons)

HHINC = Household income

UKHEAD = U.K.-born head of household.

Residuals from Regression. Visual examination of the residuals plotted against the estimated 'Y' values revealed no abnormalities of the kind described by Draper and Smith (1966, Chapter 3). Table 8.21 lists some of the attributes of households whose energy consumption varied by more than two standard deviations (the so-called "outliers"). Apart from the fact that all but two of these large displacements are positive (that is, the household is using much more energy than the model predicts) there is no other common feature.

Summary. The regression analysis shows that, in the southwestern suburbs sample area, 55 per cent of the total variance in household energy consumption was accounted for by the presence of an electric hot water service and of a space-heater (any fuel), the use of solid fuel for room heating, the number of main rooms, the size of the household and the household income. In the Salisbury East sample area, 46 per cent of the total variance was "explained" by the presence of gas as the main heating fuel and the presence of an air conditioner, the number of main rooms, the size of the household and a household head born in the United Kingdom. In summary, the group of factors dealing with house size and major appliances explained approximately 40 per cent of the variance in household energy consumption, and the group of factors dealing with household size and composition explained approximately 20 per cent of the variance. The total explained variance was reduced to approximately 50 per cent, however, due to overlap and intercorrelation.

TABLE 8.21

CHARACTERISTICS OF OUTLIERS AMONG RESIDUALS FROM REGRESSION

Region	NUMBER OF ROOMS	TYPE OF STORAGE HWS	SPACE HEATING	TYPE OF FUEL	SIZE OF HOUSEHOLD	HHINC	PLACE OF BIRTH	FIXED AIRCOND.	HOUSEHOLD ENERGY (Y Value)	Y ESTIMATE	RESIDUAL[a]
Southwestern Suburbs	5	Gas	No	Solid	2 persons	9,230	Aust	No	119.90	48.21	71.69
	5	Elec	Yes	Oil	4 persons	6,000	U.K.	No	229.06	153.91	75.15
	7	Gas	Yes	Solid	3 persons	1,810	Aust	Yes	142.88	81.42	61.46
	5	Gas	No	Gas	3 persons	5,065	Aust	No	167.47	65.85	101.6
	4	Gas	No	Elec	2 persons	1,810	Aust	No	129.85	47.94	81.92
	6	Elec	Yes	Oil	2 persons	10,230	O/seas	No	213.73	124.98	88.75
	8	Elec	Yes	Oil	2 persons	9,230	Aust	Yes	240.47	150.06	90.41
	8	None	No	Solid	5 persons	5,000	Aust	No	27.35	87.75	-60.41
	5	Elec	Yes	Oil	1 person	100	O/seas	No	165.35	99.04	66.30
	6	Elec	Yes	Gas	3 persons	6,000	O/seas	No	219.22	114.62	104.60
	7	Gas	Yes	Gas	4 persons	9,230	Aust	Yes	239.62	111.08	128.54
	7	None	No	Solid	4 persons	5,860	U.K.	No	143.09	82.01	61.08
	6	Elec	Yes	Gas	2 persons	6,180	Aust	Yes	192.43	119.89	72.54
	9	Elec	Yes	Oil	3 persons	17,340	Aust	Yes	263.51	173.90	89.61
Salisbury East	6	Gas	Yes	Gas	4 persons	18,260	U.K.	No	182.61	99.26	83.34
	8	Gas	Yes	Gas	4 persons	9,230	Aust	No	165.17	111.26	53.91
	7	Elec	No	Elec	5 persons	9,815	U.K.	No	119.46	164.03	-44.57
	5	Gas	Yes	Gas	4 persons	10,490	U.K.	Yes	145.43	99.08	46.34

Source: Household Data and Regression Analysis.

a. Positive residual indicates high consumption; negative indicates low.

The "Unexplained" Variation in Household Energy Use

Regardless of the combination of independent variables used, multiple regression analysis could not explain approximately 40 per cent of the variance in household energy consumption and a number of other factors must have been operating. The final section of this chapter suggests some of the technical and "behavioural" reasons for this "unexplained" variation in household energy use.

Measurement Error. Measurement error can occur in both the dependent and independent variables. The calculation of average annual household energy consumption for 452 households was a complex process, involving eight supply authorities, each with different methods of recording data. Although every attempt was made to minimise error, it inevitably occurs. Furthermore, the primary-energy equivalent was the average annual consumption of electricity, gas and heating oil over two years. The independent variables, however, were "measured" at one point in time (usually the date of completion of the Householder's Questionnaire). Thus the house structure or its major appliances could have changed during the two years, with unknown effects on the pattern of household energy consumption.

Technical Variables. The consumer has little control (or assumes little control) over such technical variables as variations in the tightness of fit of windows or variations in performance characteristics of "identical" appliances (such as the models of gas space-heater, gas hot water service and gas cooker installed in most of the sampled houses of Salisbury East). For example, although the householder is able to adjust the thermostat setting on a hot water service, it is more frequently left unchanged from the time of installation.

Attitudinal and Behavioural Factors. The energy consumed by a household is affected by a number of attitudinal behavioural factors which are difficult to measure. People are generally unpredictable and individualistic in their thermal comfort preferences, their ability to optimize comfort and their attitudes to energy conservation. Thermal management of a house varies enormously from one householder to another, in such activities as the proper use of doors, windows, curtains, blinds, insulation and floor coverings (to maximise sun penetration and heat absorption in winter, minimise sunshine and inwards heat transfer in summer), controlling the unheated/ heated sections of a house or operating appliances in the most efficient manner. Such knowledge and management ability is likely to be influenced by the householder's background, the number of years in Adelaide's climate and stage in the life-cycle. (For example, young children rarely remember to close doors!). Related to the life-cycle, but also fluctuating from one household to another, is the daily and weekly living routine. An "occupancy rate" (the number of hours per week that the house is occupied) can be estimated from the occupations and ages of the household members (see Desson, 1976) but it does not take into account differences during the hours that the house is occupied. For example, members in one household may spend the early evening in one room, and always retire early, whereas the normal evening activity of members of another household may be separate hobbies or activities in three or four different rooms, and a much later bed-time. Similarly, one house may be almost unoccupied at the weekend if its members are heavily engaged in recreational activities outside the home, whereas another house may have its maximum period of (energy-related) activity at the weekend.

People vary widely in living patterns and comfort requirements. Some householders consider whole or half-house heating throughout the winter months as essential, regardless of the period of occupancy; others heat one or two rooms, and only when occupied. For some people, the first response to hot or cold weather is an adjustment to their level of clothing or activity; others prefer to adjust the setting on the heater, electric blanket or air conditioner. Some households make heavy demands on the hot water supply for baths, showers, kitchen and laundry; others are more frugal. The number, nature and frequency of use of lights and other electric appliances also varies widely. Preferred temperatures for thermal comfort can vary by 5°C from one individual to another [37]. Campaigns to popularise energy conservation by governments and other organisations have been widespread in the United States, United Kingdom and countries of Europe (Crossley, 1977b; Beale, 1978). Nevertheless, surveys in New Zealand (Phillips, 1976) and in Brisbane (Crossley, 1978) show that people's attitudes on energy conservation do not carry through to their actions, so that people who support quite strongly the concept of energy conservation by individual action in the home do not actually use energy any differently from those who feel that this type of energy conservation is not necessary.

The influence of these behavioural-attitudinal factors on household energy consumption was demonstrated in this survey in an unexpected way. During the collection of data on the household's consumption of gas and electricity over a period of 24 months, the occupants changed in 54 of

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37. Maadah and Maddox (1976, 252) quote a study which showed that setting the thermostat (in an American home) at 80°F in winter instead of 70°F can increase energy consumption for heating by 40 per cent.

the sampled houses (12 per cent of the total). At the majority of addresses this change of occupants was reflected in the quarterly electricity or bi-monthly gas consumption. Although a third of these changes in the pattern of consumption only lasted two or three months (from one meter reading to the next) half continued to show a changed pattern of consumption for four to six months or longer. Only some of this change could be explained in terms of differences in the number and nature of occupants: the unexplained remainder demonstrates how significant are the ways in which different occupant behaviour and characteristics can influence energy consumption in the same house.

Thus, although household energy consumption in Adelaide is constrained by the size of the house, the number and nature of occupants, and the major appliances and amenities of the house, it is also clear that there is a wide variability in the amount of energy people use in their homes. One major constraint appears to be financial; since high energy consumption was associated with larger houses, more occupants, a high number of appliances, the presence of ceiling insulation and a high household income, there seems to be an obvious link between affluence of the householder, physical comfort of the house and high energy costs. As Crossley (1978,258) concludes "We limit the amount of energy we use to what we can afford".

CHAPTER 9

IDENTIFYING THE BEST HOUSE FOR ADELAIDE'S CLIMATE

The preceding chapters have demonstrated that, in general terms, Adelaide's housing is not well suited to the climate, and provides satisfactory levels of indoor comfort only with considerable use of energy. However, throughout the discussion many exceptions have been noted and, using these observations, this chapter discusses the combination of attributes which constitute the "best" house for Adelaide's climate. Various possibilities must be considered , such as certain house styles (the 1930's Bungalow, for example), or particular design features (such as the presence of verandahs or ceiling insulation). Also to be considered is the direct or indirect influence of the households occupying the houses: including, for example, the householders' thermal management skills, a particular attribute such as the occupational status of the household head, or a combination of several characteristics, such as previous experience in houses, length of occupancy in the present house and the household income.

A three-fold attempt is made to identify the "best" house for Adelaide's climate[1]: first, the householders' views on climate suitability (and comfort) are considered, views based on their own

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1. The comparison of opinions from more than one group is used by Troy (1971, 7) in assessing the quality of the residential environment. At least two measures were considered necessary: the "collective" measure, or standard held by the community in general, based on the argument that consumers can perceive environmental quality only in relation to their experience; and the "elitist" measure, held by a group (such as townplanners) the members of which know, from their training and expertise, what is "good for the community". Other studies have also recognized the problem of finding people to be totally indifferent to a number of features which planners consider to be important (Lansing and Marans 1969; Michelson, 1968; Rapoport, 1970; Cooper, 1975).

experience; second, professional views on climatic suitability are discussed, the opinions of designers and builders; third, the major measures of climatic suitability and comfort used in this study are reviewed, namely the climatic suitability scores (of Chapter 6), the householders' evaluations of the comfort of their own houses and their (capital) expenditure on comfort-related equipment (of Chapter 7) and the data on household energy consumption (of Chapter 8).

The Householders' Views

Tables 9.01 and 9.02 show the nature of householders' responses to the following questions:

Qu 17. Imagine you are building (or buying) a new house in Adelaide without air conditioning. What design aspects would you include (or look for) to
(a) make the most of winter sunshine and warmth,
and (b) minimise the sun's effects in summer?

Qu 19. Could you please describe what you consider to be the best type of house for Adelaide's climate, with your reasons.

Although 25 per cent of householders in both sample areas stated that they had no knowledge or suggestions (or did not reply to the first question) the remaining householders displayed at least some awareness of climatic design principles (Table 9.01). Some answers were particularly comprehensive, displaying knowledge and understanding normally attributed to an "expert":

> "Build facing north with lots of glass on northern side (sun high in summer) and blinds for control. Minimise windows on west. To maximise winter sunshine we have a large sunroom and sleepout and it's wonderful. To minimise the sun's effects in summer use trees, shrubs, blinds, verandah, grapevines, passage for cross-ventilation."
>
> (Respondent from southwestern suburbs, Householder's Questionnaire Question 17)

TABLE 9.01

DESIGN ASPECTS LISTED BY HOUSEHOLDERS IF BUILDING A NEW HOUSE TO

MAXIMISE WINTER SUNSHINE AND MINIMISE SUN'S EFFECTS IN SUMMER

Design Feature	Attributes Most Frequently Mentioned	Percentage of Sampled Householders	
		Southwestern Suburbs (N = 306)	Salisbury East (N = 146)
Orientation of whole house	North or south preferred, or general statement	51	40
Shading methods	Eaves, verandahs, awnings	39	49
Windows	Size, nature, location	34	34
Orientation of particular rooms	Kitchen, living room, bedrooms	30	10
Trees, vegetation	Many trees, deciduous	17	16
Appliances, equipment	Ceiling insulation, heating, air conditioning	14	27
Wall and/or roof material	Brick cavity walls, tiled, pitched roof	12	16
Ventilation	Necessary, "cross-ventilation good"	11	6
Other design features	Ceiling height "like present house"	8	9
Colour of material	Light	5	8
Other		12	10

Source: Householder's Questionnaire (Question 17).

Chi-square (original data) = 33.8754, df = 10, s = .001

TABLE 9.02

FEATURES LISTED BY HOUSEHOLDERS IN DESCRIPTION OF "BEST" HOUSE FOR ADELAIDE'S CLIMATE

Feature	Attributes Most Frequently Mentioned	Percentage of Sampled Householders	
		Southwestern Suburbs (N = 306)	Salisbury East (N = 146)
Nature of outer walls	Brick cavity, brick and stone	59	58
Shading methods	Verandahs, eaves, outside awnings	48	36
House style	Old homestead, bungalow/modern	48	26
Design feature of older house	Ceiling height, size of rooms, thickness of walls	29	8
Trees, vegetation	Large quantity, deciduous	27	8
Nature of roof	Tiles, pitched	24	21
Appliances, equipment	Ceiling insulation, air conditioning	21	30
Windows	Size, nature, location	19	17
Design aspects, new houses	Ceiling height, size of rooms, "Spanish/Mediterranean"	16	10
Ventilation	"Cross-ventilation" necessary	13	6
Orientation of house or of particular rooms	North or south, living room	14	7
Like present house		12	6
Maintenance, shelter	Minimum upkeep, shelter from elements	9	5
Outdoor living facilities		8	7
Colour of materials	Light	6	8
Other		20	17

Source: Householder's Questionnaire (Question 19).

Chi-square (original data) = 43.7471, df = 15, 2 = .001

Some were rather cynical:

> "If I could give an original and economical answer to this question I would be waiting for the patent's office to open tomorrow morning and then go and flog it off to AVJ or the highest bidder ..."
>
> (Respondent from Salisbury East, Householder's Questionnaire Question 17)

Others were honest:

> "I just wouldn't buy a house without air conditioning."
> "I'd ask an architect - no personal technical knowledge or skill."
>
> (Respondents from southwestern suburbs, Householder's Questionnaire Question 17)

Nevertheless, a sizeable percentage of respondents recognized the importance of orientation (whether of the whole house, or for particular rooms), the need for shading methods and the importance of window size and placement on indoor comfort.

There were fewer non-responses to Question 19 (describing the best house for Adelaide's climate) and many of these were the recently-arrived householders in the Salisbury East sample group, whose period of residence in Adelaide was insufficient to offer an opinion. There was a distinct preference for a house of solid construction (cavity brick, brick and stone outer walls, with a tiled, pitched roof) that was well-shaded from summer sun, and which had other features (such as ceiling insulation, air conditioning and heating) to further improve comfort levels (Table 9.02). Considerable thought preceded some replies:

> "I think that the ordinary cream brick, clay tiled, peak-roofed, wide eaved L-shape suburban home in a medium-sized block with a pretty front garden and liveable back garden has a lot going for it, regardless of the critics. There is a minimum upkeep, the L-shape can provide a sheltered area for outdoor living (essential in our climate), the front garden can hold parents' prized plants, and the back garden should work around the children - sandpits, hit-up wall, climbing treees etc. It would seem that wide verandahs and pale building materials are important to help combat the heat of summer, but it is just as important to allow inside plenty

of winter sun. A north-facing family room with a trellis for a deciduous climbing plant would be ideal. Sunshine in a kitchen is a great morale-booster also. Every home should have an outdoor eating area. Wide passages help ventilation and are good as play areas for children."

(Respondent from southwestern suburbs, Householder's Questionnaire Question 19)

Others provided fewer details, but indicated the wide range of opinions:

"Single-storey bungalow."
"Build in the middle of a lake, with the house sinking in summer, raising in winter."
"Stone walls 18" to 2 ft thick with verandah right round and slate-shingle roof."

(Respondents from both sample areas, Householder's Questionnaire Question 19)

Thus, when asked to describe the "best" house for Adelaide's climate, householders stated a general preference for a house of solid construction, well-shaded (by verandahs, eaves, awnings and vegetation) with various other features (high ceilings or air conditioning or good cross ventilation) according to taste. These subjective householders' views can now be compared with professional views on, and non-subjective measures of, climatic suitability and comfort.

The Professional View; Opinions of Architects/Designer and Building Firms

The question "What is the best house for Adelaide's climate?" was put to groups of other professionals, namely architects/designers and building firms. The interviewed architects were relatively consistent in their opinions, emphasizing the basic principles of orientation, shading, insulation, building materials and windows.

> "Siting is the most important feature to maximise winter sunshine and minimise summer sun: we always try for a north-south orientation, as it gives so many rewards when people move in. We will indent a house if necessary, or use the building itself to provide shade from the west - and recommend trees, especially if deciduous. We always try to provide for cross-ventilation and outdoor living areas, and we have to take into account local winds, such as the gully winds at night in the foothills. However, design will not compensate for all features (extremes) of our climate but insulation and sensible management help to minimise energy-wasting heating and cooling - and people are becoming less able to put up with small hardships."
>
> (Architect Interview, June 1975)

Most architects, particularly those on individual commissions, have the opportunity to put these design principles into practice. However, as shown in Chapter 4, architect-designed houses are relatively few in number, on widely scattered sites and above-average in price. Their impact on the general housing market is small.

Building design firms, particularly those "selling" designs to commercial builders, are less able to incorporate climatic design principles.

> "....the public are not very aware of orientation .... some can be influenced a little, but if a client has a west-facing block and insists on a particular type of design all we can do is try to restrict window size a little and suggest other means of sun control. There is more awareness (among clients) of outdoor living areas, heating and cooling methods and the value of ceiling insulation, but few consider cross-ventilation. However, most of our designs are not intended for a particular site or orientation: we prefer to provide a variety of functional room layouts each of which can be built with three or four different facades, and rely on the common-sense of the builder or client to select a suitable design for the site."
>
> (Building Design Firm Interview, July, 1975).

Builders, responsible for the bulk of design and house construction, have to be even more pragmatic:

"We try to design and build quality, appearance, practical utilities, balanced areas according to price and frequency of use. Houses with main rooms to take advantage of views, carports on weather or west side, living rooms with large windows facing north, concrete paths, driveways etc. But 99% of house buyers are appallingly ignorant of what makes a liveable home - they look for big living areas, big lounges, big bedrooms, big kitchens, big bathrooms, big laundries, big cupboards and cannot relate this to a cost of about $17.00 per square foot of floor area. They expect to pay about $2,000 deposit and $28.00 weekly - the same as two years ago."
(Building Firm Interview, June 1975).

"In ... (Housing Estate) ... you would find that the houses predominantly face west because of there being less build-up factor if they are built that way than if they ran up the hill and also, of course, people seem to think that the view to the west is something worth preserving. So if you are going to do a little sum, you are going to equate the cost of cooling a house on the 20 odd days of the year against the cost of excessive build-up which might be of the order of $2,000 or $3,000 and even given that they were aware of the benefit, then most people would still opt to cool the house at the lesser cost, plus what they imagine are the other benefits of the view, of course."

(Building Firm Letter, October 1977).

Professional expertise, like that of the householders, produced no definitive description of house style, age or architectural character that is considered most suited to Adelaide's climate. Architects tended to emphasize "passive" design principles, - the careful use of building design to maximise indoor comfort - and the modification of designs to suit individual sites and client requirements. Builders, on the other hand, tended to incorporate climatic design principles in house construction only if they helped to reduce building costs or improve sales appeal[2]. Building designers appeared to hold a view somewhere between the two extremes.

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2. For example, late in 1978, some South Australian house builders stressed the availability of "solar water heating" as a design option.

Measures of Climatic Suitability and House Comfort Used in This Study

The householders' and professionals' views on climatic suitability and comfort can now be compared with the findings of this study, where four major measures [3] of climatic suitability and comfort were used. Three "measures" were largely objective (the climatic suitability scores, the "capital cost" of comfort and household energy consumption); the fourth (householders' evaluations of the comfort of their house) was largely subjective.

Climatic Suitability Scores

From the expertise of Adelaide designers and builders (see Chapter 4) and related research on the thermal properties and performance of buildings (see Chapter 6), climatic suitability scores were developed to integrate several climatic design features into a single objective measure which identified houses best suited to summer, winter and year-round conditions. Chapter 6 showed that older houses, with less glass, more shading features, and thick walls scored well in summer time, whereas newer houses with north-facing glass and ceiling insulated scored well in winter. However, of the twenty-three Adelaide house-styles identified, no single style merged as ideal. A better

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3. The indoor temperature survey cannot be considered a "major" measure of climatic suitability and comfort. Nevertheless, it gave some indication of the extent to which indoor thermal conditions are affected by the house design and structure (such as the orientation of particular rooms, or the nature of the wall and roof materials) and by the behaviour of the occupants (such as closing doors and windows on a hot day). Such evidence serves to highlight the complex interaction between house, occupant and the achievement of indoor comfort.

performance tended to be associated with particular architectural features of the house (regardless of its age) rather than a particular house style. A rectangular house, with maximum glazing to the north, eaves (and verandahs) of correct width, cavity brick walls, an insulated ceiling and planting (deciduous and evergreen) has the features which maximise winter sunshine and cool summer breezes, but minimise summer sun and cold winter winds.

Although no individual house-style necessarily has these features, there is a greater probability that they will be found in housing of a certain age. Medium-to-large windows and ceiling insulation, for example, are far more common in houses built after 1950[4]. Of the five main groups of "house style and age", whose features are summarized in Figures 9.1 to 9.5, there is a tendency for the two groups of housing built after 1950 to score highest in terms of overall climatic suitability[5], houses built before 1930 to score highest in terms of summer climatic suitability and houses built after 1965 to score highest in terms of winter climatic suitability. Few attributes describing characteristics of the occupants were significantly related to the "measured" climatic suitability of the house, apart from a general tendency for the climatic suitability scores to increase as the occupational status of the household head increased[6].

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4. See Tables 6.15, p. 182 and 6.12, p. 177.
5. See Table 6.30, p. 203.
6. See Table 6.37, p. 216.

The Householders' Expenditures on Comfort-related Equipment

Householders' (capital) expenditures on such items as heating and cooling equipment, ceiling insulation and outside awnings tended to be higher for dwellings built after 1950[7] after five or more years of residence[8]. Although not statistically related to present income or to occupational status of the head of the household[9], this capital expenditure was quite strongly related to the householder's estimate of house comfort[10]. Those householders with higher expenditure tended to be highly satisfied; those with lower expenditure tended to be dissatisfied. Since at least half of this capital expenditure was on energy consuming appliances for the improvement of thermal comfort (space heating, air conditioning, portable heaters, fans) then a house evaluated as "highly comfortable" by its occupants was likely to also be a household of high energy consumption (see Table 9.03).

The Householders' Evaluations of House Comfort

Householders varied in their levels of satisfaction with the comfort-related features of their houses[11]. The level of satisfaction was highest among householders living in houses built before 1966[12],

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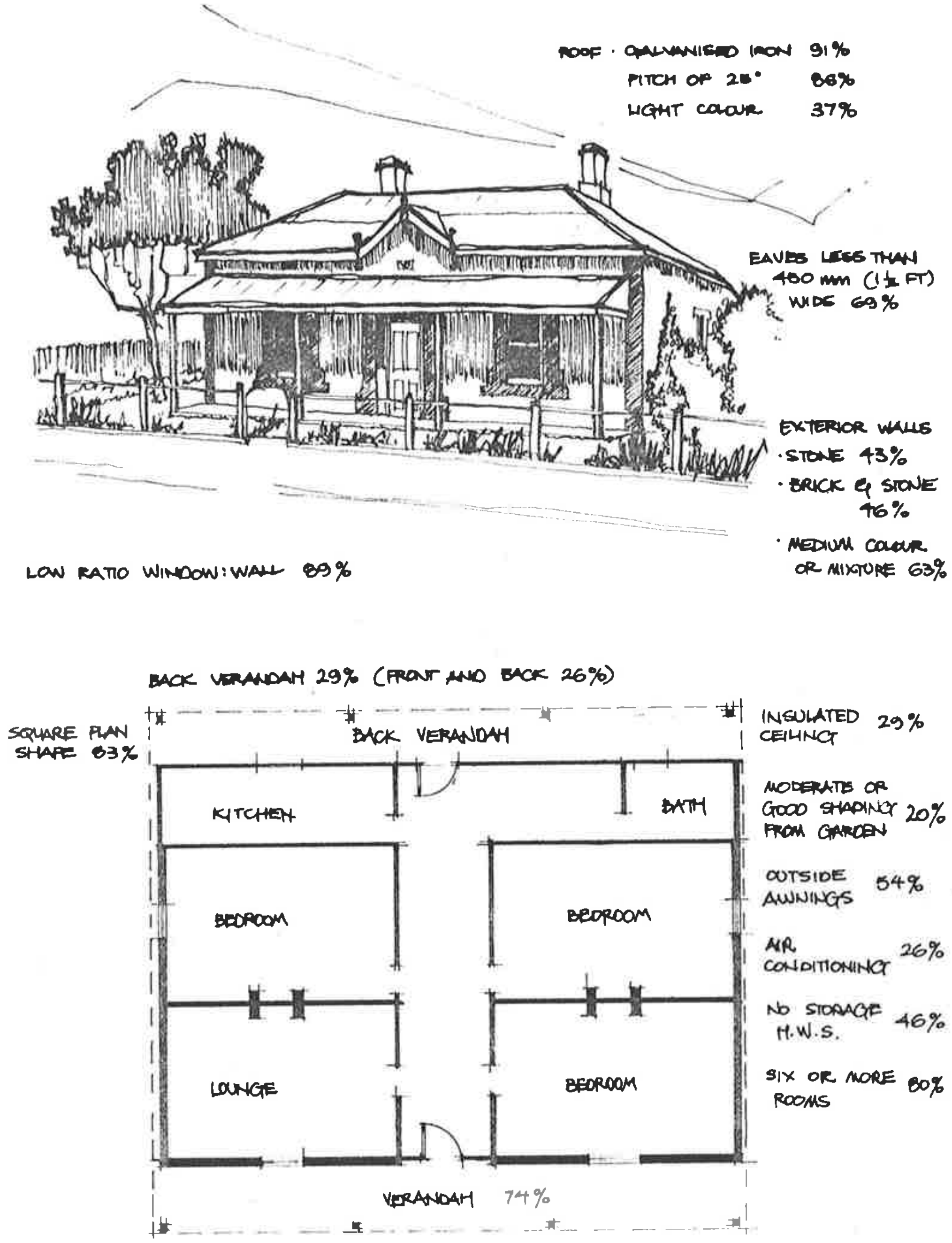
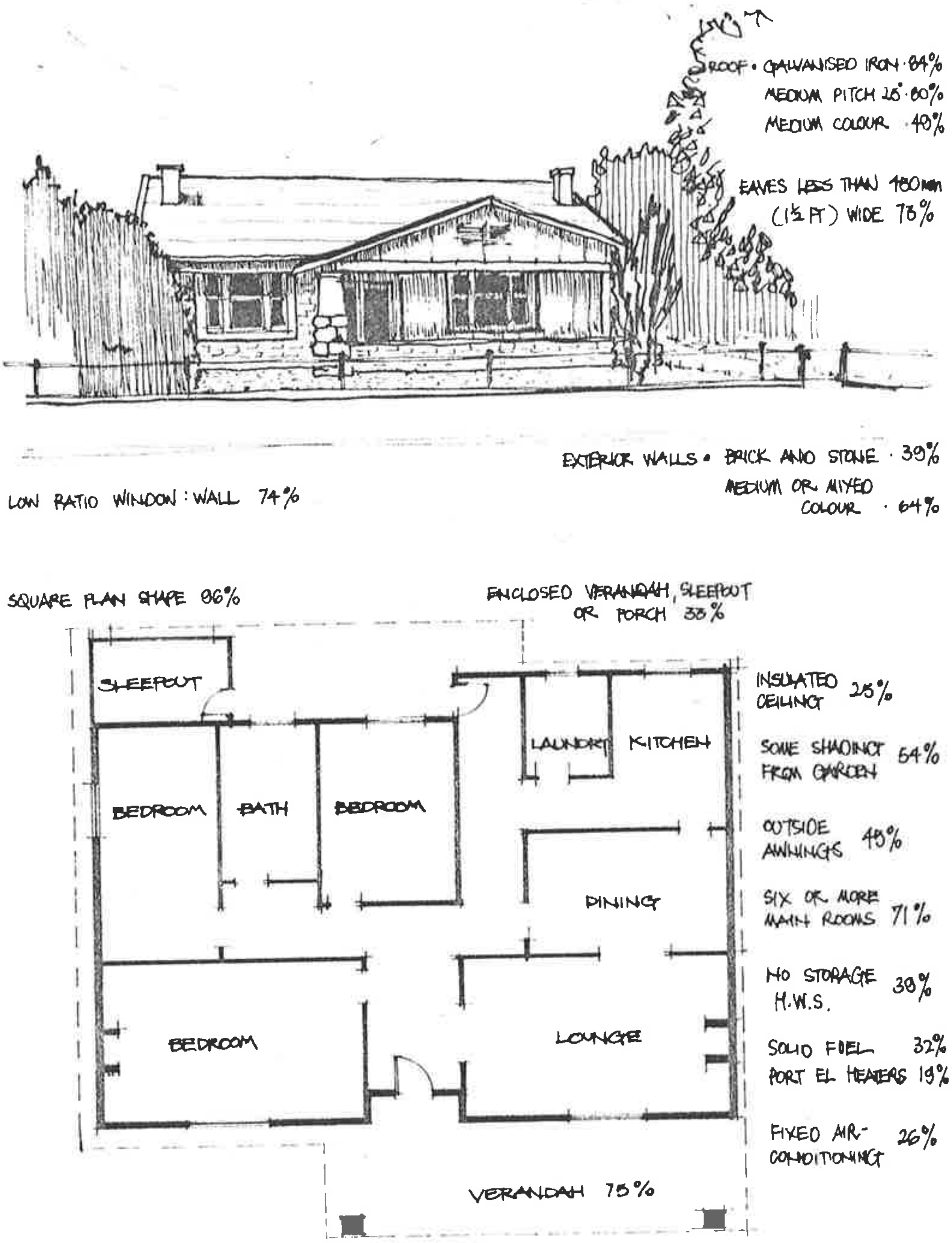
7. See Table 7.24, p. 276.
8. See Table 7.36, p. 286.
9. See Table 7.31, p. 284.
10. See Table 7.25, p. 276.
11. See Tables 7.11 to 7.16, pp. 254-263.
12. See Table 7.22, p. 274.



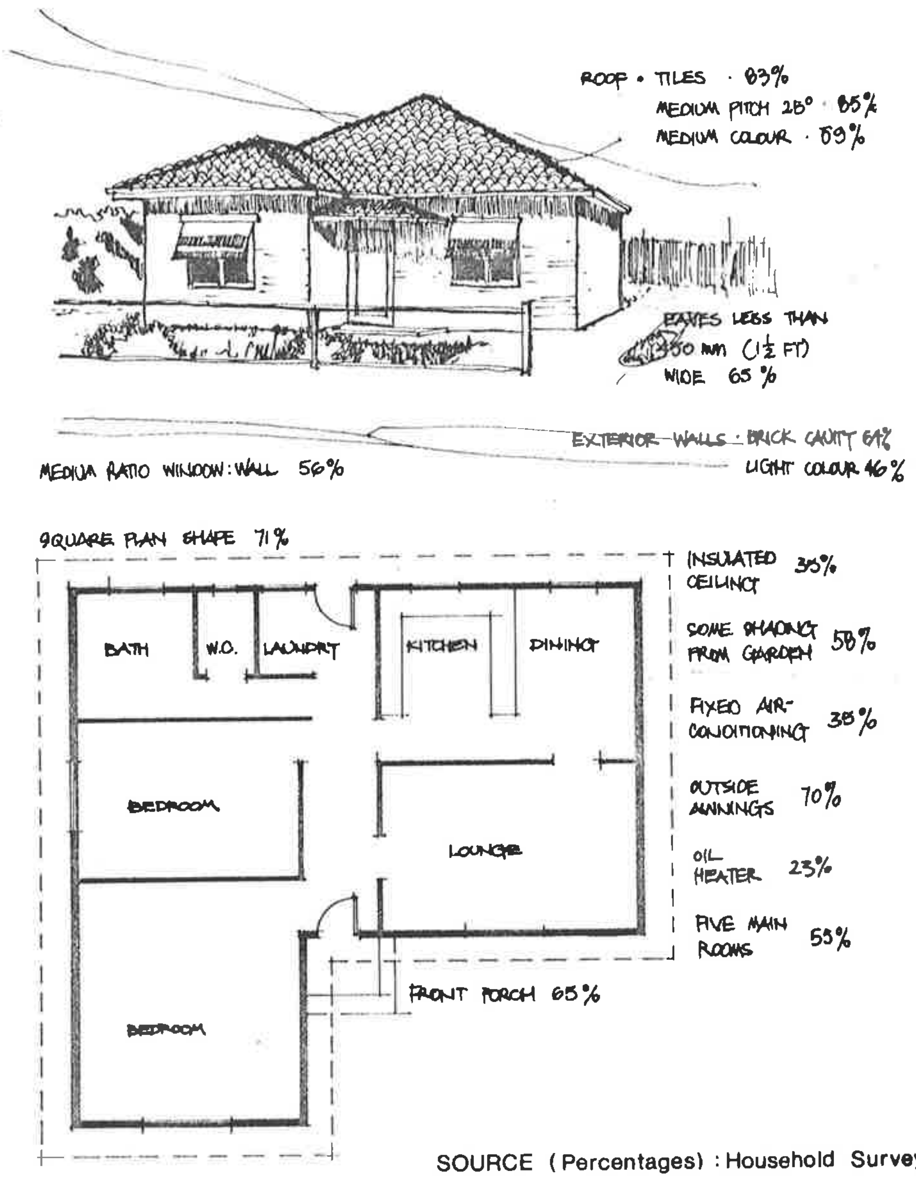
SOURCE (Percentages) : Household Survey

FIG. 9·1 FACADE AND PLAN OF A HOUSE BUILT BEFORE 1905 SHOWING PERCENTAGE OF SAMPLED HOUSES WITH EACH STRUCTURAL AND CLIMATE RELATED FEATURE (N = 35)



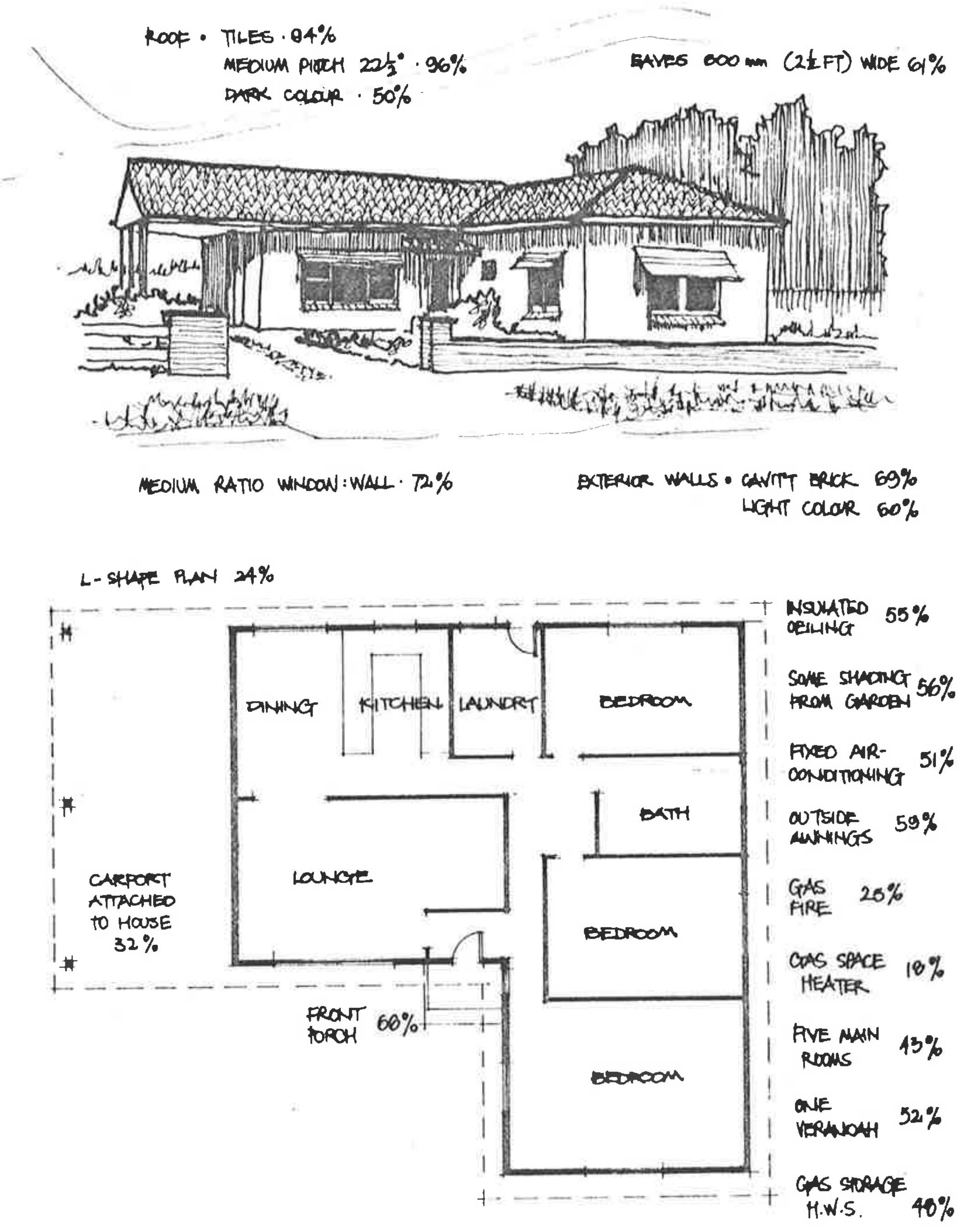
SOURCE (Percentages): Household Survey

FIG. 9·2 FACADE AND PLAN OF A HOUSE BUILT BETWEEN 1905 AND 1945 SHOWING PERCENTAGE OF HOUSES WITH EACH STRUCTURAL AND CLIMATE RELATED FEATURE (N = 69)



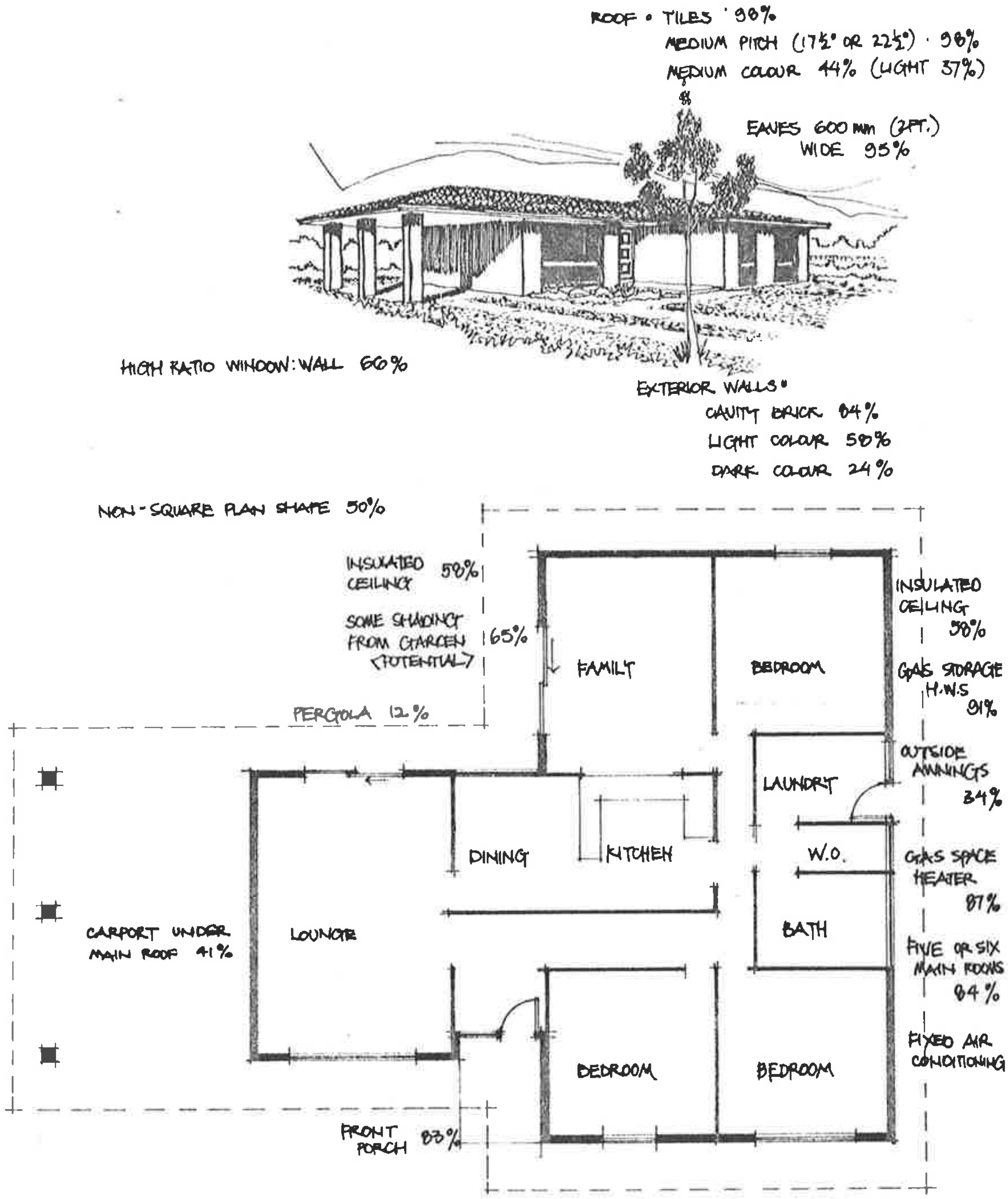
SOURCE (Percentages) : Household Survey

FIG. 9·3 FACADE AND PLAN OF A HOUSE BUILT BETWEEN 1947 AND 1952 SHOWING PERCENTAGE OF HOUSES WITH EACH STRUCTURAL AND CLIMATE RELATED FEATURE (N = 66)



SOURCE (Percentages): Household Survey

FIG. 9·4 FACADE AND PLAN OF A HOUSE BUILT BETWEEN 1952 AND 1965 SHOWING PERCENTAGE OF HOUSES WITH EACH STRUCTURAL AND CLIMATE RELATED FEATURE (N = 126)



SOURCE (Percentages) : Household Survey

FIG. 9·5 FACADE AND PLAN OF A HOUSE BUILT BETWEEN 1966 AND 1974 SHOWING PERCENTAGE OF HOUSES WITH EACH STRUCTURAL AND CLIMATE RELATED FEATURE (N = 156)

with verandahs and other shading features[13], facing north or south[14], with an insulated ceiling[15]. Furthermore, satisfaction increased with a long period of residence[16], an older, Australian-born household-head[17], in a non-earning occupation[18], and a smaller household size[19]. According to the householders' estimations, indoor comfort resulted partly from the design and structural features of the house, and partly from maturity, experience[20] and by expenditure on items such as ceiling insulation, air conditioning or outside awnings. Many householders considered that comfort could only be achieved by artificial heating and cooling[21], so that most "highly satisfied" householders also used large amounts of energy. Table 9.03 shows that the second highest average users of energy were households in which the householder was "dissatisfied", presumably to compensate for poor design and structure, or as a result of operating inefficient appliances. In other words, there was no direct relationship between the householders' evaluations of their house comfort and the average annual energy consumption of the household.

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13. See Table 7.23, p. 274.
14. See Table 7.28, p. 279.
15. See Table 7.29, p. 281.
16. See Table 7.35, p. 287.
17. See Tables 7.33 and 7.34, p. 285.
18. See Table 7.32, p. 284.
19. See Table 7.30, p. 282.
20. Several elderly, long-resident householders stated that their houses were comfortable because they and their houses were "too old to change now".
21. The relationship between possession of, and attitude towards, air conditioning in own house is shown in Table 7.08, p. 245.

TABLE 9.03

AVERAGE ANNUAL ENERGY CONSUMPTION OF HOUSEHOLDS ACCORDING TO HOUSEHOLDERS' LEVELS OF SATISFACTION WITH COMFORT OF THEIR HOUSES.

Level of Satisfaction	Sample Size	Average Annual Energy Consumption		
		Electricity (kWh)	Gas (MJ)	Primary-Energy Equivalent (GJ)
Highly satisfied	79	4,885	18,313	95.1
Satisfied	81	4,157	16,154	83.8
Moderately satisfied	96	4,316	20,593	90.9
Moderately dissatisfied	84	4,173	26,130	94.3
Dissatisfied	112	3,813	32,745	94.8

Source: Household and Energy Consumption Data

There was, however, general agreement between these householders' assessments of the comfort of their houses and the overall climatic suitability scores. Table 9.04 shows that some inconsistencies also occurred: for example, six houses with very low climatic suitability scores were assessed as highly comfortable by their occupants, while three houses with very high climatic suitability scores were occupied by householders very dissatisfied with the comfort of their houses. A west-facing, uninsulated, concrete-block "Austerity" house, with narrow eaves, a small verandah at the rear (eastern side) and two bamboo awnings was assessed as highly comfortable by its residents; whereas a north-facing, insulated, brick cavity house well protected by deciduous trees, awnings and a verandah was occupied by a householder very dissatisfied with room temperatures in summer and in winter, and the way in which the house cooled down after a heat wave. Such discrepancies

TABLE 9.04

RELATIONSHIP BETWEEN OVERALL CLIMATIC SUITABILITY SCORE OF THE HOUSE AND HOUSEHOLDERS' ASSESSMENTS OF COMFORT

Householder's Evaluation	Overall Climatic Suitability Score (Percentage of Sampled Houses)						
	2 and under	3-4	5-6	7-8	9-10	11=12	13 and over
High	11	20	11	12	21	26	36
Moderately high	18	15	19	17	18	23	14
Moderate	18	15	18	21	28	30	23
Low to moderate	22	17	19	27	13	13	14
Low	31	33	33	23	20	8	14
Total	100	100	100	100	100	100	100
	n=55	n=81	n=79	n=86	n=76	n=53	n=22

Source: Household data

Chi-square (original data) = 39.020,df=24, S=.027

Kendall's tau_c = .159, S=.000 (a negative tau indicates that the overall climatic suitability score increases as the householder's assessment increases)

highlight the difficulties in attempting to measure "comfort", and the general tendency for householders to tolerate or ignore thermal discomfort in favour of other factors of the house, such as its appearance, cost or location.

Household Energy Consumption

The analysis of household energy consumption (Chapter 8) showed that average annual consumption was related more to the major appliances, the size of the house and the nature of the household than to the style and age of the house. Energy consumption was shown to be related to the number of main rooms[22], the type of room heating equipment and type of hot water system[23], the presence of air conditioning and ceiling insulation[24], the size of the household[25], the occupational status of the household head and the household income[26]. It was also shown that much of the variation in household energy consumption could not be "explained" for such reasons as measurement error, technical variables, and attitudinal and behavioural factors.

Discussion

Some of the pairwise relationships between these four measures of climatic suitability and comfort have been discussed above. When all four "variables" are considered, the relationships are more complex. For example, the three variables, "measured" climatic suitability, the householder's capital expenditure on comfort and the household's average energy consumption showed a statistically significant positive correlation. In other words, a house with a high climatic suitability score tended also to have such modifications and equipment as ceiling

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22. See Table 8.08, p. 314.
23. See Table 8.11, p. 322 and Figure 8.1, p. 320.
24. See Table 8.12, p. 323.
25. See Table 8.13, p. 327.
26. See Table 8.14, p. 329.

insulation, space heating and air conditioning and high average annual energy consumption. The relationships between these three variables and the householder's evaluation of house comfort, however, were less consistent. Although there was a significant tendency for high capital expenditure to be associated with comfort (Table 7.25) and some tendency for householders of climatically-suited houses to assess their dwellings as comfortable (Table 9.04), there was no correlation between this assessment and the energy consumption of the household (Table 9.03).

When a fifth variable, "house style and age" was introduced, then the complexity of inter-relationships increased (the style and age of the house was suggested as a possible answer to the "best" house for Adelaide's climate). Table 9.05 summarizes data on climatic suitability scores, householder's capital expenditure on comfort, householder's evaluation of the comfort of the house and household energy consumption, relative to the five classes of house style and age. It shows that houses built before 1905 appeared to be best suited to Adelaide's summer climate and tended to be occupied by householders whose expenditure on energy-saving or energy-consuming equipment and evaluations of the comfort of the house were below average. The average household, however, occupying a house of this age used moderate annual amounts of energy. Typical houses built between 1905 and 1945 were moderately well suited to Adelaide's summer conditions and were assessed as reasonably comfortable by their occupants, despite the lowest average capital expenditure and energy consumption. Immediate post-war austerity homes (built between 1947 and 1952) were least suited climatically, but assessed as "highly comfortable" by their occupants, presumably as a result of considerable expenditure on energy-consuming equipment and a relatively-high annual consumption of energy. Houses built between

TABLE 9.05

SUMMARY OF RELATIONSHIPS BETWEEN HOUSE STYLE AND AGE AND MEASURES OF CLIMATIC SUITABILITY, COMFORT AND ENERGY CONSUMPTION

House Style and Age	Climatic Suitability Scores			Householder's		Annual Energy Consumption of Household
	Summer	Winter	Overall	Capital Expenditure on Comfort	Level of Satisfaction with Comfort of House	
Symmetrical Front and Early Villas, 1850-1905	●●●●●	●	●●●	●●	●●	●●●●
Later Villas, Bungalows and Tudor, 1905-1945	●●●	●●	●●	●●	●●●	●
Austerity, 1946-1952	●●	●●	●	●●●●	●●●●	●●●
S.A.H.T., L-shape, Conventional, 1952-1965	●●●●	●●●	●●●●	●●●●●	●●●●	●●●●●
New, 1966-1974	●●	●●●●●	●●●●	●●●	●	●●●●

Source: Compiled from data in Tables 6.30, 7.22, 7.24, 8.10

Legend:
- ●●●●● well above average
- ●●●● above average
- ●●● average
- ●● below average
- ● well below average

1952 and 1965 scored well in terms of climatic suitability, and were occupied by satisfied householders, with the highest average capital expenditure on equipment and annual energy consumption. The final group of houses, those built after 1966, performed best during winter-time, were assessed as uncomfortable (especially in summer time) by their occupants, who had spent moderate amounts on equipment, and who used relatively high annual amounts of energy, particularly of gas.

In other words, the most climatically-suited group of houses for summer were those built before 1905, for winter those built after 1966, and, for both seasons, those built between 1952 and 1966. The groups of houses with highest capital expenditure on comfort and the most highly satisfied occupants were those built between 1946 and 1966. The group of houses with lowest energy consumption were those built between 1905 and 1945. If the three criteria of climatic suitability, physical comfort <u>and</u> energy efficiency were collectively taken into account, no single "house style and age" could be identified as "best" for Adelaide. Houses built between 1952 and 1966 scored well in terms of climatic suitability and comfort but also had the highest energy consumption.

Similarly, no clear-cut pattern emerged when other possibilities (mentioned at the beginning of this chapter) were investigated as the solution to the "best" house for Adelaide's climate. Even the attribute most clearly and consistently related to the measures of climatic suitability and comfort used in this study, namely the presence of ceiling insulation, was also related to higher average household energy consumption.

The Need for Improvement in the Levels of Climatic Suitability, Comfort and Energy-Efficiency of Adelaide's Housing

Despite the difficulties in identifying the "best" house for Adelaide's climate, it is possible to generalize about the level of climatic suitability, comfort and energy efficiency in Adelaide, and thus suggest how these could be improved. A categorical conclusion about the climatic suitability, comfort and energy-efficiency of Adelaide dwellings would require an absolute measure of these attributes for comparative purposes. Although techniques for evaluating the cost effectiveness of energy conservation measures are now available (Williamson, 1978) there is no single quantitative measure which describes all aspects of climatic suitability, indoor comfort and energy-efficiency. A major difficulty is that of assessing "comfort". Computer-simulated techniques can be used to predict indoor temperatures, and the frequency of occurrence of "uncomfortable" conditions, but they do not take into account individual differences, (such as the value placed on sunlight) and variations from room to room within the house. For example, the living room may be very comfortable, but the house may also have a cold and draughty laundry, a warm, sunny sunroom and a kitchen which overheats in summer. It is thus difficult for the householder or a piece of monitoring equipment to provide an objective assessment of the year-round comfort of the house. (In this study the householders' evaluations of house comfort were obtained from their separate evaluations of nine comfort-related features). Similarly, the attempt to combine the separate attributes of design and structure into a single index of climatic suitability can be criticized on the basis that such attributes cannot be treated additively.

In the absence of any appropriate means of quantitative comparison of the climatic suitability and comfort of housing a number of qualitative interpretations of the data can be presented. For example, it might be argued that the data (of Chapters 4 to 8) show that the houses of Adelaide are sufficiently suited to the climate, given its relatively benign nature, the ways in which houses are modified if necessary and the high level of satisfaction with house comfort expressed by some householders. Such interpretation would lead easily to the conclusion that improved design is unimportant, and that there is no need to place greater emphasis on climatic design, comfort and energy-efficiency.

However, it is argued here that there is much room for improvement. Chapters 4 and 5 showed that, during the design, construction and sale of most houses, other considerations - such as costs, availability of building material and tradespeople, appearance, sales appeal, prestige and fashion - took precedence over climatic suitability and indoor comfort. Most house styles were imported from overseas. When transferred into South Australia (from the Eastern States), further modified and either rejected or assimilated, even those styles originating in similar climates tended to lose their space, visual effect and original cohesion. Marshall (1963a,20) argues that the absence of housing styles appropriate to Adelaide's climate is likely to continue while fashion, costs and limited architectural supervision remain.

A further reason for the low priority given to climatic suitability and comfort is the nature of the house-design process in South Australia. Most houses are designed by builders, for whom the usual process is to meet only the minimum standards of building regulations and to maximise the number of blocks in any housing development

(Hutchings, 1976,15). Even those firms who construct houses on land subdivided by developers tend to build a limited range of designs with proven sales appeal. The choice then available to most (new) home-buyers is either a ready-built "spec" house or a contract-built house, selected from the builder's range of plans. Although extreme care was taken by most building firms to present a range of acceptable, sales-appealing, cost-efficient designs, none systematically investigated the satisfaction (or otherwise) of the householder after a year or more of occupation. Thus, in the private sector of the house-building industry, there is virtually no feedback from dissatisfied clients to the designers and builders. Since architects are individually commissioned mostly by the wealthy or contribute to the design of project or public sector housing, there is little real possibility of architect involvement being increased to such an extent that would make a significant impact on Adelaide's suburbs. The South Australian Housing Trust recently modified many of its designs, but is still largely restricted to the provision of low-cost housing. Only seven per cent of home owners feel competent (or sufficiently desperate?) to design their own homes.

The data on climatic suitabiity and indoor comfort of the sampled houses (presented in Chapters 6 and 7, and summarized in Table 9.06) also indicate the need for improvement. Desirable climate-related features of design or structure appeared only in a minority of sampled houses (only 26 per cent faced north, for example). Indeed most houses scored less than half the maximum when evaluated for summer, winter and overall climatic suitability. Even those houses scoring over 75 per cent of the maximum (one or two per cent of the total) tended to achieve this largely by chance. Furthermore, a sizeable minority of

TABLE 9.06

SUMMARY OF FEATURES RELATED TO CLIMATE, COMFORT AND ENERGY CONSUMPTION IN THE SAMPLED HOUSES AND HOUSEHOLDS

Feature of House or Attribute of Householder	Category or Attribute	Sampled houses (N = 452)	
		Number	Percentage
Climate-related feature			
Shape of house	Rectangular	67	14.8
Orientation (main glazing area)	North	116	25.7
Outer wall material	Brick cavity	303	67.0
Colour of roof	Light	116	25.7
Ceiling insulation	Present	211	46.7
Verandahs	One or more	216	47.8
External window protection	Outside awnings	231	51.1
Garden planting	Summer shade on house	74	16.4
Climatic suitability scores			
Less than 50% of maximum	Summer	244	54.0
	Winter	273	60.4
	Overall	214	47.3
More than 75% of maximum	Summer	3	0.7
	Winter	7	1.5
	Overall	1	0.2
Comfort of house (householder's evaluation)			
Room temperatures in summer	Dissatisfied	140	31.0
Amount of shade on house	Dissatisfied	109	24.1
Cooling ability of house	Dissatisfied	91	20.1
Room temperatures in winter	Dissatisfied	71	15.7
Rooms uncomfortable in certain types of weather	Two or more	119	26.3
Energy-related features			
Space-heating	Gas or oil	225	49.8
Portable heating	Electric radiators	314	69.5
Air conditioning	Fixed	125	27.7
Storage hot water service	Electric	106	23.4
House size (main rooms)	Seven or more	89	19.7
Household size (persons)	Six or more	44	9.7
Household income (annual)	$12,000 or more	47	10.4
Householder's capital expenditure on equipment	$1,000 or more	71	15.7

Source: Summarized from various Tables in chapters 6, 7 and 8.

householders were dissatisfied with some aspect of the comfort of their house, especially its performance during summer, which had prompted them to make several comfort-related changes. The level of house modification was particularly high in the Salisbury East area, where, within five or less years of residence, half the sampled householders had installed ceiling insulation, a third air conditioning and/or outside awnings and a fifth a verandah to their houses. Even with such modifications, many householders were still dissatisfied with the comfort levels of their houses, especially during weather extremes. Most admitted that such considerations as purchase (and repayment) costs, size and room layout, general appearance and location were far more important in their house selection than climatic suitability and indoor comfort. They preferred to insulate the house, or purchase heaters, air conditioners or sunshades after the initial financial impact (of purchase) had been digested[27].

The data on household energy consumption (of Chapter 8) demonstrated the tendency for Adelaide householders to achieve physically comfortable conditions only with considerable use of energy for hot water, space heating, space cooling and other purposes. The average annual primary energy consumption (in 1974-75) of the sampled households (92.0 GJ) and

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27. White (1975, 20) argues that the average Australian's tendency to prefer a "technological" solution rather than a "natural" one, and for "an apparently low first-cost solution even at the risk of high, unpredictable future costs" may lead to reluctance to accept the often simple solutions to internal climate control that are made possible by "integrated thermal design".

consumption per capita (30.6 GJ) is thus sufficiently high[28] to warrant remedial action if finite energy sources are to be conserved. Recent studies (such as Williamson, 1978) have shown that substantial energy savings can be achieved by relatively few design and structural modifications to a house[29]. Yet, as discussed more fully in Chapter 10, there are many difficulties to be overcome before widespread energy-savings can be achieved. For example, a recurrent theme, throughout this study, obtained from all groups concerned with housing (designers, builders, real estate agents, householders, manufacturers and retailers) was the extreme variability in knowledge and

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28. Comparative figures are difficult to obtain, since measurement techniques vary. Nevertheless, Desson's (1976) study of households in the United Kingdom (where the colder climate could be expected to increase energy consumption) shows an average household consumption of 85.3 GJ per year in 1973, slightly lower than the mean obtained in South Australia in 1974-75. Furthermore, the consumption of electricity in South Australia is increasing annually, for two reasons: first, as a result of population increase (over 15,000 new consumers were supplied in South Australia during 1976); second, from a steady increase in per capita consumption (approximately four per cent per annum) part of which can be attributed to the increased ownership and operation of domestic air conditioners. (Personal Communication, J. Hoepner, Electricity Trust of South Australia, 1st June, 1977). Consumption of gas is also likely to increase, particularly since the many increases in the price of heating oil between 1974 and 1979 have made gas cheaper by comparison, for domestic usage, during 1979.

29. Williamson (1978) describes a cost-effectiveness technique for analysing the appropriateness of low energy housing solutions for Melbourne, in which a typical house (single storey, uninsulated, brick-veneer with timber floor, tiled roof and no summer-shading) is lowest in capital cost, but necessitates acceptance of an inferior level of thermal comfort. (The cost of energy required to operate it at the chosen level of thermal comfort between 20^{o} and 27^{o}C is so large that it would never be realised). A solar improved version (single storey, solid brick, concrete floor, tiled roof, maximum glazing to the north, insulated and sun-shaded) has additional capital costs, but an estimated annual energy consumption approximately one third that of the typical house. Most houses in Adelaide should perform better than this "typical house" described by Williamson (1978, 135) in as much as two thirds of them have brick cavity walls, and half have insulated ceilings, but there is little evidence of maximum north-facing glass, concrete floors and properly designed sun-shades.

understanding[30] of climatic design, comfort and energy consumption, and the sparse, unco-ordinated dissemination of knowledge. The problem is compounded by the tendency for the better educated, more articulate members of the community to demonstrate greatest knowledge, understanding and interest: this group also tended to be more affluent, able to select and occupy "better" houses, with more "energy-saving" and "energy-consuming" equipment and, consequently, operate at higher levels of indoor comfort and household energy consumption.

However, the "energy crisis" of the mid 1970's has already created a new awareness and started to change people's attitudes. Rising fuel prices (such as the 200 per cent increase in the price of heating oil in Adelaide between 1974 and 1979) and possible fuel shortages have demonstrated the need to concentrate on achieving comfort in all future houses with the minimum use of non-renewable resources. Householders of existing houses are also becoming aware of the need to "conserve" energy and reduce fuel bills.

The data presented in this study, and the difficulty in identifying the "best" house for Adelaide's climate have demonstrated the large gap between the ideal and actual situation. The overwhelming majority of houses built in Adelaide during the past 110 years have tended to ignore or under-rate the importance of climatic suitability and the provision of indoor comfort. At first this oversight was tolerated in the form of discomfort: in later years, discomfort was minimised by considerable use

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30. Tables 9.01 and 9.02 demonstrate that, although some householders showed considerable understanding of basic climatic design principles (and the ability to achieve practical application), others showed little knowledge or interest and no apparent desire to reduce energy consumption.

of energy for hot water, space heating, space cooling and other purposes. Since this coincided with an era of readily available, cheap fuel, there was no need to concentrate on achieving comfort by thermally efficient designs. Events in the latter half of the 1970's have indicated that this trend cannot continue. A change in priorities is needed to achieve a significant number of climatically-designed, comfortable and energy-efficient houses. The consequences of this change in priorities are far-reaching.

CHAPTER 10

TOWARDS IMPROVED CLIMATIC DESIGN IN HOUSING

This study has demonstrated that Adelaide houses are not well designed for the climate and that comfort is achieved only with the use of considerable energy. Given the desirability of improved thermal comfort and necessity of conserving finite energy sources, two questions remain to be considered. First, what are the implications for consumers (householders) of trying to obtain improved climatic design and energy-efficient dwellings? Second, if desirable energy savings can be achieved (with no reduction in living standards) by improved housing, and if it is assumed (drawing on the findings of this study) that there is a demand for such housing, what technical and methodological problems are going to be encountered by designers, planners, builders and decision makers? Methods of effecting change in Adelaide's housing and some of the practical difficulties and implications are discussed in this chapter.

The Nature of the Change

Improved climatic design and energy-efficiency whether in existing or new dwellings, requires changes in the ways in which houses are designed and constructed, selected, occupied, modified and managed. For any change to be widely and readily accepted, consumer advice and education will need to be improved, and satisfactory technical options (in equipment and appliances) maximised. Further incentives might need to be provided by changes in the tariff structures and costs of energy. Government action may be necessary if voluntary activities are ineffective.

Existing Houses

Most houses have a life-span of at least fifty years (probably longer in South Australia with its large percentage of stone and cavity brick construction). Furthermore, the cost of the energy required to construct the house is estimated to be equivalent to only two years operating consumption and approximately half of this operating consumption in Adelaide is for space heating and cooling[1]. With only approximately 7,000 new (detached) houses being added to the housing stock of Adelaide each year, even by the year 2000 A.D. well over half of Adelaide's householders will be living in houses built before 1975, prior to the first popular indications of the "energy crisis".

For the use of energy to be minimised in the household sector, energy-conserving measures should be primarily directed towards existing houses and their occupants. A number of options are feasible: ceiling insulation, for example, is relatively easy to install under the predominantly pitched roofs of Adelaide houses and has proven benefits both in summer and in winter and a relatively short "pay-back" period if the house is space-heated or cooled. Furthermore, with the percentage of houses being insulated increasing annually, other incentives (such as interest-free loans) or legislation, may not be necessary. Similarly, sun-shading devices for dwellings are readily available to Adelaide householders, and deciduous creepers and vines grow well in the "Mediterranean" climate. Other means of reducing heat loss and heat gain are less acceptable or more difficult to achieve. "Retrofitting"

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1. Although, as Table 8.06 shows, this may be closer to one third for houses using other fuels than electricity for room heating.

an existing house, for example, can be prohibitively expensive: if the single north-facing window is that of the bathroom or a small bedroom, for example, then only major structural alterations can place living areas to the north. The main method of "conserving" energy in existing houses probably lies in the many small, practical techniques the householder can adopt (ranging from reducing infiltration losses by effectively sealing all exterior doors and windows to regular servicing of the space heater). Other suggestions include the wearing of more clothing, (so that lower temperatures can be tolerated) or the use of partial or intermittent house heating (which needs a compensatory fast warm-up period which is aided by good insulation). These latter measures are probably less acceptable because they imply a reduction in living standards.

Public acceptance of the need for energy-conservation measures depends largely on the perceived value of the measures, comprehension of the issues involved, and the ability to translate these into meaningful action. The variation in knowledge and understanding about climatic design principles has already been shown. Consumer education and advice for householders of existing houses may be best achieved by direct action at a personal level. An independently run consumers' advice service[2], with free or low-cost visits to each house to discuss realistic improvements (to minimise heat loss, heat gain and reduce energy consumption) may be far more cost-effective than "commonsense tips" from the newspaper. The use of infrared photography is a possible

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2. "Consumer advisory services" currently available are organized by the energy-supply authorities such as the Electricity Trust of South Australia or the South Australian Gas Company.

technique for demonstrating to householders the particular areas of their house (such as the roof, windows, around doors) with high night-time thermal radiation by which most heat is escaping. For best effect, this service would need to be provided by an organisation with no vested interest in the sale of energy or equipment.

New Houses

Theoretically, the scope for increasing thermal comfort and reducing energy use through the design and construction of new houses is almost unlimited. However, there are many economic, technical and legal obstacles, both to the full utilisation of solar energy design by "passive" systems and of solar energy technologies by "active" systems. An entire industry needs to be developed, builders trained, financial arrangements created and consumer understanding encouraged.

Most truly "solar" houses have higher capital costs which, at minimum, will require adjustment to the housing loans policy of the State governments. For homeowners, accustomed to thinking only in terms of the costs at the time of purchase, reduced operating and maintenance costs appear remote and speculative: financial incentives and loan programs (Government sponsored) may be necessary[3]. Commercial builders, whose viability depends on sales, will need tangible proof of the merits of new techniques before introducing them on a widespread scale (remembering that the house-builders of South Australia,

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3. For example, the Fibreglass Insulation Manufacturers Association would like to see State governments make interest-free loans available to the householder to purchase insulation which could be paid back in instalments added on to the (two-monthly) gas or (quarterly) electricity bill.

responsible for 70 per cent of design and over 90 per cent of construction, have probably more influence on housing trends than any other single group). Leadership from the public sector (the South Australian Housing Trust) may be one solution (Platten, 1976). The "Residential Design Guide for South Australia" (South Australia, State Planning Authority, 1978) provides much needed information, of a practical but flexible nature, for use in designing new or evaluating existing living environments[4]. Energy supply and energy research organizations might be able to establish a range of demonstration solar energy homes in South Australia, each suited to the local climate, similar to those built and monitored in California, USA (Dempewolff, 1977; Anon,1979).

Since every solar house must have access to northern sun then the provision of access to sunlight needs to be (legally) preserved. Foreshadowing this need, a Law Reform Committee on Solar Energy started work in October, 1976 to investigate "the legal problems which may arise out of the use of solar energy in South Australia". The Committee's recommendations are likely to be wide-ranging, including suggested changes to the Building Act (orientation, shading of windows or insulation requirements), the Town Planning Act (street layout and subdivision) and consumer protection laws.

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4. The Guide contains fifteen sections, each headed by a clear statement of objective, (usually presented by means of a performance standard) followed by illustrations of a number of ways of achieving this objective. The performance standard of "Orientation and Siting", for example, is "Dwellings should be sited so that adequate amounts of sunlight can reach into each dwelling and private outdoor space". The section on "solar energy" states that "New residential developments should make practical use of solar energy". Interpretation in a flexible but co-ordinated and common-sense manner is encouraged.

The main potential for the use of solar power in "active" systems is currently in the provision of hot water[5], and the rate of installation of domesic solar hot water systems in South Australia is sufficiently high to indicate an increasing public acceptance. Other features of "solar" houses may be less acceptable[6], given the basic conservatism of South Australian home-owners. Widespread introduction of climatically-suitable, comfortable, energy-efficient housing may depend on how fashionable or desirable it can be made to appear, especially if the initial purchase price is higher. There are three basic groups of homeseekers: an upper income group able to afford any housing on the market; a middle income groups able to purchase only dwellings of the types and standards currently common on the market; and a low income group restricted to low cost (often public) housing. If a situation were to arise where climatically-suited, comfortable, energy-efficient dwellings dominated the new housing market in the way that housing with few of these attributes has dominated markets during recent decades, the middle and low income groups could be disadvantaged unless particular care were taken to provide the same quality of design over a wide range of purchase prices. Since, in the near future, the capital cost of

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5. Using existing technology, the approximate potential contribution of solar energy towards annual water heating is 70 per cent in Adelaide (CSIRO estimate). Supplementary power is still necessary (from electricity or gas) to compensate for the periods of cloudy, rainy weather during winter. (The very nature of this uneven demand increases the uncertainty of load predictions for the public utilities). Various estimates of the operating time taken to recover the additional capital cost of a solar hot water system in Adelaide vary from 7.1 years (Australian Consumers Association, 1978d, 213) to twenty years (Townsend, 1978, 23) depending on assumptions about the percentage solar contribution, the size of the tank required (and thus the price differential between solar and conventional systems), the annual water heating bill, the price of fuel and the interest that would have been earned on capital not invested in a solar water-heater.

6. There may be only two houses in South Australia which are space-heated by solar hot water or "hot rock" (regenerative) systems.

climatically-suited, comfortable and energy-efficient dwellings is likely to remain higher than their standardized equivalents, the purchasing power of the upper income group would probably result in households of this type being the first to occupy the improved houses. This might result in breaking the nexus between high income and high energy consumption, but it is difficult to predict the impact on the State's domestic energy consumption.

In discussing the social and psychological aspects which have influenced the nature of individual dwelling units in Australia, Thorne et al. (1972,21) stress the contribution of fashion, culture, territory, privacy, mental set and perception. Many of these considerations will be affected if a new type and standard of housing emerges. For example, there would need to be a gradual shift away from the belief that the house (and its largest windows) must fact the street, that one can install air conditioning to compensate for large west-facing windows or (in the future) that a tree-lover can grow whatever tall trees he likes at the expense of shading his neighbour's solar hot water collectors. The best technique for introducing new types and standards of housing may be the "display home" method, such as the "Low Energy House" (opened in March 1978 in Endeavour Hills, near Melbourne and in Albury, N.S.W)[7], the Jennings-modified design built at the CSIRO's Highett site in Melbourne, or the pair of houses being built by the South Australian

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7. Melbourne architects of the "Low Energy House" designed the house to maintain an average temperature of about 21°C all year, but expected to use only 35 per cent of the energy used by normal houses (an annual saving of approximately $140). Relatively similar to other houses in appearance, inside and out, the energy-saving is achieved by its flooring, insulation in the ceiling, walls and roof, special sealing of doors and windows which are hung with heavy drapes, north-facing windows and a solar hot water system (with gas booster).

Housing Trust during 1978-79[8]. The homes are not only for display, however, and all will be occupied, with particular attention paid to annual energy costs. Evidence of reduced operating and maintenance costs needs to be emphasized, to offset the expected higher construction costs.

Consumer Advice and Education

In general, most people are still complacent about energy shortages and rising energy costs - a complacency encouraged by artificially low prices for fossil fuels, plus the high capital cost of alternatives such as solar energy equipment. Any major changes in the ways n which households use energy in existing or new houses will ultimately depend on the methods by which attention is drawn to the need for conservation. The Institution of Engineers (1977) see the need for a strong and sustained educational program in many directions (schools, consumer groups, technical press and mass media) which must be fully co-ordinated[9]. Their Report (Institution of Engineers, 1977,221) suggests that codes of practice are more likely to be followed when their day-to-day impact is helping in achieving personal and societal aims, and that laws and policies are most valued when wanted by the community rather than imposed on it. Many changes in emphasis are necessary: information on efficiency ratios and running costs of appliances, for example, in addition to purchase costs; the promotion of

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8. Described as the first controlled low energy experiment of its kind in Australia (Townsend, 1979b), the houses were completed on August 16th 1979. Families were due to move in on September 30th, followed by 12 months' examination of the technical and human aspects of living in a low energy house compared to a house having no special energy-conserving features.

9. The "Life Be In It" Campaign, conducted by the Department of Tourism, Recreation and Sport during 1977-78 has demonstrated the potential and possibilities of Government-sponsored campaigns.

efficient use of energy by public utilities, rather than merely advocating its use; media advertisements advocating the wearing of a jumper rather than the use of additional heating equipment. Some consumer groups (particularly the Australian Consumers Association, Sydney and the Smallternatives Group, Brisbane) are already playing an important educative role. The problems of mounting and evaluating an Australian government-sponsored campaign to popularise energy conservation are comprehensively discussed by Crossley (1977b, 1979a). Jenkins and James (1978,1) argue that Australians have the necessary conventional technology but insufficient knowledge and imagination to improve the climatic design and comfort of their houses.

Technical Options

Although technical improvements have greater potential in the commercial and industrial sector (Brown, 1978; Norman, 1978) there are a number of possibilities in the domestic sector. For example, the Australian Consumers Association (1978c,136) recommends that manufacturers should be required to state the "Energy Efficiency Ratio" (EER) on the labels of all window or wall-mounted air conditioning[10] units sold, and that buyers select a unit with an EER of 2.2 or better, for which the higher initial cost and larger size are compensated for by quieter operation and much lower operating costs. Manufacturers might be motivated to design appliances with improved performance if they were

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10. The examples quoted above relate primarily to energy for space heating and cooling. Technology can also assist in reducing energy used for other purposes in the household. Examples include a simple insulating blanket fitted to the storage water heater (which, claims the Electricity Trust of South Australia, will enable a householder to save up to 20 per cent of his power costs for water heating) and an electronically- controlled, electricity-saving and longer-life light bulb (which, claims the General Electrical Company of the United States, will reduce household light bills by two thirds).

also required to state energy consumption and (hourly) running costs of the appliance. Manufacturers of thermal insulation in Australia started, during 1979, to market thermal insulation classified by its R-value (the international measure of thermal resistance) rather than by its thickness. Apart from maximising energy-efficiency, some appliances may give the same performance at lower energy cost if the operating method is changed (a freezer run continuously for eight hours instead of continually on-off, or a smaller storage hot water system heated twice daily).

Cost of Energy and Tariff-related Proposals

Overseas experience, particularly since 1975, has indicated that behavioural changes regarding energy use occur only as a result of severe shortages and rising energy costs. In Australia, short power cuts and periods of rationing (in the domestic sector) have affected everybody, but only as an irritating, rather than a sobering reminder of society's complete dependence upon assured and adequate energy supplies. While energy has been so cheap, and reticulated, the quarterly or two-monthly account had made little lasting impact. High energy use has been encouraged by the tariff system, where charges for electricity or for gas decrease as more is used. The first reversal of this system occurred in September 1978, when the Electricity Trust of South Australia introduced a "semi-inverted" tariff system. Excessive users of electricity in the home (above 3,210 kWh per quarter for general purpose domestic use, and/or 3,000 kWh for off-peak water heating) are to be charged at a rate ten per cent higher than for lower consumption.

However, it is expected that less than two per cent of domestic consumers, the biggest users of electricity, would be affected[11].

The proposal to attach "energy labels" to electrical appliances in Australia is likely to be more effective in encouraging consumers to be more energy conscious. During 1979 the Consumer Standards Advisory Committee recommended that most electrical goods have labels attached to tell consumers how much electricity the appliances use and how much it costs to run them. The Committee points out that the move follows progress in this area in the United States, Canada and Britain.

If, however, such "free-choice" measures did not produce the required effect, then other changes to the tariff system could discourage excessive electricity use: a "time of day" tariff, for example, could be mounted, which increases the rate for use of certain appliances at particular peak-load times of the day when energy is heavily demanded elsewhere (such as operating an automatic washing machine or clothes dryer at six o'clock on a winter evening); or the individual household could be supplied with a "Load warning" system whereby the householder is notified that any increased use of power above a certain level will be charged at a much higher rate (such as may occur if three major appliances are already operating, and the use of a fourth is desired); or an increased tariff for air-conditioning energy used in excess of a pre-determined amount per cubic metre of enclosed space.

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11. Among the 452 households of the study, quarterly electricity consumption during 1974 or 1975 exceeded the general purpose domestic limit (3,200 kWh) on only 13 occasions, involving seven houses (1.5 per cent of the total). No house exceeded the off-peak hot water limit (3,000 kWh per quarter).

Government Action

Although voluntary action is preferable, many overseas countries have advocated energy conservation by a series of tax reliefs, subsidies, incentives and direct grants. Insulation, for example, is mandatory in new housing in most countries of Continental Europe, in Britain and in some American states. No such requirement has yet been enforced in Australia, although the Victorian Government is contemplating it. The South Australian Housing Trust started to insulate the ceilings above living rooms in its houses constructed during 1977, but few private builders have followed the example. Legal proposals requiring political action, such as the licensing or prohibition of "wasteful" appliances, or restrictions on the installation of certain equipment (such as oil-fired furnaces) are probably best retained for use in emergency situations, should they arise. Government interest in energy conservation, at both Commonwealth and State levels, is evident in the formation of various Advisory Councils and Parliamentary Committees during 1976 to 1978. The South Australian Government set up a State Energy Committee in 1976; the Law Reform Committee on Solar Energy started work in October 1976; and members were appointed to the South Australian Energy Council in May 1978.

Conclusions

In the vast majority of Adelaide's houses, climatic design and energy-efficient principles have been ignored or neglected. Despite considerable complacency (bordering on apathy) among many people concerned with housing, sufficient evidence is presented in this study to suggest that a much higher priority should be given to climatic suitability, home comfort and energy-efficiency in future. Good thermal design of buildings offers significant potential benefits in both energy and money economies, and in improved levels of comfort. Energy-conservation measures in existing houses may be best achieved by the individual householder, but the acceptability of energy-efficient new dwellings depends on the efforts of the designers, planners and builders on the one hand, and the real estate agents, lending authorities and house-buying public on the other. Good orientation, sensible placement of glass areas and integration of the house with the garden are easily achieved, whatever the "price-bracket" of the house. Outer walls of brick cavity or insulated brick veneer, eaves and verandahs of sufficient size, rooms, doors and windows arranged to maximise cross-ventilation, and a ceiling insulated during construction, add relatively little to the capital cost, while helping to minimise reliance on artificial heating and cooling.

Any widespread change in the basic type, standard and management of housing will be slow, although the anticipated rise in the cost of energy should provide a sustained incentive to concentrate on energy-savings in the field of living and working environments. However, no compromise in comfort standards would be necessary, provided basic principles of climatic design are followed. If good design features are included, all houses of the future could be better suited to the local climate, physically comfortable and energy efficient.

APPENDICES

APPENDIX I

INFORMATION FROM SAMPLED HOUSES AND HOUSEHOLDS

The following are reproduced below:

1. Letter to the sampled householders of the southwestern suburbs sample area, p. 397.
2. Letter to the sampled householders of the Salisbury East sample area, p. 398.
3. Householder's Questionnaire, pp 399-403.
4. House Details Form, pp 404-405.
5. Instructions (to householders) for the use of U-type maximum-minimum thermometers and a temperature observation chart, pp 406-407.

The Questionnaire Schedule

The questionnaire was designed for administration either by personal interview (by the author) or self-completion by the householder. Only the booklet's front-page 'letter' to the householder differed in the two sample areas : both are reproduced in this Appendix.

The House Details Form was completed (by the author) after the householder had been interviewed, a Householder's Questionnaire left (with reply-paid envelope) under the front door of the house, or a completed questionnaire received from a Salisbury East householder. A house facade photograph was also taken at the time. Administration time for the three tasks (interview, house details form, photograph) varied between twenty and sixty minutes.

THE UNIVERSITY OF ADELAIDE

BOX 498, G.P.O., ADELAIDE, SOUTH AUSTRALIA 5001

Telephone: 223 4333 (Area Code 08)   Telegraphic Address: UNIVAD

Dear Householder,

As a postgraduate student in the Geography Department I am conducting a survey into the relationship between climate and housing. The aim of the research is better-designed houses for Adelaide's climate, and the questionnaire to householders is a major part of the total programme.

I would be most grateful if you would fill out the attached questionnaire. In doing this, please note that

(1) names are not required, and that all information supplied will be treated in the strictest confidence,

(2) many questions can be answered by placing a tick in the appropriate box, e.g.

Yes ☐   No ☑

(3) "this house" (chosen by random selection)* refers to the one with the address ....
....

(4) a reply-paid envelope is enclosed for the return of the completed questionnaire.

If you require further information or assistance, please contact me at the University, telephone 223 4333 (extension 2018), or at home (evenings), telephone [illegible]3 2163.

Thanking you for your assistance,

Jill Kerby

(Mrs.) J. S. Kerby,
Ph.D. student,
Department of Geography.

* *From aerial photographs, every 20th house around the block.*

THE UNIVERSITY OF ADELAIDE

BOX 498, G.P.O., ADELAIDE, SOUTH AUSTRALIA 5001

Telephone: 223 4333 (Area Code 08) Telegraphic Address: UNIVAD

Dear Householder,

As a postgraduate student in the Geography Department I am conducting a survey into the relationship between climate and housing. The aim of the research is better-designed houses for Adelaide's climate, and the questionnaire to householders is a major part of the total programme.

One significant group of homes to be included in this survey are those built by Alan Hickinbotham Pty. Ltd., and sold between July 1970 and December 1973. (I understand your home is one of these.*) Mr. Alan Hickinbotham has given his personal support to this particular survey to find out how successful his company has been in designing homes for South Australian living.

I would be most grateful if you would fill out the attached questionnaire. In doing this, please note that

(1) names are not required, and that all information supplied will be treated in the strictest confidence,

(2) many questions can be answered by placing a tick in the appropriate box, e.g.

Yes ☐ No ☑

(3) "this house" refers to the one with the address ....

(4) a reply-paid envelope is enclosed for the return of the completed questionnaire.

* *If, due to a clerical error, this address does* *<u>not</u>* *refer to a Hickinbotham home, a completed questionnaire will still be appreciated.*

SECTION A: DETAILS OF HOUSE AND OCCUPANTS

1. Address .... Collector's District ....
 .... Postcode ....

2. Is this house
 owned or being bought by you? ☐
 being rented by you? ☐
 other? (please state) ..... (place tick in box)
 .... ☐

3. (a) In what year did you move into this house? ....
 (b) What year was this house built (if known)? ....
 If built after 1950
 (i) Who designed the house? ....
 (ii) Who was the Builder of the house? ....

4. What is the main material of the outer walls of this house?
 Brick cavity ☐ Timber ☐
 Brick-veneer ☐ Fibro-cement ☐
 Stone (type) .... ☐ Concrete-block ☐
 Brick and stone (type) Other (please state)
 .... ☐ .... ☐

5. Which of the following do you have in this house?
 Lounge ☐ Rumpus Room ☐
 Lounge-dining ☐ Sunroom ☐
 Kitchen ☐ Study ☐
 Kitchen-dining ☐ Laundry ☐
 Dining-room ☐ Carport ☐
 Family Room ☐ Garage ☐

6. How many of the following do you have in this house?
 Bedrooms ... Porches (under 8' long) ...
 Enclosed sleepouts ... Verandahs (over 8' long) ...
 Other rooms ... Other outside structures ...
 Δ (e.g. shed)
 (Place number in space)

7. Who lives in this house?
 number of adult males .... of adult females ....
 number of children (under 18 years) ....
 ages of children (years) ....

8. For each adult (18 years & over) please supply the following information

	Occupation	Age	Country of birth	If migrant, years of residence in Australia
Adult 1				
Adult 2				
Adult 3				
Adult 4				

SECTION B: GENERAL QUESTIONS RELATING TO THIS HOUSE

9. In choosing this house, how important was each of the features listed below? (Tick appropriate box)

	Very important	Important	Moderately important	Not very important	Not considered
The cost					
The room layout					
Convenience to employment					
The block and/or garden					
Nearness to shops and schools					
Nearness to public transport					
The outside appearance (of house)					
The inside appearance					
The size of the house					
The view and/or setting					
The general location					
Suitability to Adelaide's climate					
Special features (please state)					
....					
....					
....					
....					

10. Please list the major changes made to this house since you moved in (e.g. added two rooms, insulated the roof, built a garage, remodelled the bathroom ... etc.).

11. What features of the house (and immediate environment) would you like to change or improve next?

SECTION C: CLIMATIC ASPECTS OF THIS HOUSE

12. Indicate with a tick ☑ which of the following you have in this house.

(a) Roof Insulation — Yes ☐ No ☐
What type? ....

(b) Electric Fan (Portable) — Yes ☐ No ☐
How many? ....

(c) Exhaust Fan (Fixed) — Yes ☐ No ☐
In which rooms? ....

(d) Air-conditioning — Yes ☐ No ☐

What type?
- Reverse-cycle ☐
- Fixed evaporative cooling ☐
- Portable evaporative cooler ☐
- Other .... ☐

What zones?
- Whole house ☐
- Half house ☐
- One or two rooms ☐

(e) Outside Blinds or Awnings — Yes ☐ No ☐

How many of what type?

Place number
- .... aluminium
- .... canvas
- .... bamboo
- .... other (please describe) ....

(f) Room Heating — Yes ☐ No ☐

What type and where?

Fixed
- Gas ☐ in .... rooms
- Electric ☐ in .... rooms
- Solid fuel (e.g. wood) ☐ in .... rooms
- Liquid Fuel (oil, kero) ☐ in .... rooms
- Other .... ☐ in .... rooms

Portable
- Electric ☐ how many? ...
- Liquid fuel ☐ how many? ...
- Other .... ☐ how many? ...

(g) Shrubs, trees, vines etc. providing substantial shade to parts of the house (including from neighbouring properties)

Yes ☐ No ☐

When is this shade provided?	Summer	Winter
in the morning	☐	☐
in the middle of the day	☐	☐
in the afternoon	☐	☐
in the evening	☐	☐

What type of vegetation?
- deciduous (loses leaves) ☐
- evergreen ☐
- both ☐

13. Which of the above features (of Question 12) were added or installed by you? Place a ring around the box (☑) of those that were.

14. Please indicate for this house, your present level of satisfaction with each of the following. (Tick appropriate box)

	Very satisfied	Satisfied	Dissatisfied	Very dissatisfied	Not sure
a) Size and placement of windows					
b) Outdoor living areas (patio, terrace, verandah, garden etc.)					
c) Amount of shade on house from eaves, blinds, trees, shrubs etc.					
d) Room temperatures indoors in summer with existing cooling system					
e) Room temperatures in winter with existing heating					
f) Amount of daylight indoors					
g) House's ability to cool down after a heat wave once a cool change arrives					
h) Amount of air movement indoors in summer (doors, windows open)					
i) Lack of draught in winter (doors, windows closed)					

If needed, this space is for comments or explanations of the above answers.

15. Are there any rooms or parts of your house which are particulary uncomfortable in certain types of weather? If so please describe (as in example below).

Room or part of house which is uncomfortable	Type of weather	Reason for discomfort	Situation could be improved by
Kitchen	Cold, winter days	faces south, thus no winter sun	Installing strip-heater in kitchen

SECTION D: GENERAL QUESTIONS

16. Which of these statements best describes your attitude to air-conditioning (cooling) in (a) this house, and (b) other Adelaide houses in general?

Tick one or more boxes	(a) This house	(b) Other houses
it is necessary throughout the whole house	☐	☐
it is desirable throughout the whole house	☐	☐
it is necessary only in certain rooms	☐	☐
it is desirable only in certain rooms	☐	☐
it is too expensive to install, run etc.	☐	☐
it is not worthwhile for the small number of hot days in Adelaide's summer	☐	☐
it is not desirable for health reasons	☐	☐
it is (please state)	☐	☐

17. Imagine you are building (or buying) a new house in Adelaide without air-conditioning. What design aspects would you include (or look for) to
    (a) make the most of winter sunshine and warmth, and
    (b) minimise the sun's effects in summer?

18. (a) How would you describe Adelaide's climate?

(b) What do you like least about Adelaide's climate?

19. Could you please describe what you consider to be the best type of houses for Adelaide's climate, with your reasons.

20. Please use the back of this sheet if you wish to comment on this survey in any way.

THANK YOU.

HOUSE DETAILS

Date ....

Address ....

Collector's District ....

.... Postcode ....

House Number ....

1. House style and age ☐

1) Early Colonial	1850-1880	☐	1
Symmetrical Front		☐	2
2) Bay Window	1860-1890	☐	3
3) Villa Front	1890-1914	☐	4
4) Queen Anne	1910-1922	☐	5
5) Bungalow	1918-1935	☐	6
6) Tudor	1930-1938	☐	7
7) Spanish Mission	1935-1945	☐	8
8) Austerity	1940-1950	☐	9
Georgian		☐	10
9) Contemporary	1950-1965	☐	11
L-Shape		☐	12
Triple-Front		☐	13
Ranch		☐	14
Other Modern		☐	15
10) Spanish/Mediterranean	1965-1973	☐	16
Environmental/Pioneer		☐	17
Other New		☐	18
11) Brand New	1974→	☐	19

2. Other details (sketch)

Style description ....

....

3. Nature of a) garden

mainly lawn	☐	1
lawn & gdn beds	☐	2
lawn & shrubs	☐	3
Lawn, gdn, shrubs	☐	4
mainly gdn beds	☐	5
gdn beds & shrubs	☐	6
mainly paving	☐	7
recently started	☐	8
other	☐	9

b) trees

few medium trees	☐	1
few tall trees	☐	2
few both sizes	☐	3
many medium trees	☐	4
many tall trees	☐	5
many both	☐	6
just planted	☐	7
none visible	☐	8
adjacent block only	☐	9

4. House Orientation (front of house)

N	☐	1
NE	☐	2
E	☐	3
SE	☐	4
S	☐	5
SW	☐	6
W	☐	7
NW	☐	8

5. House type

one storey	☐	1
split-level	☐	2
two-storey	☐	3
other	☐	4

6. Size of house (floor space)

small	<10 sq	☐	1
average	11-15 sq	☐	2
large	16-20 sq	☐	3
extra large	>20 sq	☐	4

7. Floor plan

elongated	☐	1
square	☐	2
complex	☐	3
L-shape	☐	4
other	☐	5

8. Roof type

tiles	☐	1
galvanised iron	☐	2
aluminium	☐	3
aluminium tiles	☐	4
other	☐	5

9. Roof pitch

flat	☐	1
low	☐	2
medium	☐	3
high	☐	4

10. Colours - Roof Walls

	Roof		Walls	
light	☐	1	☐	1
medium	☐	2	☐	2
dark	☐	3	☐	3
mixture	☐	4	☐	4
red brick & freestone			☐	5

11. Ratio of window to wall

low	<1:3	☐ 1
medium	1:3-2:3	☐ 2
high	>2:3	☐ 3
mixture		☐ 4

12. Shading - eaves

none	☐ 1
$<1\frac{1}{2}$ ft wide	☐ 2
$1\frac{1}{2}$-3 ft wide	☐ 3
>3 ft wide	☐ 4

13. Shading effectiveness (vegetation)

no effect	☐ 1
some effect	☐ 2
moderate effect	☐ 3
very effective	☐ 4

14. Shading - other features

a) verandah
- front ☐ 1
- back ☐ 2
- side ☐ 3

b) porch
- front ☐ 1
- back ☐ 2
- side ☐ 3

c) carport ☐ 1
garage ☐ 2
enclosed - sleepout ☐ 3
- verandah ☐ 4
- porch ☐ 5
outside blinds ☐ 6
fixed awning ☐ 7
pergola ☐ 8
other ....
.... ☐ 9

15. Local environment

tree lined streets	☐ 0
overlooking	
- park	☐ 1
- water	☐ 2
- main road	☐ 3
- other	☐ 4
industrial area	☐ 5
mixed res. area	☐ 6
sealed road & footpath	☐ 7
sealed road	☐ 8
other	☐ 9

16. Effort by occupant to modify climate aspects

	house	garden
maximum effort	☐ 1	☐ 1
good effort	☐ 2	☐ 2
moderate effort	☐ 3	☐ 3
some effort	☐ 4	☐ 4
no visible effort	☐ 5	☐ 5
negative effort	☐ 6	☐ 6

17. Method of questionnaire completion

A	(personal interview)	☐ 1
B	(filled in by householder)	☐ 2
C		☐ 3
D		☐ 4

18. Reason (if given) for not agreeing to interview ....
....
....

INSTRUCTIONS FOR USE OF MAXIMUM-MINIMUM THERMOMETERS

This type of thermometer shows

a) the temperature at any time (by the silver mercury thread),

b) the daily maximum and minimum temperature.

The U-shaped tube contains mercury and another liquid (clear). The liquid expands as the temperature increases, and pushes against the mercury column which in turn pushes a small metal bar. The right-hand side bar remains at the highest position (maximum temperature) reached during the recording period. The position of the bar in the left-hand side of the U-tube indicates the minimum temperature reached. (The reading in each case is taken at the bottom point of the bar.)

INSTRUCTIONS FOR POSITION OF THERMOMETER

Hang thermometer(s)

a) in a shaded position (i.e. no direct sunlight, not near the oven or hotplates),

b) with free air circulation, but out of strong draughts,

c) if only one, as far as possible in a central position in the house, the other(s) as requested.

INSTRUCTIONS FOR RECORDING

1. Read instrument(s) <u>about</u> 8 a.m. - 9 a.m.

2. Before touching the thermometer(s) read the temperature shown by the <u>bottom</u> point of each of the two metal bars.

3. On the Temperature Observations Chart enter the temperature from the right-hand metal bar in the maximum and from the left-hand in the minimum columns, on the date of reading.

   <u>NOTE</u>: Scale of left increases <u>downward</u>.

4. To reset the thermometer for the next reading

   either a) press button,

   or b) with the magnet supplied, draw the metal bars back to touch the mercury.

5. If you have been away, enter the readings on the dates that they are taken and leave a blank in the space above. (Any necessary adjustments will be made later.)

6. The 'Remarks' column is for any other comment you might like to add about the day's temperature, or adjustment made to the house (e.g. pulled outside awning down, used fan, turned oil heater on ... etc).

TEMPERATURE OBSERVATIONS

Month .... 19....   Month .... 19....

Location of Thermometer ....   Location of Thermometer ....

Maximum* Reading °C	Minimum* Reading °C	At 8-9 a.m. on date + Remarks	Maximum Reading °C	Minimum Reading °C	At 8-9 a.m. on date + Remarks
		1			1
		2			2
		3			3
		4			4
		5			5
		6			6
		7			7
		8			8
		9			9
		10			10
		11			11
		12			12
		13			13
		14			14
		15			15
		16			16
		17			17
		18			18
		19			19
		20			20
		21			21
		22			22
		23			23
		24			24
		25			25
		26			26
		27			27
		28			28
		29			29
		30			30
		31			31

*Note: because the reading is taken once daily, the maximum showing at 9.a.m. is normally the highest temperature reached of the preceding day (usually between 2 and 6 p.m.): the daily minimum normally occurs sometime near sunrise.

APPENDIX II

THE BUILDING FIRM QUESTIONNAIRE

Representatives of the sampled building firms were personally interviewed. The interview was based on the questions contained in the Building Firm Questionnaire which was mailed in advance to the General Manager, with a covering letter. This letter and the questions are reproduced in this Appendix.

Dear

As a postgraduate student in the Geography Department I am conducting a survey into the relationship between climate and housing. The aim of the research is better-designed houses for Adelaide's climate, and the questionnaire to Building Firms is a major part of the total programme.

This questionnaire is being sent to the thirty leading* home-builders in South Australia, who have also shown a keen interest in house-design, standards of construction etc.

Thus I would be most grateful if I could make an appointment with you, or your representative, to discuss these questions.

All information will be treated in the strictest confidence.

Thanking you for your assistance,

Jill Kerby

(Mrs.) J.S. Kerby,
Ph. D. student
Department of Geography.

* *Reference: "The Builder" and other sources.*

1. Please indicate the relative importance of each of the following features in the design and sale of your houses.

	Very important	Important	Moderately important	Not very important	Not Considered
The cost					
The room layout					
Convenience to employment					
The block and/or garden					
Nearness to shops and schools					
Nearness to public transport					
The outside appearance (of house)					
The inside appearance					
The size of the house					
The view and/or setting					
The general location					
Suitability to Adelaide's climate					
Special features (please state)					
....					
....					
....					
....					

2. Who designs the houses that you build? What influence does a (potential) client have?

3. In designing houses for Adelaide conditions, how do you include consideration of

   a) size and placement of windows in relation to direct sunlight, amount of daylight indoors, air-movement, etc.?

   b) outdoor living areas (patio, terrace, verandah, garden, etc?)

   c) amount of shade on house (from eaves, porches, verandahs, trees, etc.)?

   d) room temperatures indoors in summer?

   e) room temperatures indoors in winter?

   f) amount of air movement indoors, and cross-ventilation, in summer?

   g) prevention of draughts in winter?

4. Which of these statements best describes your attitude to airconditioning (cooling) in
   (a) your firm's houses, and
   (b) other Adelaide houses in general?

Tick one or more boxes	Your houses	Other houses
it is necessary throughout the whole house	☐	☐
it is desirable throughout the whole house	☐	☐
it is necessary only in certain rooms	☐	☐
it is desirable only in certain rooms	☐	☐
it is too expensive to install, run, etc.	☐	☐
it is not worthwhile for the small number of hot days in Adelaide's summer	☐	☐
it is not desirable for health reasons	☐	☐
it is (please state)	☐	☐

5. If you had a client wanting to build or buy a new house in Adelaide without airconditioning and who wanted to
   (a) make the most of winter sunshine and warmth, and
   (b) minimise the sun's effects in summer,
what advice would you give?

6. Finally, could you provide the following information, in order to provide a statistical base for the survey?
   Name of firm ....

A. What types of activities does this firm engage in?

House Building		Real Estate	Buying	Selling	Rental
Client's own block	☐	Houses	☐	☐	☐
Firm's block	☐	Land	☐	☐	☐
Firm's subdivision	☐	Business Premises	☐	☐	☐
Display home/village	☐	Other activities	☐	☐	☐
Client's design	☐	1.			
Other (please state)	☐	2.			
....		3.			
....		4.			

B. Please indicate the following for your firm.

Number of houses (detached)	Adelaide Metrop. Area	Rest of State
(i) under construction at present date		
(ii) completed in 12 months prior to 30/12/74 completed in 12 months prior to 30/12/73		

*Note: "Adelaide Metropolitan Area" extends from Gawler to Willunga, and from the Gulf to Bridgewater.

APPENDIX III

REAL ESTATE INSTITUTE QUESTIONNAIRE

The questionnaire was mailed to all ordinary members of the Real Estate Institute of South Australia, with a letter of endorsement from the Institute's president, and a reply-paid envelope for its return. Preliminary results, printed in the Real Estate Institute's Bulletin of May/June, 1975 are also reproduced here.

Dear Sir or Madam,

As a postgraduate student in the Geography Department I am conducting a survey into the relationship between climate and housing. The aim of the research is better-designed houses for Adelaide's climate, and the questionnaire to real estate firms is an important part of the total programme.

I would be most grateful if you would fill out the attached questionnaire. In doing this, please note that

(1) all information supplied will be treated in the strictest confidence,

(2) your name .... } Please fill in
firm ....
location (e.g. suburb) ....
has been given to me by the Real Estate Institute of S.A.

(3) a reply-paid envelope is enclosed for the return of the completed questionnaire.

If you require further information or assistance, please contact me at the University, telephone 223 4333 (extension 2018), or at home (evenings), telephone 278 2163.

Thanking you for your assistance,

Jill Kerby

(Mrs.) J. S. Kerby,
Ph.D. student,
Department of Geography.

1. In house sales (any type) by your firm, how important to clients would you rate each of the features listed below? (Tick appropriate box)

	Very Important	Important	Moderately Important	Not very Important	Not considered
The cost					
The room layout					
Convenience to employment					
The block and/or garden					
Nearness to shops and schools					
Nearness to public transport					
The outside appearance (of house)					
The inside appearance					
The size of the house					
The view and/or setting					
The general location					
Suitability to Adelaide's climate					
Special features (please state)					
....					
....					
....					
....					

2. Similarly, when inspecting a house for sale, how important to clients would you rate each of the following climatic aspects?

	Very important	Important	Moderately important	Not very important	Not considered
a) Size and placement of windows					
b) Outdoor living areas (patio, terrace, verandah, garden etc.)					
c) Amount of shade on house from eaves, blinds, trees, shrubs etc.					
d) Room temperatures indoors in summer and/or the cooling system					
e) Room temperatures in winter and/or the heating system					
f) Amount of daylight indoors					
g) House's ability to cool down after a heat wave once a cool change arrives					
h) Amount of air movement indoors in summer (and cross ventilation)					
i) Lack of draught in winter (doors, windows closed)					
j) Other (climatic) features					
....					
....					
....					
....					

3. Please list any climatic aspects of housing that your salesmen mention when selling houses.

4. For any further comments, please use the space below.

CLIMATE-HOUSING SURVEY

A sincere thankyou to those members who filled in the climate-housing questionnaire, especially for the useful additional comments from some respondents. The questionnaire to Real Estate Institute members forms part of my research programme into the climatic suitability and indoor comfort of Adelaide's housing.

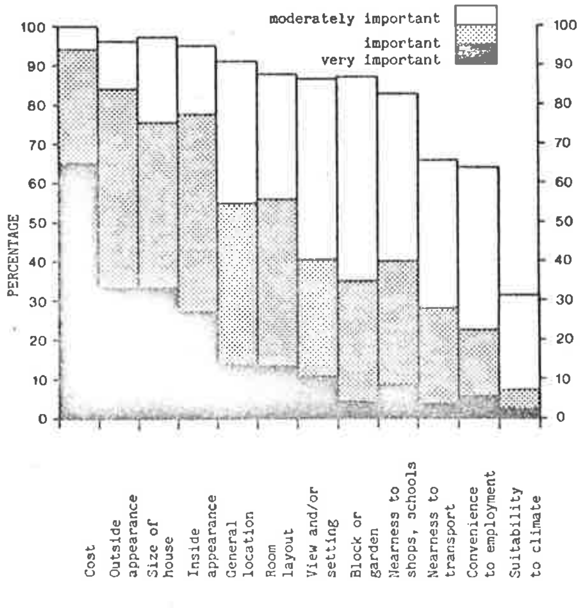
Other components have been questionnaires to, or interviews with, householders, architects, building firms, air conditioning firms, etc. plus instrumentation in selected houses. Data analysis and preparation of the thesis is continuing.

SURVEY RESULTS - Real Estate Questionnaire

161 forms were returned (to 10th June 1975) giving a response rate of approximately 25%. Of those returned, 131 were from city, suburban or hills locations, 22 from the country, 5 not known and 3 questionnaires blank.

The results of Question 1 are shown in the diagram below. The dominating influence of cost is clear (94% of replies rated it to be very important or important). Ranking the remaining factors on the basis of grouped response seemed to indicate outside appearances, size and inside appearance as the next most important, followed by room layout and general location. Moderately important features were the block or garden, view or setting and nearness to shop and schools. Of least overall importance were nearness to public transport and to employment, with "suitability to Adelaide's climate" rating lowest of all (24% rated it as not very important, 29% as not considered).

Q1 RESPONSES : IMPORTANCE OF VARIOUS FEATURES IN HOUSE SALES



A quarter of the replies to Question 1 listed on or more "special features" with the availability of finance, ensuite or second bathroom, family room, garaging/carport, and construction aspects being most frequently mentioned.

Results to Question 2 showed the much lower level of importance of climatic aspects (as anticipated). The items rated highest overall were outdoor living areas (81% of replies ranking them important/moderately important) followed by size and placement of windows and amount of daylight indoors. "Indoor air movement and cross-ventilation" was considered of least importance.

One fifth of the replies to Question 2 listed other (climatic) features: orientation, airconditioning,ceiling insulation and particular aspects of windows were most frequently mentioned.

Of the 113 replies to Question 3 (71% of total) the most frequently listed climatic aspects mentioned in sales were orientation of the house (especially if north-south), protection from sun, rain, wind, ceiling insulation, shading features, good ventilation (inside the house or from gully, sea breezes) and heating/cooling systems.

71 respondents (nearly half the total) added further comments (Question 4). Many stressed the importance of the purchase price of the house (especially finance arrangements) and its external appearance, style, presentation etc. Several stated that although each buyer has different needs, many have limited choice and non-climatic considerations must (or always) come first.

SUMMARY

Thus, cost, appearance and house size seem to be the major considerations in housing real estate, but the relative importance of other features (e.g. room layout or nearness to shops or schools) varies according to the nature of the client and of the location. Although suitability to Adelaide climate ranked lowest of all, practice seemed to indicate that certain features (e.g. aspect of house, sun protection, outdoor living areas, existence of ceiling insulation, heating and cooling systems and good ventilation) are worthy of mention.

Jill Kerby

P.S. Further (completed) questionnaires or other contributions welcome.

APPENDIX IV

DISCUSSION OF METHODOLOGICAL CONSIDERATIONS

This Appendix contains:

1. A discussion of the representative nature of the household samples, pp 416-421 (Tables IVA to IVD).

2. A discussion of bias which may have resulted from the dual method of questionnaire administration to householders (Tables IVE to IVG).

3. The method of placing 23 Adelaide house-styles/ages into classes (Table IVH).

A Discussion of the Representative Nature of the Household Samples

Tables IVA to IVD compare various attributes of the sampled houses and households with the equivalent data (1971 Census) for the population of the Local Government Areas (hereafter LGA's) which contain the Census Collector's Districts from which the samples were drawn and for the whole of Adelaide (Adelaide Statistical Division). The CCD's in the southwestern suburbs sample are contained in part of four LGA's (Brighton, Marion, Mitcham and Unley): the Salisbury East sample in one LGA (Salisbury). One would expect reasonably good correlation between the characteristics of the sampled houses and the Local Government Areas which contain the CCD's; less agreement is likely between the LGA's and the whole Adelaide Statistical Division, due to their particular location. Several anomalies do occur, for various reasons. The 1971 Census was completed before most of the sampled houses in Salisbury East were built and three years before the survey in the southwestern suburbs. Furthermore, the Salisbury East sample was chosen as a homogeneous group (one builder, recently constructed, similar design and price) so that variety in material of outer wall, number and layout of rooms is not likely. Furthermore, the "equivalent data" (for the sampled houses and 1971 Census) are not entirely comparable. "House" in the sample refers only to detached and a few semi-detached; in the 1971 Census tables, "house" refers to several types (separate semi-detached, attached, terrace and villa unit). The higher percentage of stone houses in the southwestern suburbs can partly be attributed to the method of classification (brick and stone buildings are common in several building periods, yet only one "main material" is specified for Census purposes) and partly to it being an older established area. The higher proportion of brick veneer houses in the Salisbury East area is typical of newer outer suburbs.

The number of rooms for the sampled houses was collated from the householder's stated listing of all rooms in the house: double-purpose rooms, such as kitchen-dining, bedroom-playroom, can cause discrepancies by being counted as one or two rooms. The Salisbury East sample shows the predominance of five and six main-rooms in the Hickinbotham range, being newer housing, whereas the southwestern suburbs sample has a higher proportion of larger houses (seven or more main rooms) because there are many older villas, bungalows, or post-war houses with additions. Slightly more than half of the Adelaide Statistical Division houses in the 1971 Census had five main rooms.

The size of household in the sampled houses shows a slightly higher percentage in the two- and three-person groups in the southwestern suburbs, reflecting the older, established housing and age of householder, and a concentration of three, four and five persons in Salisbury East, reflecting the typical first or second-home buyer (predominantly from the United Kingdom)[1], with one, two or three children. The medium to high socio-economic status of some of the sampled houses in the southwestern suburbs probably contributes to the higher percentage of professional and administrative occupations (thus fewer craftsmen and labourers) but there is little overall difference in the distribution of occupations of the head of the Salisbury East households and of the Adelaide Statistical Division (Table IVD).

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1. The builder of most of the sampled houses in Salisbury East (Alan Hickinbotham Pty Ltd) had sponsored migrants from the United Kingdom until 1974.

TABLE IVA

MATERIAL OF OUTER WALL OF SAMPLED HOUSES AND OF THE POPULATION OF HOUSES IN THE SAMPLED L.G.A.'S AND THE ADELAIDE STATISTICAL DIVISION

Material of Outer Walls	Southwestern Suburbs		Salisbury East		Percentage of population of Adelaide Statistical Division (1971)
	Percentage of sampled households (1974)	Percentage of L.G.A. Population[a] (1971)	Percentage of sampled households (1975)	Percentage of L.G.A. Population[b] (1971)	
Brick cavity	72	77	84	72	74
Brick veneer	2	3	14	21	7
Stone	19	10	-	4	9
Concrete	3	3	1	1	3
Timber	-	3	-	1	3
Other	3	4	-	2	4
Total	100 N = 306	100 P = 53,268	100 N = 146	100 P = 14,065	100 P = 233,157

Source: Householder's Questionnaire (Question 4), Bureau of Census and Statistics, 1971 Census of Population and Housing, vol. 7.4, 1-99.

Chi-square (original data, Southwestern suburbs, L.G.A. population rounded to nearest '00) = 19.824, df = 5, s = .01

(original data, Salisbury East, L.G.A. population rounded to nearest '00) = 16.385, df = 5, s = .01

a. L.G.A.s of Brighton, Marion, Mitcham and Unley.

b. L.G.A. of Salisbury.

TABLE IVB

NUMBER OF MAIN ROOMS OF SAMPLED HOUSES AND OF THE POPULATION OF HOUSES IN THE SAMPLED L.G.A.'S AND THE ADELAIDE STATISTICAL DIVISION

Number of main rooms	Southwestern Suburbs		Salisbury East		Percentage of population of Adelaide Statistical Division (1971)
	Percentage of sampled households (1974)	Percentage of L.G.A. Population (1971)	Percentage of sampled households (1975)	Percentage of L.G.A. Population (1971)	
One, two or three	-	5	-	1	5
Four	8	13	-	6	13
Five	38	44	42	78	51
Six	32	25	43	13	21
Seven or more	21	13	16	3	10
Total	100 N = 306	100 P = 53,268	100 N = 146	100 P = 14,065	100 P = 233,157

Chi-square (original data, Southwestern suburbs) = 49.31, df = 4, s = .0001

(original data, Salisbury East) = 223.76, df = 4, s = .0001

Source: Householder's Questionnaire (Questions 5 and 6) and Bureau of Census and Statistics, 1971 Census of Population and Housing, vol. 7.4, 1-99.

TABLE IVC

SIZE OF THE SAMPLED HOUSEHOLDS AND OF THE POPULATION OF HOUSEHOLDS IN THE SAMPLED L.G.A.'S AND THE ADELAIDE STATISTICAL DIVISION

Size of household (number of persons)	Southwestern Suburbs: Percentage of sampled households (1974)	Southwestern Suburbs: Percentage of L.G.A. Population (1971)	Salisbury East: Percentage of sampled households (1975)	Salisbury East: Percentage of L.G.A. Population (1971)	Percentage of population of Adelaide Statistical Division (1971)
One	10	13	-	3	12
Two	33	29	11	16	26
Three	21	18	20	21	19
Four	17	19	40	29	21
Five	10	12	19	18	13
Six	7	6	8	8	6
Seven or more	2	3	3	5	4
Total	100 N = 306	100 P = 53,268	100 N = 146	100 P = 14,065	100 P = 233,157

Source: Householder's Questionnaire (Question 7) and Bureau of Census and Statistics, <u>1971 Census of Population and Housing</u>, vol. 7.4, 1-99.

Chi-square (original data, southwestern suburbs, L.G.A. population rounded to nearest '00) = 6.266, df = 6, s = .50

(original data, Salisbury East, L.G.A. population rounded to nearest '00) = 9.218, df = 6, s = .20

TABLE IVD

OCCUPATION OF HEADS OF SAMPLED HOUSEHOLDS AND OF THE POPULATION OF THE ADELAIDE STATISTICAL DIVISION

Occupation[a]	Percentage of heads of sampled households: Southwestern suburbs (1974)	Percentage of heads of sampled households: Salisbury East (1975)	Percentage of heads of population of Adelaide Statistical Division (1971)
Professional	20	14	11
Administrative	14	9	11
Clerical	10	13	9
Sales	11	7	7
Service	4	3	5
Farmers	-	-	2
Transport workers	5	4	7
Craftsmen, Tradesmen	33	39	44
Armed Services	-	-	1
Other and not stated	3	11	3
Total	100 n = 225	100 n = 142	100 P = 169,176

Chi-square (original data, Adelaide population rounded to nearest '00) = 52.059, df = 18, s = .001

Source: Householder's Questionnaire (Question 8) and Bureau of Census and Statistics (unpublished data).

a. Excludes 'housewives', 'retired' and 'student' heads.

The Possibility of Methodological Bias in the Household Survey

It is possible that the results of the household survey were influenced by the dual method of administration of the Householder's Questionnaire. Evidence of significant methodological bias, where the distributions of answers to questions vary according to the method used, was found in the response to questions on the importance of various features in house-selection, on the householder's assessment of the comfort of the house, and the respondent's knowledge of design-for-climate principles. Tables IVE to IVG show the differences between the responses of personally-interviewed householders and those from whom a self-administered questionnaire was received.

Many of these differences in householder's responses are attributable to differences in the type of housing and of household. For example, the new houses of Salisbury East (where all questionnaires were householder-administered) had many design and structural features related to a high level of discomfort, particularly in summer. Furthermore, most of the householders in Salisbury East were recently arrived migrants from the United Kingdom, perhaps not yet acclimatised. Yet their level of knowledge of design for climate principles (Table IVG) was better than either of the other two groups of respondents.

In rating the importance of various features when selecting a house to purchase or rent, Table IVE shows that personally-interviewed householders were more likely to rate a feature as being "important", "moderately important" or "not very important" than the two extreme ratings "very important" or "not considered". Householders who self-administered the questionnaire tended to use a wider range of ratings in their responses to question five. Similarly, those who self-administered the questionnaire tended to select lower ratings in their assessments of the comfort of the house (Table IVF). Possibly the ability to be objective and critical of one's own house is improved when faced with a form to complete, compared to an immediate verbal response during an interview. This time factor may have also contributed to the apparent higher level of knowledge of design-for-climate principles among householders who self-administered the questionnaire (Table IVG). A written response permits a greater amount of thought and consideration of a problem, as well as removing possible interviewer bias, and the need to offer socially-acceptable responses. On the other hand maybe some care less about accuracy and honesty.

The only means of eliminating such methodological bias would have been to interview all householders personally or leave all questionnaires to be completed by the householder. Given the limited resources of one interviewer and the desire to complete the schedule during the three months of spring (southwestern suburbs sample) or autumn (Salisbury East sample) the dual method of questionnaire administration was essential.

TABLE IVE

RESPONSES TO QUESTION 5 (THE IMPORTANCE OF VARIOUS FEATURES IN HOUSE SELECTION) BY METHOD OF QUESTIONNAIRE COMPLETION

Feature of House	Method of Questionnaire Completion: Personal interview, Southwestern suburbs (n = 160), Percentage rating feature "very important"	"not considered"	Householder Administered: Southwestern suburbs (n = 146), Percentage rating feature "very important"	"not considered"	Householder Administered: Salisbury East (n = 146), Percentage rating feature "very important"	"not considered"
Cost	45	3	58	6	66	0
Room layout	17	5	22	13	35	0
Outside appearance	6	2	17	18	9	12
Inside appearance	9	2	16	18	16	2
Size of the house	22	2	21	16	19	4
General location	18	3	16	14	14	12
Block and/or garden	8	4	23	11	21	1
View and/or setting	5	4	27	10	41	0
Nearness to shops and schools	12	4	30	11	36	0
Nearness to public transport	11	3	9	23	10	5
Convenience to employment	17	8	21	10	8	3
Suitability to Adelaide's climate	2	30	13	36	14	30

Source: Householder's Questionnaire (Question 5).

TABLE IVF

HOUSEHOLDER'S ASSESSMENT OF COMFORT OF HOUSE BY METHOD OF QUESTIONNAIRE COMPLETION

Assessment of Comfort of House	Method of Questionnaire Completion (percentage of sampled households)		
	Personal interview	Householder Administered	
	Southwestern suburbs	Southwestern suburbs	Salisbury East
High or very high	13	26	12
Moderately high	25	20	9
Moderate	25	20	2
Low to moderate	24	11	38
Low or very low	13	23	39
Total	100 n = 160	100 n = 146	100 n = 146

Source: Householder's Questionnaire (Questionnaire 14).

Chi-square (original data) = 86.812, df = 8, s = .0001

TABLE IVG

RESPONDENT'S KNOWLEDGE OF "DESIGN FOR CLIMATE" PRINCIPLES BY METHOD OF QUESTIONNAIRE COMPLETION

Level of knowledge[a]	Method of Questionnaire Completion (percentage of respondents)		
	Personal interview	Householder Administered	
	Southwestern suburbs	Southwestern suburbs	Salisbury East
Good	3	21	23
Moderate	11	16	19
Fair	50	23	28
Poor	26	20	18
Very poor or none	10	19	12
Total	100 n = 160	100 n = 146	100 n = 146

Source: Householder's Questionnaire (Question 17).

Chi-square (original data) = 65.806, df = 8, s = .0001

a. "Level of Knowledge" is a composite measure, derived from respondents' answers to questions 17 and 19; see pp. 352-356.

TABLE IVH

PLACEMENT OF 23 HOUSE-STYLES/AGES INTO FIVE GROUPS

Group	Components	Number	Typical Years Built
Symmetrical Front and Early Villas	Single-fronted cottage	1	1840-1900
	Symmetrical (or double) front	14	1850-1890
	Bay window villas	2	1870-1890
	Plain villas	14	1880-1905
	Return-verandah villas	4	1885-1915
	Total	35 (8%)	
Later villas, Bungalow and Tudor	Louvred-roof villas	13	1905-1918
	"Queen Anne"/Art Nouveau	5	1910-1914
	Bungalows	34	1916-1930
	Triple-fronted bungalows	5	1925-1935
	Tudor	10	1928-1938
	Spanish Mission	2	1929-1945
	Total	69 (15%)	
Austerity	S.A.H.T.	25	1946-1952
	Other, privately built	41	1946-1952
	Total	66 (15%)	
S.A.H.T., L-shape, Conventional	Contemporary	4	1950-1972
	Triple-fronted	14	1952-1965
	Ranch or Colonial	9	1952-1972
	S.A.H.T.	32	1952-1965
	L-shape	29	1958-1965
	Other, privately built	38	1952-1965
	Total	126 (28%)	
New	Spanish/Mediterranean	5	1970-
	Other, privately built	151	1966-
	Total	156 (34%)	

Source: House Details Form (Item 1) and House Facade Photographs.

APPENDIX V

STATISTICAL INFORMATION

The Appendix contains:

1. The suburbs of Adelaide in ranked order of socio-economic status as measured by Stimson and Cleland (1975, 214). The sample areas of this study are located in parts of the underlined LGA-Parts shown in Table VA (pp 428-429). Note that 1 (Thebarton) refers to lowest status, and 128 (Beaumont/St. Georges) to highest status.

2. Table VB (p.430) which shows the detailed responses on the importance of various features in house purchase (household samples) and house sales (Real Estate Institute Sample).

3. Table VC (p.431) which shows the mean monthly values of seven meteorological variables for 24 months, 1974-1975. (The seven variables were tested for linear correlation with the quarterly electricity and bi-monthly gas consumption of each sampled household.)

TABLE VA

SUBURBS OF ADELAIDE IN RANKED ORDER OF SOCIO-ECONOMIC STATUS

Rank Order	Suburb	Rank Order	Suburb
1	Thebarton (6)	49	Valley View (109)
2	Wingfield/Angle Park (32)	50	Ascot Park (67)
3	Port Adelaide (93)	51	Dover Gardens/Sturt (62)
4	Hindmarsh (7)	52	Enfield (27)
5	Mile End (5)	53	Parkside (21)
6	Elizabeth Field (116)	54	Flinders Park (80)
7	Kilburn (25)	55	Klemzig (29)
8	Brompton (8)	56	Norwood (15)
9	Taperoo (89)	57	Campbelltwon/Paradise (37)
10	Ferryden Park (31)	58	Northfield (28)
11	Pennington (88)	59	Fitzroy (11)
12	Elizabeth Vale (114)	60	Modbury (120)
13	Seaton (84)	61	Plympton Park (66)
14	Salisbury North (104)	62	Athelstone (38)
15	Dudley Park (30)	63	Reynella (125)
16	Mitchell Park (69)	64	Noarlunga (128)
17	Elizabeth Downs (111)	65	Marion/Clovelly Park (68)
18	Evandale (14)	66	Edwardstown (51)
19	Beverley (79)	67	St. Peters/Stepney (13)
20	Elizabeth East/North (112)	68	Unley/Hyde Park (22)
21	Alberton (94)	69	Holden Hill (122)
22	Richmond (77)	70	South Plympton (65)
23	Findon (82)	71	Forestville (17)
24	Para Hills (108)	72	Rostrevor/Newton (39)
25	West Croydon (78)	73	North Plympton (71)
26	South Adelaide (3)	74	Goodwood/Wayville (18)
27	Elizabeth West (115)	75	Warradale/Seacombe Gdns. (61)
28	Hendon (85)	76	St. Agnes (119)
29	Elizabeth South (113)	77	Woodville South (86)
30	Salisbury Plains (107)	78	Kurralta Park/Keswick (73)
31	Hillcrest/Gilles Plains (33)	79	Banksia Park/Fairview Park (118)
32	Para Gardens (105)	80	West Richmond (74)
33	Semaphore Pk/Royal Park (83)	81	Kensington (16)
34	Semaphore (92)	82	Gawler (117)
35	Windsor Gardens (24)	83	Magill (41)
36	Salisbury (106)	84	Royston Park/Marden (34)
37	Christies Beach (126)	85	Col. Light Gardens (48)
38	Ingle Farm (110)	86	Hope Valley (121)
39	Hectorville (40)	87	Oaklands Park (60)
40	Payneham (35)	88	St. Marys (50)
41	Blair Athol/Gepps Cross (26)	89	Plympton/Camden Park (72)
42	Kilkenny (87)	90	Grange (95)
43	Largs (91)	91	Underdale (76)
44	Trinity Gdns/Payneham Sth (36)	92	East Adelaide (4)
45	North Largs (90)	93	BlackForest (19)
46	Prospect (10)	94	Glandore (64)
47	Fulham Gardens (81)	95	Cumberland Park (52)
48	Morphett Vale (127)	96	Nailsworth/Collinswood (9)

TABLE VA

(Continued)

Rank Order		Rank Order	
97	Glengowrie (59)	114	West Beach (97)
98	Henley Beach South (96)	115	Bellevue Hts/Eden Hills (49)
99	Happy Valley (124)	116	Hawthorndene/Glenalta (55)
100	North Glenelg (98)	117	Walkerville (12)
101	Novar Gardens (70)	118	Unley Park/Highgate (23)
102	Seacliff Pk/Secombe Hts (63)	119	Kensington Gdns/Rosslyn Park (45)
103	Seacliff (103)	120	Myrtle Bank/Fullarton (20)
104	Glenelg (99)	121	Hawthorn (53)
105	Somerton Park/Hove (101)	122	Kingswood)54)
106	Glenunga (44)	123	North Adelaide (1)
107	Kensington Park/Leabrook (42)	124	Rose Park/Tusmore (43)
108	Brighton (102)	125	Mitcham/Torrens Park (57)
109	Fulham/Lockleys (75)	126	Belair (56)
110	Glenelg South (100)	127	Burnside/Wattle Park (46)
111	Stirling/Bridgewater (123)	128	Beaumont/St. Georges (47)
112	Lower Nth Adel/West Adelaide (2)		
113	Panorama (58)		

Source: Stimson and Cleland (1975, 214).

Note: Underlined L.G.A.-Parts show location of sample areas of this study.

Lowest status = 1, highest status = 128.

Numbers in brackets refer to part Local Government Areas (part-LGA).

TABLE VB

IMPORTANCE OF VARIOUS FEATURES IN HOUSE PURCHASE (HOUSEHOLD SAMPLES)

AND HOUSE SALES (REAL ESTATE INSTITUTE SAMPLE)

House Feature	Sample[a]	Percentage of sample rating feature as: Very Important	Important	Moderately Important	Not Very Important	Not Considered	Other[b]	Chi-square Df Significance
Cost	S.W. Sub	51	31	10	4	1	3	21.68[c]
	Sal. E.	66	29	5	-	-	-	6
	R.E.I.	65	29	22	-	-	-	.01
Room layout	S.W. Sub	19	41	22	9	2	7	50.17
	Sal. E.	35	47	12	2	-	4	10
	R.E.I.	13	43	32	8	-	5	.001
Outside appearance	S.W. Sub	14	40	28	12	2	5	62.23
	Sal. E.	21	48	21	6	1	3	10
	R.E.I.	34	51	12	2	-	2	.001
Inside appearance	S.W. Sub	17	40	26	12	1	4	58.71
	Sal. E.	41	43	14	1	-	1	10
	R.E.I.	27	50	17	3	-	2	.001
Size of the house	S.W. Sub	26	49	16	3	1	5	16.06[d]
	Sal. E.	36	44	16	3	-	1	8
	R.E.I.	34	42	21	-	-	4	.01
General location	S.W. Sub	19	44	20	11	2	4	36.11
	Sal. E.	8	37	36	13	3	3	10
	R.E.I.	14	42	36	6	-	2	.001
Block and/or garden	S.W. Sub	12	32	26	20	4	7	48.55
	Sal. E.	16	30	34	16	2	3	10
	R.E.I.	4	31	52	10	-	3	.001
View and/or setting	S.W. Sub	7	27	28	26	7	6	54.28
	Sal. E.	10	40	33	9	5	3	10
	R.E.I.	11	19	46	11	-	3	.001
Nearness to shops and schools	S.W. Sub	16	38	21	15	5	5	48.31
	Sal. E.	19	43	28	4	4	2	10
	R.E.I.	8	31	43	13	1	4	.001
Nearness to public transport	S.W. Sub	13	39	24	16	3	5	49.91
	Sal. E.	14	27	25	18	12	4	10
	R.E.I.	4	24	38	21	6	8	.001
Convenience to employment	S.W. Sub	17	31	21	19	8	5	51.76
	Sal. E.	9	12	43	21	12	3	10
	R.E.I.	5	17	41	30	3	4	.001
Suitability to Adelaide's climate	S.W. Sub	7	18	21	21	25	8	45.76
	Sal. E.	14	21	24	8	30	3	10
	R.E.I.	2	5	24	32	28	3	.001

Source: Householder's Questionnaire (Question 9) and Real Estate Institute Questionnaire (Question 1).

Notes: a. S.W. Sub = Southwestern suburbs sampled households (N = 306)
Sal. E. = Salisbury East sampled households (N = 146)
R.E.I. = Real Estate Institute sample (N = 147)

b. Other = not answered, not applicable or not sure

c. Calculation of chi-square (original data) excludes "not considered" and "other"

d. Calculation of chi-square (original data) excludes "not considered"

TABLE VC

MEAN MONTHLY VALUES OF SEVEN METEOROLOGICAL VARIABLES DURING 1974 AND 1975 AT ADELAIDE

Year and Month		Mean 0900 temperature (°C)	Mean 1500 temperature (°C)	Mean daily maximum (°C)	Mean daily minimum (°C)	Mean monthly temperature (°C)	Rainfall (mm)	Degree Days (base 18.3°C)
1974	January	23.4	28.2	29.7	20.0	24.9	50.4	0.7
	February	19.7	25.5	26.7	17.6	21.9	70.8	1.2
	March	22.4	26.7	27.9	18.6	73.3	7.0	0.7
	April	17.2	19.8	21.1	14.1	17.6	60.6	41.7
	May	13.5	17.1	18.1	10.8	14.5	63.8	132.6
	June	11.4	15.2	16.2	9.0	12.6	32.4	179.7
	July	10.9	14.0	15.1	8.7	1.9	107.2	213.5
	August	11.9	15.1	16.2	9.3	12.7	46.4	180.4
	September	12.7	15.5	16.6	9.2	12.9	70.2	170.1
	October	16.1	18.5	20.0	12.4	16.2	111.4	85.2
	November	16.7	21.4	22.7	12.7	17.7	4.8	54.6
	December	18.9	22.6	24.9	15.1	20.0	14.0	18.8
1975	January	19.0	23.7	25.2	15.1	20.1	27.6	17.8
	February	22.2	28.1	29.8	18.7	24.3	7.6	0
	March	16.6	19.2	24.0	14.7	19.3	81.8	41.8
	April	16.8	20.7	21.8	13.2	17.5	20.0	57.3
	May	15.1	18.6	19.6	12.1	16.1	87.6	88.6
	June	10.2	15.1	16.0	7.9	11.9	18.0	93.1
	July	12.0	16.1	17.5	9.4	13.5	94.8	162.7
	August	11.5	14.4	15.5	8.8	12.1	33.2	181.0
	September	14.6	17.3	18.9	11.0	14.9	48.0	123.3
	October	15.1	17.9	19.2	12.2	15.7	81.2	118.3
	November	18.9	23.3	25.0	15.3	20.1	17.4	35.7
	December	21.7	26.5	28.1	17.4	22.7	5.4	9.9

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