A Study of Vernacular Ventilation Techniques in Hot Humid Climates : *an opportunity for an appropriate transfer of technology to Madras, India*

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ABSTRACT

Vernacular architecture is a result of various social, cultural and environmental factors. It represents a collection of efficient responses that have passed the test of time, and is very relevant today in helping us develop an approach towards sustainable and energy efficient architecture. The focus of this thesis is on the physical product of vernacular architecture -- the artefact -- as an efficient response to the environment of which it is a part. This thesis entails the study of different vernacular responses with respect to natural ventilation in hot and humid climates.

With the changing needs and aspirations of a society, however, many facets of its vernacular tradition are altered and often replaced. The city of Madras in India represents one such society where traditional building practices -- ventilation systems being one of them -- are being replaced by newer, 'international' building methods. In Madras, which lies in a hot and humid climatic region and where ventilation is necessary for human comfort, people depend primarily on mechanical means of ventilation. However, with increasing power shortages in the city, it is important to enhance natural ventilation options in housing. The approach this thesis has adopted is to study different vernacular ventilation strategies developed in similar climatic regions, for appropriate transfers to a particular dwelling type in Madras. The proposed transfer process is conducted in three stages: first is the *identification* of ventilation strategies and devices to be transferred, second is the *selection* of the strategies and devices that respond to the contextual conditions of the place of transfer and their graphical organisation in matrices, and third is the *implementation* of the selected strategies and devices with appropriate modifications.

This research affirms the relevance of a cross-cultural transfer of technology in the vernacular context of architecture, not only to find solutions to problems affecting some indigenous technologies, but also to enrich and revitalise these technologies. To these ends, it is important to establish a methodical and contextual process of transfer.

Une étude des techniques vernaculaires de ventilation dans des climats chauds et humides: ***une occasion pour un transfert approprié de technologie à Madras en Inde***

RESUME

L'architecture vernaculaire est le résultat de facteurs socio-culturels et environmentaux variés. Elle représente une collection d'outils, qui ont résisté au passage du temps et qui peuvent nous aider à développer une approache vers une architecture durable et énergétiquement efficace. Le centre d'intérêt de cette thése est sur le produit physique de l'architecture vernaculaire -- l'artefact -- comme réponse à l'environment dont il fait partie. L'object d'étude se porte sur différentes solutions vernaculaires de ventilation naturelle dans des climats chauds et humides.

Cependant, avec le changement des besoins et aspiraions d'une société, plusieurs facettes de sa tradition vernaculaire sont altérés et souvent remplacés. La ville de Madras en Inde, représente une telle société, où les pratiques de la construction traditionnelle -- les systèmes de ventilation inclus -- sont remplacés par de nouvelles methodes "internationales" de construction. A Madras, une région climatique chaude et humide où l'aspect de ventilation est nécessaire pour assurer le confort de l'homme, des systèmes méchaniques de ventilation sont utilisés. Or l'apport d'énérgie étant insuffisant, il est important d'améliorer les options naturelles de ventilation résidentielle à Madras. L'approche adoptée dans cette thèse est d'étudier des stratégies vernaculaires de ventilation, développées dans des régions climatiques similaires, pour en transferrer à un type particulier d'habitation à Madras. Le processus proposé de ce tranfert comprend trois étapes générales : l'*identification* des stratégies ou mécanismes de ventilation à transferrer, la *sélection* des stratégies ou mécanismes qui répondent aux conditions contextuelles du lieu de transfert et leur schématisation sous forme de matrices, et finalement, l'exécution du transfert des stratégies et mécanismes sélectionnés, en incluant des modifications appropiées.

Cette recherche affirme ainsi la validité d'un tranfert de technologies interculturel dans le context vernaculaire de l'architecture, non seulement pour résoudre des problèmes affectant certaines technologies indigènes, mais aussi pour les enrichir et les revitaliser. A ces fins, il est important d'établir une approche contextuelle et methodique.

ACKNOWLEDGEMENTS

For a person not given to writing, I went through untold hardships in the compilation of this thesis. But for the help and guidance of friends and well-wishers, this document would not have been possible.

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The most important people in my life -- my mother, father and sisters -- have always been a great source of encouragement and strength to me. To them I dedicate this thesis.

GLOSSARY OF TERMS [1]

Alindram	Sanskrit term for verandah
Anganam	Sanskrit term for courtyard
Brahma Sthanam	Place in a house where the north-south and east-west axis meet; loosely translated it means 'Divine area', generally left open to sky
Brahma Sutram	East-West axis of a house
Koodam	An extended verandah adjoining a courtyard; usually a family space
Madhya Sutram	The central spine of a house
Muttram	Tamil term for courtyard
Pooja	Prayer room (or activity)
Rezhi	Entrance lobby
Soma Sutram	North-South axis of a house
Thinnai	Raised platforms on the entrance verandah; a space for gatherings
Vaastu Saastra	Ancient vedic texts in India, which are a record of oral traditions of architecture of ancient times. These *saastra*s are a collection of rules and standards for building.
Vamsamoolam	A series of openings forming an 'air funnel' in a house, from which other rooms draw air; loosely translated it means 'lifeline.'

[1] Most of the terms used are in Sanskrit describing certain parts of a house.

LIST OF ILLUSTRATIONS

Introduction

The majority of dwellings in the world are built by their inhabitants without professional assistance. This practice of building one's own house has evolved over the years, into a unique expression of the vernacular, more by a process of trial and error than by any professional intervention.[1] The built environment so formed is a complex product of many variables such as climatic and environmental considerations, social and cultural issues, economic and political issues, lifestyle and settlement types. Vernacular architecture can hence be seen as a collection of time-tested efficient responses which do not dominate the environment but compromise with nature in order to live with it.[2] The fact that many indigenous architectural solutions of the world have survived over the years, and continue to exist today, is testimony to their ability to suitably address the environment of which they are a part. Such buildings "represent the accumulation of centuries of assimilated wisdom in the techniques of transforming local materials to shelter the community."[3] According to some researchers, more and more architects are turning to vernacular architecture for inspiration because it is recognised that these indigenous structures satisfy the communities' psychological needs far better than most modern settlements do.[4]

However, there are instances in indigenous architecture where factors such as ceremonial and religious beliefs or even adverse environmental factors like insects result in buildings that are not comfortable in terms of their indoor environments.[5] Nevertheless, in most cases, vernacular buildings characteristically respond favourably to climate, particularly because their builders usually do not possess the technology or mechanical equipment to effect artificial indoor comfort. For their own comfort, builders have had to create, with limited materials and technology, buildings which successfully respond to climate.[6]

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[1] Paul Oliver; Dwellings - Houses across the world, (Oxford: Phaidon Press Limited, 1987), p. 8
[2] Colin Duly; The Houses of Mankind, (London: Thames and Hudson Ltd., 1979), p.30
[3] Maurice Mitchell; Cash, Culture and Housing, (London: VSO/IT Publications, 1992), p. 12
[4] Susan Denyer; African traditional architecture - an historical and geographical perspective, (London: Heinemann, 1978), p.4
[5] Amos Rapoport; House Form and Culture, (New Jersey: Prentice-Hall ,Inc., 1969), p.24
[6] Rapoport; 1963, p. 84

A dwelling is more than just a shelter. It is "both process and artefact. It is the process of living at a location and the physical expression of doing so."[7] John F. Turner, a prominent scholar in Housing, has described 'housing' as being not only a noun but, more importantly, a verb. The process by which a society establishes its built environment is as important as the efficiency of the dwelling to address the elements of nature.[8] There are many factors that influence the nature of traditional built form. According to Amos Rapoport, culture is the primary determinant in the formation of the traditional built environment. Folk tradition, which accounts for the bulk of the built environment, "is the direct and unself-conscious translation into physical form of a culture, its needs and values - as well as the desires, dreams and passions of a people."[9] House form, according to him, is the result of "a whole range of socio-cultural factors seen in their broadest terms. Form (of the dwelling) is in turn modified by climatic condition and by methods of construction, materials available and the technology."[10]

While this research recognises the significance of the manifold socio-cultural and material factors that govern vernacular built form, the focus is on the physical product of vernacular architecture -- the artefact.

Research problem

Ventilation is a very important factor in providing comfort for humans in hot and humid climates. This research is concerned with efficient vernacular responses with respect to natural ventilation in these climatic regions. Although there are many efficient indigenous ventilation techniques in the world, with changing needs and ever-increasing population, many cultures are constantly adapting to newer developments. In the process, many facets of the vernacular are altered and often replaced. Madras, India, is an example of a region undergoing such changes. This research discusses an approach of enhancing ventilation strategies in this region.

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[7] Oliver; 1987, p.7
[8] Mitchell; 1992, p.12
[9] Rapoport; 1963, p. 21
[10] Rapoport; 1969, p. 47

Madras, a city along the eastern coast of southern India, is hot and humid for most of the year. Traditionally, houses in this region were planned according to *Vaastu Saastra,*[11] which set out ground rules or premises for building -- local builders explore local styles, and processes that are based on the original premise -- but often the root is forgotten. In the wake of rapid modernisation and changing lifestyles, many traditional building practices (ventilation systems being one of them) are being ignored or considered 'outmoded.'

Madras is a linear city with a long coastline. The sea breeze, which sets in late in the afternoon, comes as a welcome relief to the residents. However, the majority of dwellings depend solely on mechanical means of ventilation in the form of fans and, where affordable, air conditioners. Traditionally, strategies for ventilation utilised ambient wind and relied on a planned layout of the settlement -- each dwelling was designed so as not to hamper air flow into other dwellings. This has been undermined by the increase in urban density which inhibits the flow of air. Moreover, at the dwelling level, the use of standardised windows and openings placed at fixed heights, with little consideration for human activity levels, further hampers efficient indoor ventilation. With increasing power shortages in Madras, there is a need to look for energy efficient methods of ventilation.

This research aims to address the ventilation problems of housing in Madras by enhancing the palette of energy-conscious vernacular ventilation options.

Research approach

The approach adopted studies different efficient vernacular ventilation strategies that respond to similar climatic conditions, and suggests the possibility for an appropriate transfer to improve the indoor air environment of a specific dwelling in Madras. The main argument of the thesis is that *it is relevant to consider cross-cultural transfers of vernacular techniques in order to enhance and enrich indigenous technology.*

[11] Vedic texts believed, by Western scholars, to be written around the 2nd century AD

In identical climatic zones, there are instances of diverse cultures responding to the forces of nature in a similar fashion.[12] On the other hand, culture, religion and other related factors further shape dwellings, which explains the rich vernacular variety around the world.[13] Hence, responses generated by different indigenous forms in similar climatic zones are richly varied but each, in its own way, addresses climate effectively.

In the development of technology around the world, interactions between cultures have led to an exchange of information and equipment. Similar inventions appear in different parts of the world. In some cases these inventions are genuinely independent, but for the most part they are 'stimulated'; i.e. the achievements of one society stimulate people elsewhere to make different but related inventions. In modern day terminology, this is referred to as a 'transfer of technology.'[14]

These transfers and interactions occur in different ways. In colonial times, transfers were imposed on the 'ruled' society. In the modern context, many programmes are designed to effect transfers of technology from industrialised to 'developing' countries. As Pacey puts it, transfers are often like a conversation in which incomplete information sparks new ideas which result in 'responsive inventions.' Sometimes an interaction is like a dialogue in which the recipients of new knowledge 'interrogate' it based on their own experience and local wisdom. This research is concerned with such a transfer, akin to a dialogue, in which the recipient modifies the new information appropriately to suit local conditions.[15]

Although indigenous architecture is firmly tied to its social and cultural bonds, and the material resources available, history provides many examples of influences and transfers of technology from one culture to another. The appropriateness of any transfer, of course, depends on various parameters that influence the built form in the recipient context.[16] For instance, the method of roof construction without the use of centering, as in the Nubian

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[12] African Kung Bushmen in the Kalahari desert and the aboriginal people of Australia, the Aruntas, have similar circular dwellings which are simple ephemeral responses to the climate - Norbert Schoenaeur; History of Housing, (Montreal: McGill University Press, 1993), pp. 6-9

[13] Rapoport; 1963, p.19

[14] Arnold Pacey; Technology in World Civilisation - A Thousand-Year History, (Cambridge, Massachusetts: MIT Press edition, 1990), pp. vii, viii

[15] Pacey; 1990, pp. vii, viii

[16] Pacey; 1990, p.51

vaults that were revived by Hassan Fathy after 1940, have been used in Niger in a programme carried out by the Development Workshop since 1980.[17] Until recently, traditional buildings used the trunks of *Dom* palms to provide beams for roofs and suspended floors. However, desertification, followed by droughts in the 1970s, has reduced the availability of timber. As a result, the Development Workshop introduced vault and dome roofs built with uncompressed and unstabilised blocks requiring no timber either for formwork or in the finished structure. According to Mitchell, "the examples of traditional building which we see today are only those that have survived, either as long-lasting products or as oft-repeated processes, out of numerous other examples which have not."[18] Therefore there is reason to believe that there is potential in looking at vernacular architecture as efficient building systems for specific environments, and that these systems can be used, with appropriate adaptations, in different places with similar environments.

In this research, examples of natural ventilation techniques of different vernacular cultures, in warm and humid climates, are studied. This forms the basis for identifying opportunities to effect an appropriate transfer of technology to the specific warm humid climatic zone of Madras.

Definitions of key words

Terms which will be frequently used in this thesis are defined below.

A <u>ventilation device</u> is the actual systemic application -- the 'hardware'-- constructed to effect ventilation.

<u>Ventilation strategies or techniques</u> are systems which effect natural ventilation in a dwelling. It could be the result of a ventilation device or a combination of devices. (In this thesis, the term 'ventilation' indicates 'natural ventilation in a dwelling' unless otherwise specified).

[17] Mitchell; 1992, pp. 13, 14
[18] Mitchell; 1992, p.14

Vernacular architecture [19] is the time-tested built environment shaped by variables such as climatic, environmental, socio-cultural, economic, and political considerations. In the context of Madras, the term 'vernacular' includes not only traditional dwellings that have persisted through this century but also the colonial-inspired bungalows and current types of apartment housing, which are popular and likely to remain for decades.

Appropriate transfer of technology refers to the transfer of information and techniques from one culture to another wherein the new body of information is modified appropriately to suit local conditions of the recipient culture. In this thesis, the 'technology' to be transferred is different vernacular ventilation techniques, and the 'recipient culture' refers to the culture of Madras.

Objectives

The thesis aims to study different indigenous ventilation techniques in hot, humid climates and to identify appropriate strategies for transfer to a specific hot and humid climatic zone in India -- Madras. A particular house, which is part of the vernacular of Madras, will be studied and suggestions offered to improve the indoor environment by transferring some of the ventilation strategies identified. The 'appropriateness' of this transfer depends on socio-cultural conditions and material resources available in the context of Madras, as well as on the specific requirements of the chosen dwelling. A synthesis of this information will identify opportunities for an appropriate transfer of technology and will suggest suitable modifications to the existing dwelling in Madras. This thesis thus aims to propose guidelines for the development of an approach to enrich the existing vernacular techniques of Madras, with workable ventilation devices and methods. This leads to the principal research question:

How can vernacular ventilation strategies from different regions within a similar climatic zone be appropriately transferred to the specific context of Madras, India ?

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[19] Vernacular architecture has been defined in many different ways by experts. Oliver describes vernacular architecture as the response generated by the people themselves without professional assistance. Rapoport has a similar definition for 'folk tradition.' Rudofsky has identified the ingenuity and 'organic qualities' of 'Indigenous architecture' and has called it architecture without architects. Some others give the same definition for 'primitive architecture.' In this thesis, terms such as 'vernacular', 'indigenous', 'traditional', 'folk' are all synonymous and are defined as above.

The thesis will also attempt to answer two other related questions.
What are the criteria that determine the appropriateness of a particular device in a chosen context? What are the existing vernacular ventilation practices in the region of Madras?

Research Methodology

The research is divided into three parts: a *study of ventilation*, an *exploration of vernacular ventilation devices (case studies)*, and the *transfer process*.

The first part aims to understand the term 'ventilation' and its importance in hot and humid climates. Design strategies based on factors that affect ventilation in a dwelling are also discussed. These factors form the basis for establishing the criteria for the second part of the study - the exploration of vernacular ventilation devices - case studies.

The exploration is conducted through a literature survey of secondary sources, which identify various ventilation strategies and devices used in different indigenous cultures of hot and humid climates. These strategies form a 'base palette' for the transfer process.

The transfer process is divided into three stages: identification, selection and theoretical implementation. The first stage involves the identification of the devices to be transferred (the strategies identified in the exploration) and the particular dwelling in Madras to which the transfer is to be effected. In addition, the vernacular ventilation devices found in the region during the field study are documented and incorporated into the base palette of strategies.

The second stage involves an appropriate selection of strategies and devices from the ones identified. These devices have to satisfy two levels of selection criteria: firstly, pertaining to the context of Madras, and secondly, pertaining to the specific requirements of the chosen dwelling. Selection is done in a sieve-like, filtration process, selecting devices that are most likely to suit the conditions in Madras and the particular dwelling, and rejecting those which do not. The air flow pattern generated by some of the selected devices are tested in a smoke tunnel.

The final set of selected devices are then used in the third stage of the transfer process, the implementation stage. Modifications are suggested for the devices with respect to the specific requirements of the chosen dwelling. A scale model of the house incorporating some of the suggested devices is tested in the smoke tunnel.

For easier understanding, the first two stages of the transfer process -- identification and selection -- are substantiated by sequential graphic matrices presenting ventilation strategies and devices. Matrix I presents the information collected in the exploration of vernacular ventilation strategies. With the addition of locally existing devices and strategies in the Madras region, this matrix is enhanced. These devices mark the identification stage of the transfer process. The two levels of selection are graphically illustrated by 'sieves', Sieve I and Sieve II. Sieve I 'sifts' the devices in Matrix I, resulting in a filtered set of devices which are most suitable to the context of Madras -- Matrix II. The devices in this matrix are then 'sifted' through Sieve II, resulting in a final set of devices, Matrix III, that are most appropriate to the chosen house in Madras. These devices are then used in the implementation stage of the transfer process.

Scope and Limitations

The literature review of secondary sources in the exploration of case studies of different vernacular ventilation devices is not exhaustive. As many devices as could be collected within the stipulated time allocated for this stage of the thesis have been studied. There are many other devices in this climatic zone which the thesis does not cover.

The study of ventilation is conducted essentially to understand the process of ventilation in simple terms and does not attempt to include numeric calculations that quantify ventilation flow and its effects. Moreover, the solar angle and movement calculations undertaken are not elaborate since this data is widely available. Most of the units of measurements follow the metric system. Only the dimensions related to the building construction in Madras are in feet and inches, which is the predominant existing practice.

Although the thesis suggests improvements to the indoor environment of an existing dwelling by proposing the implementation of certain ventilating devices, these are merely theoretical suggestions. The best and arguably only way to suitably test the efficiency of these devices is by actual implementation on site, which is beyond the scope of this thesis. So when the term 'implementation' is used, it signifies theoretical implementation.

While stating the Research Problem, it was briefly mentioned that 'many traditional building practices are being ignored and considered outmoded.' This thesis does not attempt to investigate the reasons behind it. Such an investigation would be a thesis in itself. In addition, traditional Indian practices of architecture based on *Vaastu Saastra* are only discussed briefly. Only aspects pertaining to ventilation in the dwelling have been discussed.

The dwelling chosen for the transfer process is a traditional urban house in Madras which has been in existence for more than a hundred years. Since the main thrust of the thesis is in the *process* of effecting an appropriate transfer of ventilation devices, any house type which belongs to the vernacular of the city might have been considered. While there are other dwelling types that are part of the Madras vernacular, including the popular three to five storeyed apartment buildings, the author's familiarity with the chosen two storeyed dwelling, its history and some of its former residents, allowed for a more thorough study. This familiarity helped trace the quality of the indoor environment in this building over the years to its present state. In addition, it was found in the field study that the current residents of the house use only mechanical ventilation devices, like fans, to achieve indoor comfort. There is poor existing indoor air movement despite ambient breeze just outside the dwelling.

The three-stage transfer process -- identification-selection-implementation -- proposed by the thesis does not attempt to formulate rigid guidelines for an appropriate transfer of ventilation strategies. The proposed process is the translation of intuitive thought into a loosely structured format.

Organisation of the thesis

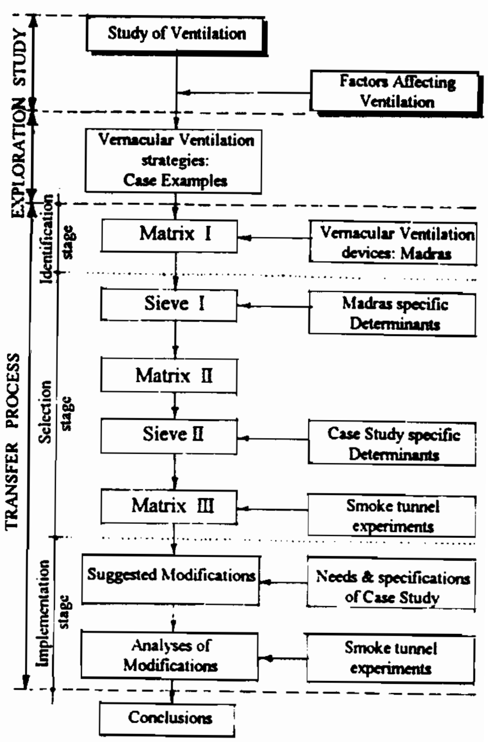
The research is organised into five chapters. Chapter I: *A study of ventilation* discusses the process and functions of ventilation in hot humid climates and establishes factors that influence design strategies in these climates. Chapter II: *Exploration of vernacular ventilation devices -- Case studies* identifies different vernacular ventilation devices found in this climatic zone. Chapter III: *The context of transfer -- Madras* identifies the case study, the dwelling to which the proposed transfer is to be effected (Part I). The chapter also documents some of the vernacular ventilation devices found in the region (Part II). Chapter IV: *Establishing a selection process* establishes a process of selecting devices most suitable for the proposed transfer. Chapter V: *The transfer -- analyses and inferences* illustrates the modifications to the selected devices and the suggested implementation. Lastly, the conclusions drawn by the thesis, certain general comments on the research conducted, and directions for future research are discussed.

Matrix I and Sieve I are included in the appendices (Appendix II and Appendix III respectively) since they are too long to be included in the main body of text. Matrix II, III and Sieve II are included in Chapter IV.

The sequence of the thesis is indicated by a flow diagram which appears on the introductory page of every chapter. As a guide, the sections discussed in a particular chapter are highlighted.

Chapter I

A study of ventilation



This chapter discusses ventilation, its function and role in achieving ideal comfort conditions in hot and humid climates. It begins with a brief discussion of the general characteristics of these climatic regions and comfort conditions for human beings followed by a study of the process of ventilation in dwellings. This chapter aims, first, to identify the climatic and environmental factors that affect ventilation in dwellings in hot humid climates, and second, to establish design strategies that address these factors to enhance natural ventilation in the built form.

In hot humid climatic zones, ventilation is one of the most important factors in maintaining human comfort. An efficient natural ventilation system is one which, in Olgyay's terms, "works with, not against, the forces of nature and makes use of their potentialities to create better living conditions."[1] The design strategies discussed are based on conclusions drawn from the extensive research carried out in this field which suggest ideal responses in the built environment to climate. Calling them 'design strategies for hot humid climates' would be inexact as it is impossible to classify different regions under a single category as 'hot humid zones.' There are many inherent micro climatic differences which affect the built form. According to Konya, "rarely do climatic elements have the same characteristics in different localities, no matter how similar their climates appear to be."[2] However, by grouping climates, one can identify

[1] Victor Olgyay; <u>Design with Climate</u>, (New Jersey: Princeton University Press, 1963), p.10
[2] Allan Konya; <u>Design Primer for Hot Climates</u>, (London: Architectural Press Ltd., 1980), p.19

certain characteristics which are common to different areas and can therefore more easily assess the influences of similar elements shared by these regions.[3]

1.1 General characteristics of Hot Humid climates

Hot humid climates are generally found between the latitudes 15°N and 15°S.[4] The most prominent characteristics of these regions are hot and sticky conditions for human beings and the continual presence of dampness. There is very little seasonal variation despite periods of rain and occasional gusty winds. The air temperature during the day normally reaches a maximum of about 32°C. At night, the low varies between 21°C and 27°C. The relative humidity varies from 55% to 100%. Precipitation is high throughout the year becoming more intense during the monsoon months. The skies are moderately cloudy throughout the year. Heavy clouds and water vapour in the air filter direct solar radiation but due to typically overcast conditions, there is a high percentage of glare and diffused radiation. Moderate heat and high rainfall, combined with a high moisture content in the air, provide conditions favourable for the growth of vegetation. Winds are of low and variable velocity but generally constant in direction. On windward coasts there are persistent but moderately strong winds. Strong winds can occur during rain squalls with gusts of up to 100 kilometres per hour.[5]

1.2 Comfort conditions

The human body maintains a constant internal temperature by releasing superfluous heat to the environment. As a result, a continuous exchange of heat between the body and its surroundings takes place through radiation, convection, conduction and evaporation (Fig.1.1). In order to maintain a constant body temperature of around 37°C, heat produced by the human metabolic process must be dissipated from the body.[6] Heat gain by the body through solar radiation or warm air must also be minimised.

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[3] Refer to Appendix I, Fig.A - showing hot humid regions of the World
[4] There are regions which show similar climatic characteristics but occur outside this belt
[5] Otto Koenigsberger et al; Manual of Tropical Housing and Building, (Madras, India: Orient Longman Limited, 1975), p.26
[6] Koenigsberger et al; 1975, p.42.

When the surrounding temperature of the air and walls is more than 25°C, the clothed human body cannot lose enough heat by either convection or radiation. The dissipation of heat from the body occurs only through perspiration.[7] In order to evaporate, water must absorb heat. Since humans normally lose about one litre of water every day in perspiration, a fair amount of heat is taken from the body to evaporate it.[8] The amount of heat dissipated by evaporation depends on three factors: the clothing worn, levels of surrounding vapour pressure[9] and the amount of air movement.

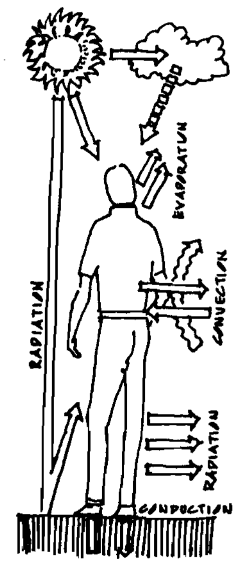

Fig. 1.1
Heat exchange between human body and its surroundings (*Source: Konya, 1980, p.26*)

The lower the vapour pressure and the more the air movement, the greater will be the evaporative potential;[10] the greater the evaporative potential, the greater the comfort provided. However, clothing lessens the air movement close to the body and increases the humidity over the skin thus reducing the evaporative potential.[11]

In a highly humid zone, evaporative cooling and perspiration are greatly reduced and even inhibited. The evaporated sweat from the body quickly forms an 'envelope' of saturated air around the body. This envelope prevents any further evaporation from the body and undermines the last means of heat dissipation. Thus, to achieve some degree of thermal comfort, the saturated air envelope must be removed. Air flow across the body helps dissipate the saturated air and accelerates evaporation. However, this is not sufficient because without ventilation (air exchange) both the temperature and humidity in a room will build to high levels, due to perspiration and heat dissipation from human

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[7] B.Givoni; Man Climate and Architecture, (London: Elsevier Publishing Company Ltd., 1969), p.27
[8] Konya; 1980, p.27
[9] Vapour pressure is that amount of the atmospheric pressure exerted by the water vapour content of the atmosphere. It is exerted by a variable quantity of water vapour contained in atmospheric air (Olgyay; 1962, p.20).
[10] Evaporative potential is the capacity of the body to lose body heat through evaporation of perspiration.
[11] Konya; 1980, p.26

bodies, leading to uncomfortable conditions. Thus, adequate ventilation is of paramount importance in achieving comfort conditions in warm and humid climates.[12]

1.3 Functions of ventilation

The heat and moisture output of human bodies, combined with cooking and washing activities, increase temperature and humidity indoors. Thus there is a need for frequent air changes and for sensible air movement across the body surface to provide physiological cooling. The process of ventilation consists of two components: air exchange--the exchange of indoor air with fresh outdoor air, and air movement--the movement of air in relation to human comfort.

Natural ventilation performs three distinct functions in providing thermal comfort for human beings: it supplies fresh air, provides convective cooling and facilitates physiological cooling. While the first two functions are considered 'air exchange,' the third function is considered 'air movement.'

Supply of fresh air

Fresh air supply is ideally governed by the type of occupancy, number and the activity of the occupants in the space. Usually, in hot and humid climates, certain limited solutions are prescribed for natural ventilation. Often, the provision of 'permanent ventilators,' i.e. openings which cannot be closed is necessary.[13] These may be in the form of grilles or 'air bricks' built into the walls or permanent, latticed screens incorporated into the windows.

Convective cooling

Cooling can be effected with an exchange of indoor air for fresh outdoor air, if the latter is at a lower temperature than the indoor air. The moving air acts as a heat carrying medium. This occurs in hot climates when internal heat gain raises temperatures even higher than outside temperatures. Temperature and pressure move on a gradient, the former from cold to hot and the latter from high to low. This movement generates a breeze or wind. Natural ventilation thus occurs as a result of a dynamic wind force, or as a result of convection due to differences in temperature and air pressure, referred to as the

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[12] Ken Yeang; from 'Notes for a critical vernacular in contemporary Malaysian Architecture', in UIA/International Union of Architects, no.6, 1984

[13] Koenigsberger et al; 1975, p.120

stack effect.[14] The stack effect relies on pressure forces created by differences in temperatures between lighter indoor and denser outdoor air.

The principle involved is the stacking of air in terms of its temperature wherein the warmer and lighter indoor air will flow out at the top and the cooler, denser outdoor air will flow in at the bottom (Fig.1.2). This phenomenon can be facilitated by the provision of ventilators, ventilating shafts, or openings in the roof.

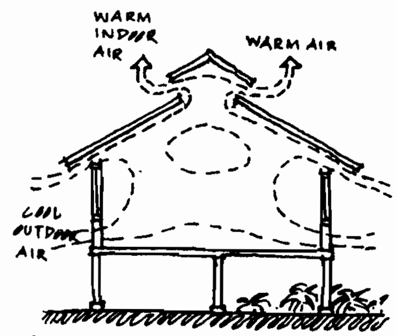

Fig. 1.2
Stack effect (*Source: Konya, 1980, p.33*)

<u>Physiological cooling</u>

The movement of air over the skin surface accelerates heat dissipation by increasing convective heat loss and by accelerating evaporation. This results in the cooling of the skin and is called physiological cooling. In highly humid regions, the cooling effect is restricted by high vapour pressure preventing evaporation, but greater velocities will have some effect.

So air movement is most needed in effecting evaporative cooling. This can be seen in the Effective temperature[15] nomogram which shows that with higher wind velocities, higher temperatures can be tolerated (Fig.1.3). Thus when there are no other forms of heat dissipation available and when the temperature of the air and surrounding surfaces and the skin are almost the same, cooling by air movement becomes necessary.

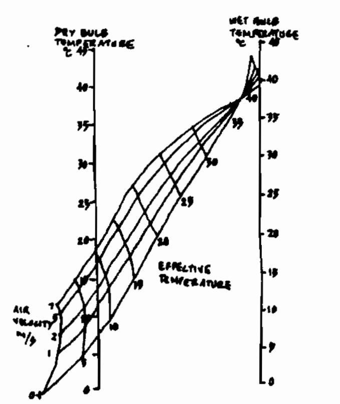

Fig. 1.3
Effective Temperature nomogram
(*Source: Givoni, 1969, p.78*)

1.4 Factors affecting ventilation in a dwelling

Ventilation in a dwelling is affected by factors both outside and within. The external factors that affect ventilation in a dwelling are determined by environmental and climatic

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[14] Konya; 1980, p.52

[15] Effective temperature can be defined as the temperature of a still, saturated atmosphere which would, in the absence of radiation produce the same effect as the atmosphere in question (Koenigsberger; 1975, p.47-49)

parameters that surround the structure. The ventilation patterns within a dwelling are also influenced by internal factors: building elements (roof, wall, floor), cross ventilation, openings and their shading devices, other ventilation strategies, internal layout and partition design. The following sections discuss design strategies suggested by experts in the field with respect to these external and internal factors that affect ventilation.

1.5 Design strategies

1.5.1 External factors affecting indoor ventilation

The environmental and climatic factors that affect the form and response of the building to ventilation are: siting of the built form, its plan, physical form, orientation, wind movement and vegetation.

Siting of the built form

Siting of the built form is the first and most important design criterion in a hot humid region. Buildings are arranged to facilitate the free movement of air. Hence, a suitable approach for laying out a settlement is to scatter the units with sufficient distance between dwellings to generate wind corridors and provide for a "spontaneous organic freedom" (Fig.1.4).[16]

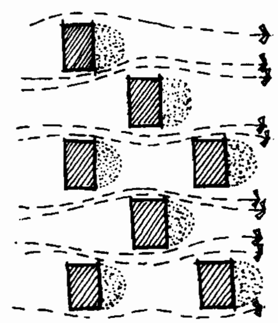

Fig. 1.4
Spread out layout of built form

Plan

To facilitate cross ventilation, houses are usually slender and long in plan (Fig.1.5). It is preferred that all rooms have two facing walls with openings, to allow through ventilation.

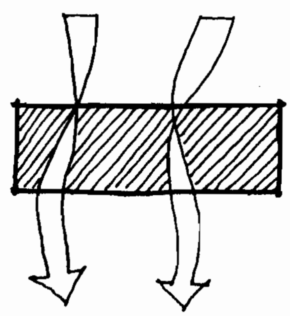

Fig. 1.5
Long and slender plan form

[16] Olgyay; 1963, p.8

Physical form

Physical form is based on the structure and shape of the dwelling. To provide comfort, the structure should be well shaded and facilitate cool air movements. Due to high rainfall in these regions, the roofs are generally steeply sloped, and provide shade to the living spaces below. It is advantageous to elevate dwellings on stilts, thereby avoiding stagnant air at the ground surface and capturing upper air movements at greater velocities (Fig.1.6).[17]

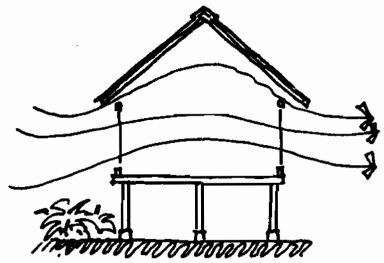

Fig. 1.6
Dwelling raised on stilts

Raising the building has other advantages, such as protection from ground dampness, insects and rodents which are abundant in tropical climates and cooling provided by the shaded space below the raised floor which prevents convected heat from the ground from entering the house.

External features of a building itself can strongly influence air pressure build up.[18] For instance, if the incident air flow is at an angle of 45° to the elevation of the house, a projecting wall can double the positive air pressure created (Fig.1.7). To be most effective, a wing wall should project out as far as the window is wide. Upward projecting eaves also produce a 'funnelling' effect, which can be used to the advantage of air movement within the house. The opposite of the above actions will produce a reduction of pressures and direct the air upward within the house.[19]

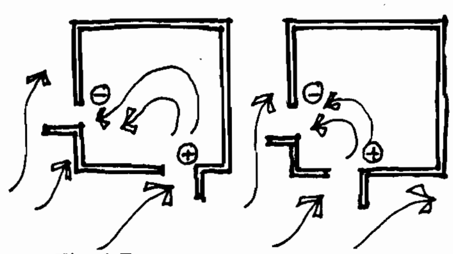

Fig. 1.7
Influence of external features
(Source: Fisher, PA, 1984, p.99)

[17] Konya; 1980, p. 58
[18] Koenigsberger; 1975, p. 124
[19] Thomas Fisher; 'The well-tempered tropics', Progressive Architecture, 1984 April, vol.65 no.4, p.99

Orientation

For optimum orientation of buildings, solar movement as well as wind direction should be taken into consideration. Unfortunately, good solar orientation and that most suitable for catching prevailing winds seldom coincide. If an arrangement is made with respect to minimising solar heat gain, it may often conflict with the requirement of orientation for wind. So a compromise is required.[20] According to Koenigsberger, "the solar geometry cannot be changed, but skillful use of elements built outside, e.g. screen walls or even the projecting wing of a building, can change the direction of air movement."[21] With low rise buildings where walls receive little radiation, orientation for wind is more advisable although an analysis would have to be done for individual cases.

In an experiment, Givoni has shown that if the unit is oriented at an angle of 45° to wind direction, the average indoor air velocity will increase (Fig.1.8 a,b).[22] In Fig.1.8b, greater velocity is generated along the windward sides, and the wind shadow is much broader, resulting in an increased negative pressure. With increased negative pressure, there is a suction effect and hence an increased indoor air flow.[23]

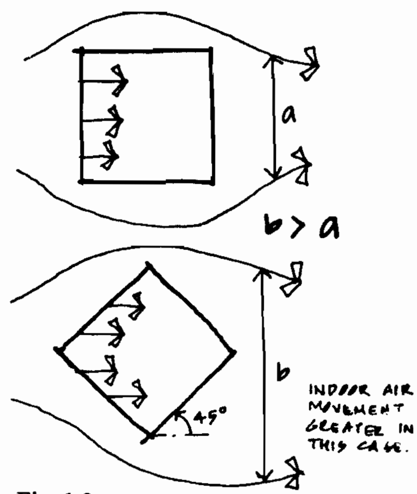

Fig. 1.8
Orientation of built form
(*Source: Konya, 1980, p.52*)

Wind movement

Air flowing across any surface is subject to friction which reduces wind velocity. The type of ground cover affects the wind speed gradient (Fig.1.9). With an uneven ground cover, the rate of increase in speed with height is much more than with an unbroken smooth surface, such as water.

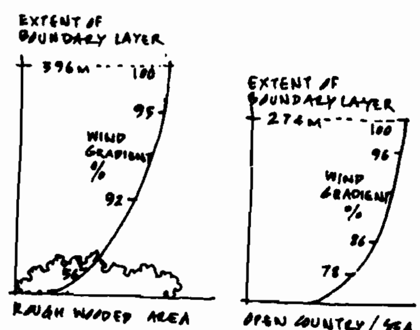

Fig. 1.9
Wind speed gradient
(*Source: Koenigsberger, 1975, p.216*)

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[20] Konya; 1980, p. 52
[21] Koenigsberger et al; 1975, p.216
[22] Konya; 1980, p.52
[23] Koenigsberger et al; 1975, p.124

In hot humid regions, due to low wind speeds, there should be a full utilisation of the prevailing winds with maximum utilisation at the 'human level.' Large stretches of water can give rise to coastal breezes. On-shore breezes during the latter half of the day may lower the maximum temperature by as much as 10°C but increase the humidity.[24]

Vegetation

Trees and vegetation have a moderating effect on site climate in terms of radiation, humidity, air temperature and air movement, and should be carefully designed to direct and accelerate desirable cooling breezes into the house.[25] Studies done by Olgyay, Konya and others show an air flow pattern modification with landscaping. Shade trees should be high branching so that they do not interfere with breezes. In an area shaded by trees, the air flowing into the building is cooled (Fig.1.10 a). Planting trees and hedges in the right sequence and distance from the building can provide desirable air flow in the units (Fig.1.10 b). Landscape elements can create high and low pressure areas around the house with reference to its openings (Fig.1.10 c).[26]

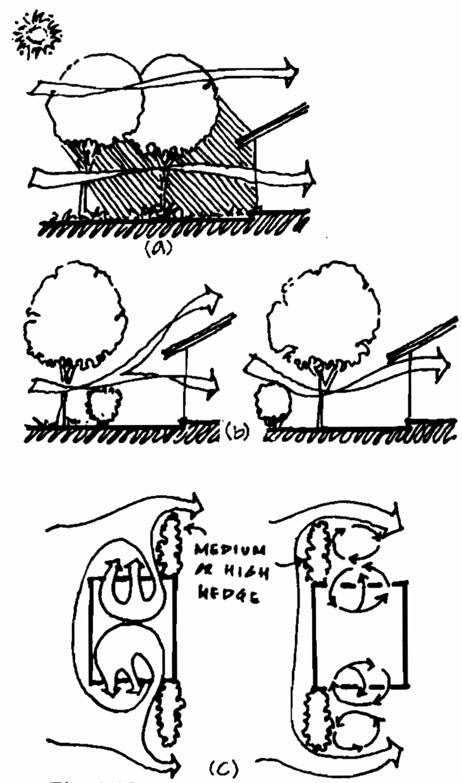

Fig. 1.10
Effect of landscape on built form
(*Source: Konya, 1980, p 52*)

1.5.2 Internal Factors affecting indoor ventilation

Factors affecting indoor air flow are: building elements, cross ventilation, openings and their shading devices, other ventilation devices, and internal partitions.

Building elements

Different parts of the building affect ventilation in different ways. The building elements that affect ventilation most are roofs, walls, verandahs and courtyards (openings, canopies and shading devices will be discussed under 'openings').

[24] Koenigsberger et al; 1975, p.216
[25] Olgyay; 1963, p.100
[26] Olgyay; 1963, p.102

The roof is the most important element in a hot and humid climate. The largest thermal impact occurs here. The roof should be of low thermal capacity and must prevent the indoor temperature from increasing above the outdoor temperature. This can be achieved by having a reflective upper surface for the roof.[27]

A double roof construction with a ventilated roof space helps lower the temperature of the habitable spaces below (Fig.1.11).[28] The ventilation of the 'volume' of habitable rooms is also an important factor as ventilation of the roof space can cause a ceiling temperature drop of 2°C without any constructional change.[29] The ceiling should also be of a low thermal capacity.

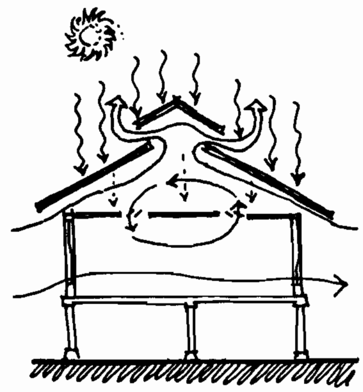

Fig. 1.11
Double roof contstruction
(Source:Olgyay,1963, p.102; Konya,1980, p.52)

Roof vents and openings close to the ceiling assist in convective cooling. Ridge vents that take advantage of the negative pressure behind a roof ridge (Fig.1.12) also work to pull air through a building. Wide overhangs may be necessary, apart from providing rain and glare protection, to induce air movement within a building.

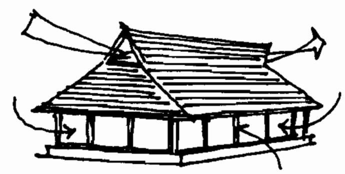

Fig. 1.12
Ridge vent

Walls have less importance in this climatic zone. They are used primarily for screening insects, for security, the marking of boundaries and for allowing flexibility of wind penetration. East and west exposures should be well shaded as they receive maximum insolation. Preferably, openings on these walls should be avoided unless they are wind facing, in which case the openings should be suitably shaded.

Covered verandahs are very important in hot humid regions. Being shielded from the sun and glare, and open on the sides, verandahs promote air movement. In these regions, most of the daytime activities take place on these verandahs. Covered terraces, awnings

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[27] Otto Koenigsberger et al; Roofs in warm humid tropics, (London: Lund Humphries, 1969), p.48
[28] Koenigsberger et al; 1969, p.48
[29] Koenigsberger et al; 1975, p 219

and projected windows are different adaptations of the same principle that provides naturally ventilated, partly open spaces as part of the built environment.

Courtyards are seldom used in these regions. They are more efficient in hot and dry climates. Nevertheless, they can be used as an open space to effect cross ventilation or be used as an air or light well.

Cross ventilation

Air-flow through the building is a result of a pressure difference between the windward and leeward sides (Fig.1.13).[30] When moving air is obstructed by a structure, it exerts a pressure on the obstructing surface. It slows down the laminar air flow and this causes the formation of a wedge-shaped mass of air on the windward side of the structure, which in turn deflects the remaining air upwards and sideways. A separation layer between the stagnant air and the building and the laminar flow of the air is formed. At the separation layer, due to friction, the upper surface of the stagnant air is disturbed, thus creating turbulence or a vortex.

The laminar air flow tends to maintain a straight path after it has been diverted because of its momentum. As a result, it takes a while before returning to the ground surface after passing the obstacle. A slight vortex at a reduced pressure is formed on the leeward side, referred to as 'wind shadow.' While on the windward side such vortexes occur at an increased pressure, on the leeward side they form at a reduced pressure. The efficiency of cross ventilation in a building depends on the openings, their position, size and controls which will be discussed in the following section.

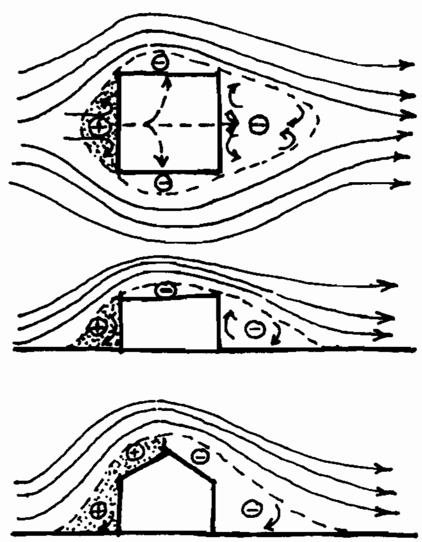

Fig. 1.13
Pressure difference induced air flow
(Source: Konya, 1980, p.53)

[30] Koenigsberger et al; 1975, p. 121

Openings and their shading devices

Openings play a decisive role in effecting ventilation within the building in terms of their positions, sizes and controls. Air flow must pass through the living zone (Fig.1.14 a). If the opening at the inlet is at a high level, regardless of the opening position at the outlet, the air flow will take place at the ceiling. A larger solid surface creates a larger pressure build-up which diverts the air stream. As a result, in a two-storey building, while the air flow in the lower floor may be satisfactory, on the upper floor it may be directed towards the ceiling (Fig.1.14 b).[31]

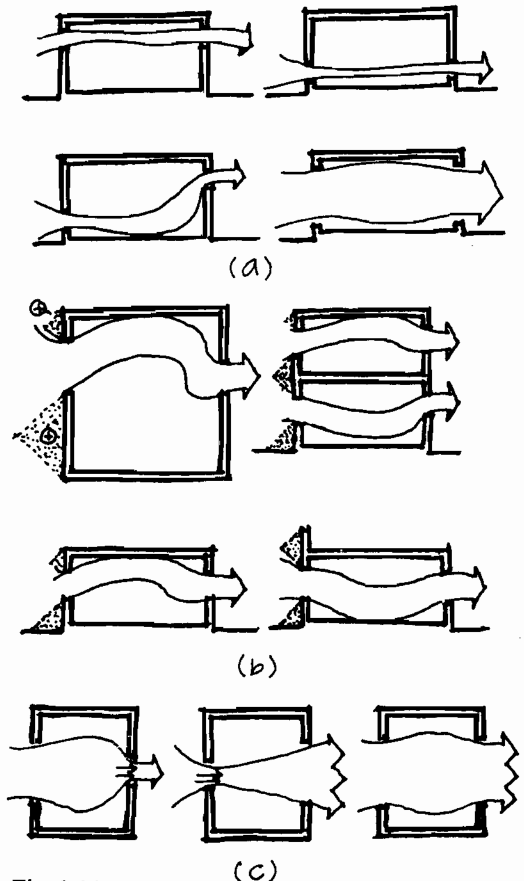

Fig. 1.14
Air flow as a result of openings' size, position
(Source: Konya, 1980, p.53; Koenigsberger et al, 1975, p.125)

When the wind exerts a force on a wall, the greatest air velocity is obtained through a small inlet opening with a large outlet due to the Venturi effect.[32] Such an arrangement is useful only if the wind direction is constant and of a substantial velocity. If this is not the case, it will be necessary to have air movement in the whole space and large inlet openings will be preferable (Fig.1.14 c). The inlet to outlet ratio of 1:1 is optimum.[33]

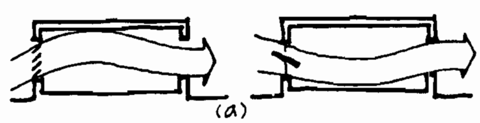

Fig. 1.15
Air flow modified by shading devices
(Source: Koenigsberger et al, 1975, p.126)

Sashes, canopies, louvres and other elements controlling the openings also influence the air flow pattern. Sashes can divert the air flow upwards. Casements or reversible pivot sashes channel air downwards into the living zone (Fig.1.15 a). When

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[31] Koenigsberger et al; 1975, p.125
[32] Venturi effect : In the broadening funnel connecting the small inlet to the large outlet, the sideways expansion of the air jet further accelerates the particles.
[33] G.V.Manahan; 'Passive cooling technology for buildings in hot-humid localities'

a canopy or sunshade is introduced over a window it eliminates the pressure build-up over that window. The positive pressure from below a covered window directs air flow upwards into the room, away from the living zone (Fig.1.15 b). When a gap is left between a building face and a canopy, a downward pressure is ensured, thus effecting a flow into the living zone. The situation is further improved when a louvred canopy is introduced.[34]

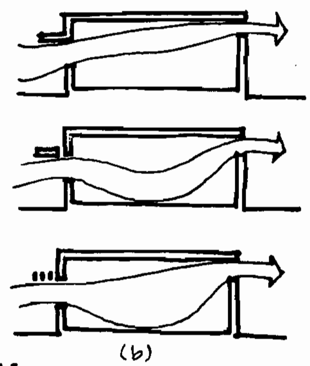


Fig. 1.15
Air flow modified by shading devices
(Source: Koenigsberger et al, 1975, p.126)

Shading devices like louvres present a problem as far as directing air flow into the living space is concerned. The position of the blades turned slightly upwards will channel the air towards the ceiling (Fig.1.15 a). Shading devices must be carefully designed in order not to hamper the natural air flow. The material used for shading devices must be of a low thermal capacity to ensure quick cooling after sunset.

Fly screens and mosquito netting, a necessity in most tropical regions, reduce high wind velocities (about 15m/s) by up to 70%.[35] According to some researchers, at lower wind speeds (about 5m/s), meshes reduce air velocities by 25%.[36] Material selection is very crucial in this regard as is also the flexibility screens afford in terms of easy application, removal and repair.

<u>Other ventilation devices</u>

Other ventilation devices that affect air flow in buildings are grilles or 'air bricks', canopies and overhangs, raised ceilings and partitions.

Grilles and 'air bricks' are permanent openings in walls and are essential in many hot humid areas (Fig.1.16 a). 'Air bricks' are gaps in a wall created by placing bricks in a honeycomb pattern. Grilles

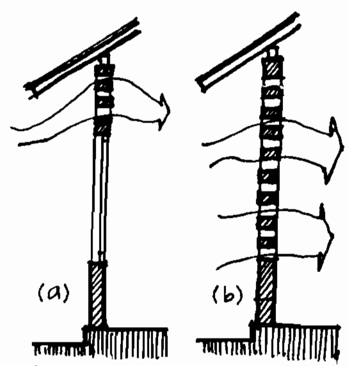


Fig. 1.16
'Air brick' walls

[34] Konya; 1980, p.54
[35] Koenigsberger et al; 1975, p.
[36] Givoni; 1969, p.275

prefabricated, perforated elements inserted in walls as permanent openings.

These grilles normally occur at different heights depending on the use. Air bricks are normally above human height, closer to the ceiling, to facilitate constant convective cooling to the interior. Sometimes, entire walls can be made of 'air bricks' or grilles which are very effective ventilating devices (Fig.1.16b). But in insect-infested areas screens are necessary.

Pergolas and lattices can be used effectively in improving indoor ventilation. In some cases, pergolas can be covered by deciduous creepers which offer thick foliage during the summer months, while dropping their leaves during the cooler months. Rooms with high ceilings and openings at the upper level facilitate convective cooling. Hot air is constantly rising clear of the human activity level and being replaced by cooler air, thus increasing comfort conditions (Fig.1.17).[37]

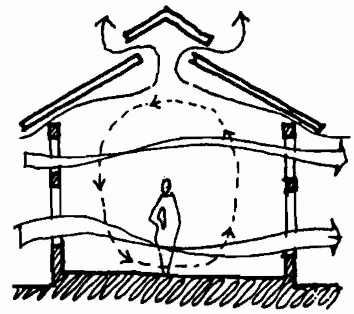


Fig. 1.17
High ceilings

Internal partitions

Any obstruction to the passage of the wind reduces its speed. In an interior space, partitions and furniture lower air velocity. They must be suitably located so as not to deprive the living zone of adequate air movement. However, partitions can be used to provide favourable conditions in interior spaces by creating turbulence in the human activity zones in order to increase the comfort level (Fig.1.18).

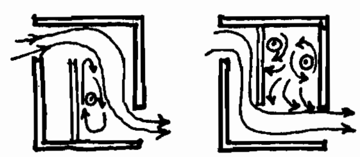


Fig. 1.18
Indoor air flow affected by partitions
(Source: Konya, 1980, p.53)

[37] However, according to some experiments, increased height of the space does not affect indoor air motion.(Givoni, 1969, p.154)

Summary

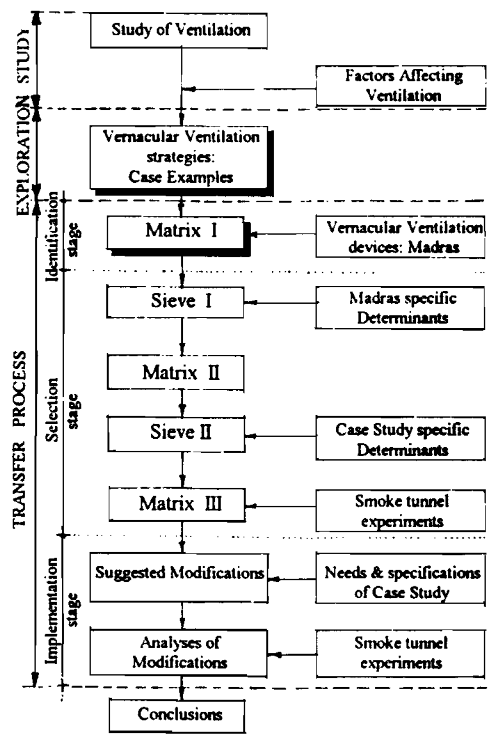
Certain external and internal factors affect ventilation in dwellings. Based on these factors, the above study has discussed different design strategies for providing effective natural ventilation. Although they represent the ideal conditions for ventilation design, there are a few examples of indigenous responses that do not conform to these guidelines, primarily due to various socio-cultural and environmental circumstances. For instance, in an urban indigenous settlement where it is not physically possible to 'scatter the dwellings,' the vernacular develops other devices to address the climate. While such a scenario has not been suggested in the design strategies discussed, there are always such restrictions and constraints to any design application.

The factors that affect ventilation in dwellings, identified in this chapter, form the basis for evaluating vernacular ventilation strategies in the next chapter.[38]

[38] In this thesis, ventilation devices that occur in the roofs, walls or floors of a building will be identified as *dynamic* or *passive* ventilating devices. A dynamic ventilating device is one which harnesses dynamic forces like wind. It essentially occurs on the windward side and directs the wind to the living zone and enhances air movement It could also increase the stack effect in the house by creating draughts at the upper levels of the roof, removing the hot air and causing air to be sucked into the dwelling. The motive forces in passive ventilating devices are essentially thermal forces due to temperature and pressure variations. They let out warm air or cooking fumes by virtue of their position in the dwelling taking advantage of the differences in temperature and pressure between indoor and outdoor air.

Chapter II

Vernacular ventilation techniques - Case Examples



This chapter examines a few indigenous settlements in hot and humid conditions, and their ventilation strategies. For each example, a brief background of the region, prevailing climate and settlement type will be presented. The physical response of the vernacular ventilation strategies and devices will then be described. The examples discussed are from Malaysia, Papua New Guinea, Thailand, Saudi Arabia, Bangladesh, the Philippines, Southern China, Indonesia and Nigeria.

This study will be summarised graphically, in Matrix I, based on the factors affecting ventilation identified in the previous chapter. Matrix I (Appendix II), illustrates each device or strategy with a brief description.

2.1 Malay vernacular dwellings

Climatic characteristics of Malaysia

Location: Between latitudes 1° and 7°N

Mean Maximum Temperature: 32°C, absolute maximum 37°C

Mean Minimum Temperature: 24°C, absolute minimum 18°C

Uniformly warm all year, warmest from February to April

Average Humidity: 83%

Average Annual Rainfall: Very high: 2000 - 3000 mm

Monsoon months: All year except January to March

Wind speed: Low, less than 6 m/s

High glare and radiation from the sky

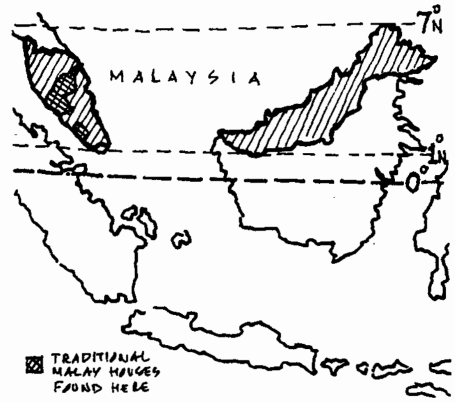


Fig. 2.1
Map of Malaysia

The Malaysian architectural heritage is culturally diverse. There are colonial residences (Malaysia was once a British and Dutch colony), traditional Malay village dwellings, Chinese shophouses, as well as Indian and Islamic influenced buildings. These typologies reveal a sophisticated set of architectural responses to climate, some of which were evolved indigenously while others were results of cross-cultural influences. In this study, ventilation techniques used in traditional Malay village houses and urban Chinese shophouses will be examined.

Traditional Malay dwellings are designed with a deep understanding and respect for nature. Although different regions of Malaysia share common cultural roots, each has evolved its own architectural identity and form. The Malacca house, the Kelantan house, the Perak house, the Minangkabau house are different regional styles that have their own identity but share similar climate-responsive design characteristics.[1] The Chinese shophouses are not indigenous forms but have evolved due to cultural circumstances, (Chinese immigration), and climatic factors.[2]

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[1] Prof.Parid Wardi Sudin; 'Malay House', Mimar, vol.2, 1981 p.56 (also 'Traditional Malay houses of Peninsular Malaysia', UIA/International Union of Architects, no.6, 1984)
[2] Penny Gurstein; 'Traditional Chinese shophouses of Peninsular Malaysia, UIA/International Union of Architects, no.6, 1984, pp. 20-22

2.1.1 Traditional Malay house

Traditionally, Malay houses are built on stilts. Characteristically, they have an open plan regulated by construction modules. Spaces are not rigidly fixed in their functions; curtains are used as spatial dividers. Kitchens are usually separated from other living spaces. Toilets are never attached to any part of the house but are available in the vicinity of the house.[3]

The built environment (Fig.2.2) consists of elements such as covered verandahs, open terraces, *serambis* (entrance verandahs) , rooms with high ceilings, and ventilated pitched roofs with extended overhangs that act as sun-shading devices. Doors and windows are generally timber-louvred.[4]

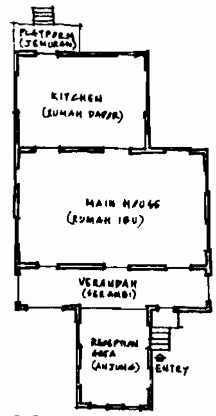

Fig. 2.2
Traditional Malay house plan
(Source: Abidin, 1981, p.29)

Ventilation strategies

Traditional Malay houses are situated irregularly in response to the topography of the land. This ensures that the wind velocity in all houses will not be substantially reduced by interference from other houses. The elongated plan of these traditional houses allows easy passage of air and cross ventilation, while minimal partitions promote unhindered air movement. Also, stilted houses can catch prevailing winds at higher velocities than those closer to the ground (Fig.2.3).

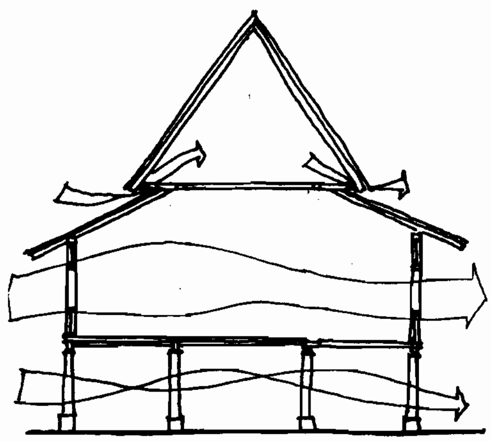

Fig. 2.3
Typical Malay house section
(Source: Yuan, 1988, pp. 20-21)

The roof of the traditional Malay house is steeply pitched, which facilitates rapid dispersal of rain water. The steep pitch also creates a high ceiling which is ideal for inducing air movement,

[3] W B B Wan Abidin; The Malay House : Rationale and change, MS thesis submitted at MIT, 1981, p.29
[4] Ken Yeang; 'Notes for a critical vernacular in contemporary Malaysian Architecture', UIA/International Union of Architects, no.6, 1984, p.32

ventilation and escape of hot air (Fig.2.3). Roofing material (*nipah*, *rumbia* or *bertam* thatch) is of a low thermal capacity which absorbs little heat during the day and cools adequately at night.

There is provision for ventilation joints in the roof construction of the traditional house (Fig.2.3). The movement of air causes air exchanges which constantly remove accumulated hot air under this part of the roof.

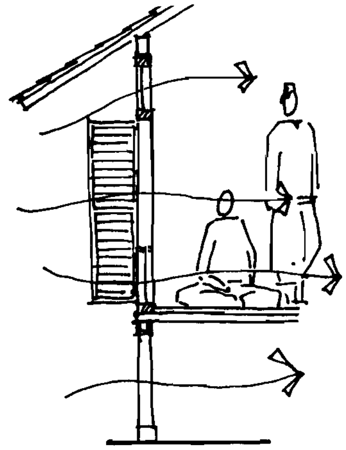

Fig. 2.4
Jendelas (Source: Yuan, 1988, p.20)

The long, vertical, timber-louvred windows, *jendela*, extend downwards to the floor (Fig.2.4). Ventilation takes place at the body level as this area has been identified in traditional building practice as the most vital area for comfort.[5]

2.1.2 Chinese shophouse

With the immigration of Chinese merchants, shophouses evolved to become part of the Malay vernacular. Shophouses are narrow fronted and deep and share walls with adjacent units (Fig.2.5). The depth of these houses ranges from 100 to 150ft. Widths vary from 12 to 28ft, with a width-to-depth ratio of 1:3 to 1:7. A covered colonnade forms the transition from the street, with a shop in front, kitchen and storage in the rear. The upper floor comprises dining and sleeping areas. The building form that emerged minimises the effects of heat, rain and glare by the use of thick brick walls, high ceilings, and an air well to cross ventilate the rooms.[6]

Ventilation strategies

The central air well is the focus of the arrangement of space. It provides light, ventilation and facilitates the collection and disposal of rain-water. In deep lots, air wells play an important role in ventilation. On the upper level, the openings on the walls adjoining the air well have louvred shutters which provide light and ventilation to the

[5] Lim Jee Yuan; 'Traditional Housing: A solution to homelessness in the Third World - The Malaysian Example', The Ecologist, vol.18,no.1, 1988
[6] Gurstein; 1984, p.22

rooms. Partitions and interconnecting doors between rooms have latticed woodwork to facilitate indoor air movement.

There is another ventilating device, an elevated roof, much like a hat, which sits on top of an opening in the ridge of the roof (Fig.2.5). As such, it keeps out rain while allowing wind to enter the openings which cool the heated roof and reduce radiation to the rooms below. These openings, sometimes louvred, generate air movement in rooms by introducing a draught at the roof level which replaces the accumulated convective heat.

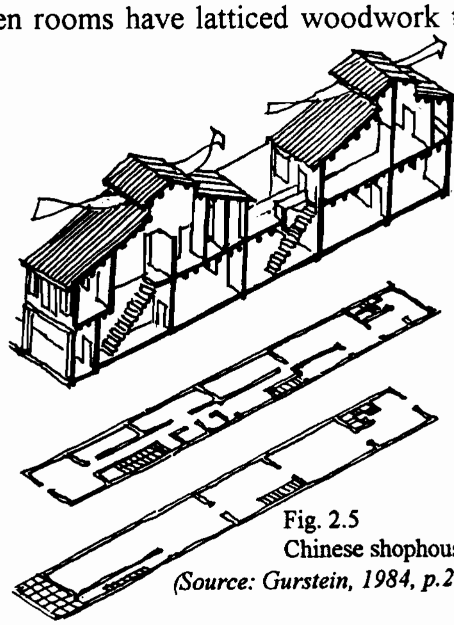

Fig. 2.5
Chinese shophouse
(Source: Gurstein, 1984, p.22)

High ceilings (4m or more above floor level) further assist the convection process. Through ventilation is further aided by decorative holes (vents) in the front wall, louvred shutters on the first floor windows (on the street facade and on walls overlooking internal air wells) and latticework in the upper portions of most room partitions.[7]

2.2 Traditional dwellings of Papua New Guinea

Climatic characteristics of Sepik region Papua New Guinea

Location: Between the equator and latitude 12°S

Mean Maximum Temperature: 27°C, absolute maximum 32°C

Mean Minimum Temperature: 20°C, absolute minimum 14°C

Uniformly warm through the year, warmest between December and February. Coolest months: July and August

Average Humidity: 75%

Average Annual Rainfall: High: 2000 -2500 mm

Monsoon months: December to March

Wind speed: Low, less than 3m/s

High glare and radiation from the sky

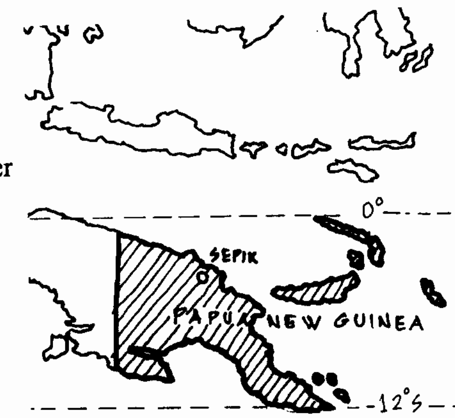

Fig.2.6
Map of Papua New Guinea

[7] According to Rapoport, however, the Chinese house in Malaya is an example of an 'anti-climactic solution'; the courtyard and heavy masonry construction of the Chinese house is not as well suited as the traditional dwellings to the hot and humid climate.(Rapoport; House Form and Culture, 1963, p.21). However, in this study, we are concerned with particular strategies of ventilation rather than the justification of a particular house type.

Papua New Guinea is a vast country with many different peoples. This section concentrates on the settlements in the Middle Sepik river valley. Until the 1970s the construction techniques of the Sepik people were solely dependent on the exploitation of their physical environment--forest, swamps and river.[8] Today, urbanisation is fast eroding this delicate ecology; however, the Sepik people traditionally lived in harmony with their environment and learned to build their dwellings to suit the climate. They used thermally efficient plant materials, which are abundant, to establish a built environment that is well suited to the climate.

2.2.1 The traditional house

Most people living on the banks of the Middle Sepik built their villages along longitudinal plans. Village houses were built on stilts deeply set into the clay along the river banks. Family houses, which generally sheltered an extended family, comprise a single room about five to eight metres wide by twelve to twenty metres long. To maintain privacy, individual 'basketry' mats with mosquito netting were provided. Large quantities of plant materials were needed to build these houses. Dozens of large tree trunks were required for the stilts, beams, joists, and dozens of palm and bamboo trunks were used for the roof frame and the floors; hundreds of sago and borass palm leaves covered the roof and the walls. Different components of the dwelling were tied together with treated liana creeper.[9]

Ventilation strategies

Since the house was treated as a single enclosure with minimal partitions, this arrangement facilitated cross ventilation with little hindrance to internal air flow. The long narrow buildings with suspended lath curtain walls allowed air to circulate freely (Fig.2.7). The horizontal members of the lath

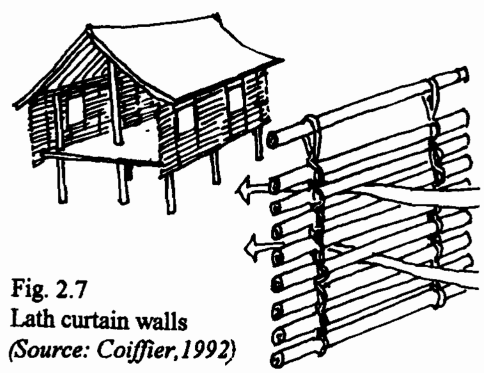

Fig. 2.7
Lath curtain walls
(Source: Coiffier,1992)

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[8] Christian Coiffier, 'From exploitation of the forest to urban dependence in Papua New Guinea', in TDSR, vol. III, no.II, 1992, p.50

[9] Coiffier, 1992, p.51

curtain cut off the sun, while allowing breeze through. The raised platforms of the houses are shielded from heat by trees, which also cool the air passing through them (Fig.2.8).

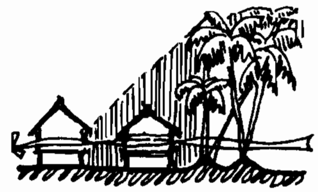

Fig. 2.8
Effect of vegetation

2.3 The Thai House

Climatic characteristics of Thailand

Location: Between latitudes 6° and 20°N
Mean Maximum Temperature: 33°C; absolute maximum 40°C
Mean Minimum Temperature: 24°C; absolute minimum 13°C
Summer months: March to May
Winter months: November to February
Average Humidity: Very high: 85%
Average Annual Rainfall: High: 1500 mm
Monsoon months: May to October
Wind speed: Low: less than 6 m/s
High glare and radiation from the sky

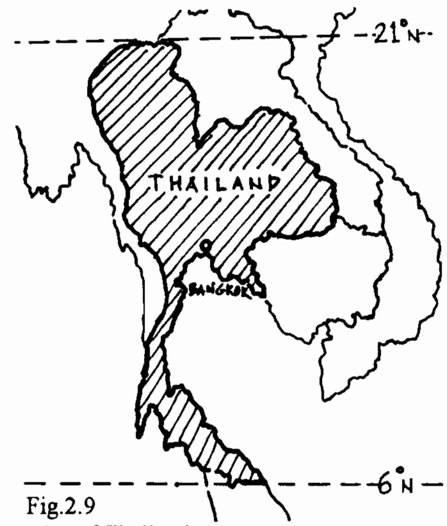

Fig.2.9
Map of Thailand

The process of building a house is a very important and elaborate ritual among Thais (more important than ceremonies for births and marriages). The domestic space is considered significant as a symbol of the social, economic, political, moral, religious and cosmological facets of a settlement. As a dwelling designed in response to its climate, the traditional Thai house performs well, but the interpretation of these responses is often veiled in cosmological and religious dictates.[10]

2.3.1 Traditional Thai house

The most interesting feature of the Thai house is that about 80% of its components are prefabricated.[11] This is both convenient and economical in regions where, for reasons of war and climate, communities have to be highly mobile. House building is done with

[10] Andrew Turton, 'The Thai house - ideology of domestication', Architectural Association Quarterly, 1980, v. 12, no.2, p.4
[11] (Author not known), 'Central Thai House', Abitare, 1992, Dec., no.313 (supplement), p.28

great speed. The houses are built in standard sizes so that parts of one can be fitted to another. The ease of dismantling is facilitated by the minimal use of nails, fine jointing, and the use of wooden pegs in construction, making it easier and cheaper to move. [12]

Most of the traditional Thai houses are simple wooden structures raised on sturdy stilts with sharply angled roofs. [13] Roofs are slender, pointed structures with decorative features. Walls are wood-panelled, leaning slightly inwards to accentuate the slope of the roofs. The plan of these houses (Fig.2.10) shows that all rooms open onto airy verandahs or upper platforms.[14] Where siting permits, the houses face south with their hierarchical progression of rooms running northwards. The houses are approached by a ladder at the head of which is an open balcony. This opens into a guest room, to the west of which is the kitchen. The guest room is linked to the 'large house' or 'sleeping place' by a threshold space.

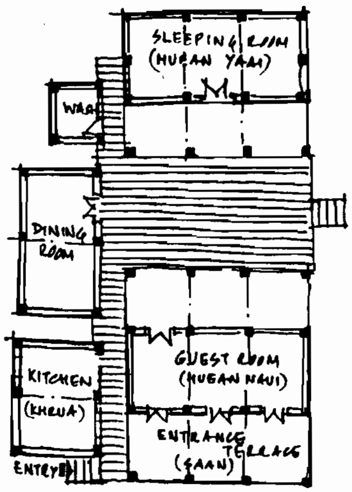

Fig. 2.10
Typical Thai house plan
(Source: Blundell Jones, 1988, p.69)

Ventilation strategies

Every detail of Thai houses has a special function. High elevation from the ground is a practical necessity in low lying regions subject to annual flooding (Fig.2.11). The raised platform also aids in catching the prevailing winds at a higher level where speeds increase. Steep roofs with long overhangs protect interiors from heavy rains and modify breezes that flow through the house. The high gable ends provide adequate height for cooling by convection[15] and walls provide good ventilation through different devices (Fig.2.11).

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[12] Barry Michael Broman; Old houses of Bangkok - fragile link, (Bangkok, The Siam Society: DD Books, 1984), p.14
[13] Peter Blundell Jones; The Thai House, Spacio E Societa, 1988, Jan.-March, no.40, p.
[14] Jones, 1988, p.
[15] Sumet Chumsai; Naga - Cultural Origins in Siam and the West Pacific, (Singapore: Oxford University Press, 1988), p.

Above the window there are permanent timber lattices that provide constant air movement and are completely free of glare due to the steep angle of the roof and its deep overhangs. The walls are formed of inclined horizontal boards to allow free passage of air within (Fig. 2.12 a). Walls can also be of woven bamboo mats which 'breathe' while not allowing harsh light and large insects through. Floors of the Thai house are permeable. They permit ventilation and also facilitate disposal of food scraps (Fig. 2.12 b). The windows, often timber-louvred, are top-hung. Although they cut off glare, they provide ventilation as well as a view.(Fig.2.13).[16]

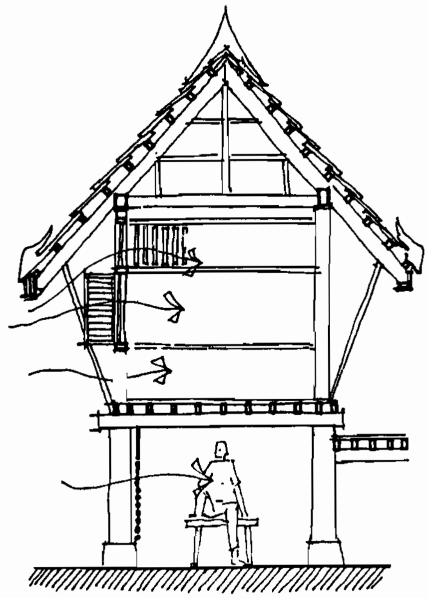

Fig. 2.11
Typical Thai house section
(Source: Hengrasmee, 1972, p.119)

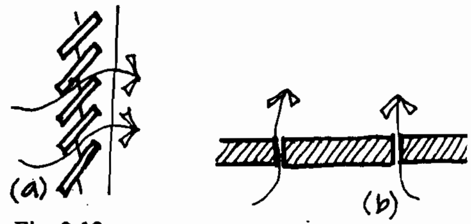

Fig. 2.12
Ventilation through walls and floors
(Source: Hengrasmee, 1972, p.119)

There are some other devices used in traditional houses in Bangkok, such as mats of woven bamboo or rice thatch, that cut off glare but allow air to pass through.[17] These mats can be rolled up when an uninterrupted breeze is required and this feature is prevalent in Madras too. It is generally used in the area below the stilted floors when sitting space is required (Fig.2.11).

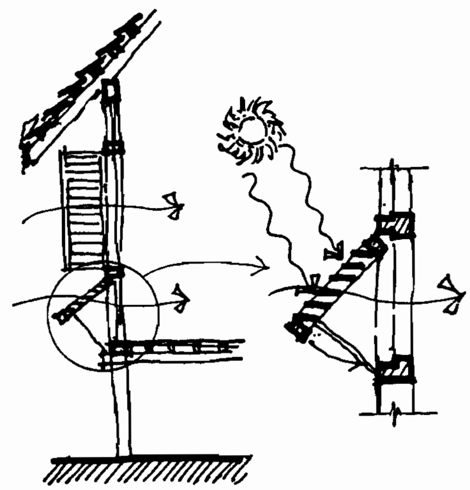

Fig. 2.13
Top-hung, self-shading windows
(Source: Hengrasmee, 1972, p.119)

[16] Ditti Hengrasmee; The Characteristics of Modern Thai Architecture, M.Arch Thesis, (Montreal: McGill University Press, 1972), p.119
[17] Broman; 1984, p.48

2.4 Vernacular dwellings of Saudi Arabia

Climatic characteristics of West coast of Saudi Arabia

Location: Between latitudes 16° and 28°N

Mean Maximum Temperature: 33°C, absolute high 42°C

Mean Minimum Temperature: 24°C, absolute low 13°C

Summer: April to August; Winter: December, January

Average Humidity: High; 75% to 80%

Average Annual Rainfall: Irregular; 200 mm

Monsoon months: November to January

Wind speed: seldom greater than 8m/s; occasional squalls of greater than 15m/s

Intense glare and radiation from the sky

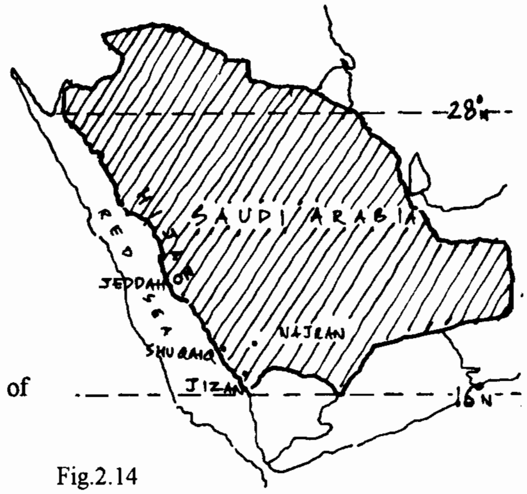

Fig.2.14
Map of Saudi Arabia

Saudi Arabia is a predominantly hot and dry region. While this is true for most of its land area, the majority of the population (as much as 65%) lives on a 12 to 15 kilometre wide strip along the hot and humid western coast, in the uplands of the south-west or in the composite climate of the Arabian Gulf coast.[18] In this section of the thesis, the vernacular architecture of the hot and humid coastal regions of the western province, Hijaz and the southern regions of Najran, Jizan and Shuqaiq will be discussed.

2.4.1 The western coast of Hijaz

In Hijaz, the vernacular architecture evolved into a refined building art owing to cross-culturalisation from trade with Asian, European and other Middle-Eastern countries. Building activities across the Red sea, in Egypt, influenced construction skills of the Saudi people and the importance to detail.

[18] Kaizer Talib; Shelter in Saudi Arabia,, (London: Academy edition, 1984), p.39

Ventilation devices

The traditional climatic response of the vernacular architecture is in the construction of tall, airy structures which allow cross-ventilation and take advantage of coastal breezes (Fig.2.15).[19] Perforated facades of projected elaborately decorated wood screens, called *mashrabiyas* or *rowshans*, are created to provide the cross ventilation needed in this climatic zone (Fig.2.16).[20] The *rowshans,* which cover a great part of the facade of buildings, perform two important functions. They allow for cross-ventilation and provide privacy for residents, which is very important in Islamic households. *Rowshans* are constructed of cantilevered timber framework and are often prefabricated. [21] Some windows have openings at the bottom (Fig.2.17) which act as windscoops. These windows are called 'magic eyes' as they allow one to look down into the street without being seen. These windows catch upward air currents caused by turbulence created against a windward wall.[22] Other windows (*tagah* or *nafezah*) which do not project but are louvred or covered with decorative screens also provide adequate ventilation while giving privacy .

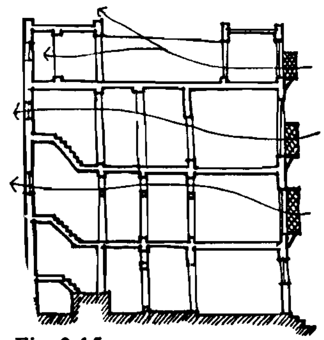

Fig. 2.15
Typical Hijaz house section
(Source: Talib, 1984, p.73)

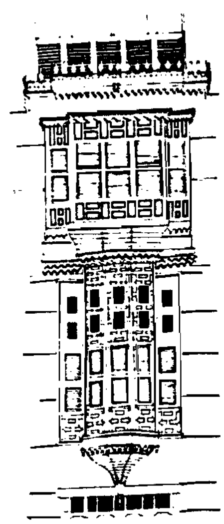

Fig. 2.16
Rowshan

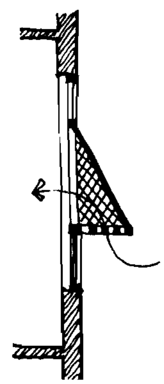

Fig. 2.17
'Magic eye'

(Source: Talib, 1984, p.76)

The dwelling plan provides cross-ventilation to each room through direct or indirect access to exterior walls. The provision of latticed screens above doors and partitions aids

[19] Talib, 1984, p.73
[20] Abdullah Sultan Alafghani; The Saudi house in the past, present and future, Dissertation in fulfilment of DPAU, University of Glasgow, Glasgow UK
[21] Geoffrey King; 'Architecture of South west Saudi Arabia', Architecture Quarterly, 1976, vol.8, no.1, pp.23, 24
[22] Oliver, 1987, p.121

cross-ventilation. Sleeping areas and family rooms are located on upper floors to take maximum advantage of sea breezes.

The buildings are constructed at a distance from each other, which facilitates free air movement in and around each building. Where this is not possible (as in the congested areas of Jeddah), the number of *rowshans* and *tagahs* on the facade is increased.[23]

2.4.2 The Southern regions of Najran, Jizan, Shuqaiq

In the southern regions of Najran, Jizan and Shuqaiq, there is a strong African influence in traditional architecture. This was introduced to the region by people of Sudanese and Ethiopian origin who settled here centuries ago. Najran is located farthest from the coast among the three. Shuqaiq is a little inland from the sea, closer to the coast than Najran. Jizan is located further south along the coast. All three regions have dwellings that are circular with conical roofs.

Ventilation strategies

The dwellings of Najran and Jizan are similar. The roofs are covered with dried thatch and walls are lightly plastered with mud. These light conical structures resist the accumulation of heat and also 'breathe' well. These dwellings do not have large openings other than the door. Hence, air exchanges take place through the roof.

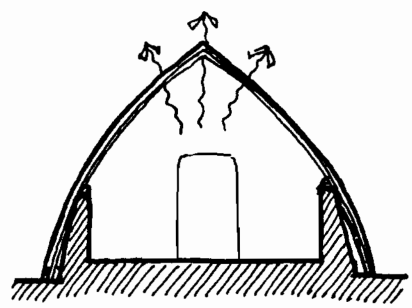

Fig. 2.18
Conical roofs of Najran dwellings
(Source: Talib, 1984, p.79)

According to Talib, on the inside of the conical hut, at the apex there is a lightly applied layer of mud plaster which allows hot air to escape through the 'semi-transparent' roof construction.[24] On the outside, the reeds provide a protective shield for the internal mud-plastered domed roof (Fig.2.18).

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[23] Talib; 1984, p.68

[24] Talib; 1984, p.79 (This process of air exchange was not stated by any other reference source in this thesis)

In Shuqaiq, the dwellings are similar in shape and form to the ones in Najran and Jizan except that there are usually two entrances into each house which permits more air circulation within.[25]

2.5 Traditional house form in Bangladesh

Climatic characteristics of hot humid regions of Bangladesh
Location: Between latitudes 21° and 27°N
Mean Maximum Temperature: 31°C, absolute high 39C
Mean Minimum Temperature: 14°C, absolute low 9°C
Summer: March to June; Winter: November to February
Average Humidity: High: 75%
Average Annual Rainfall: Very high: 2000 mm
Monsoon months: June to October
Wind speed: Low: less than 4 m/s
High glare and radiation from the sky

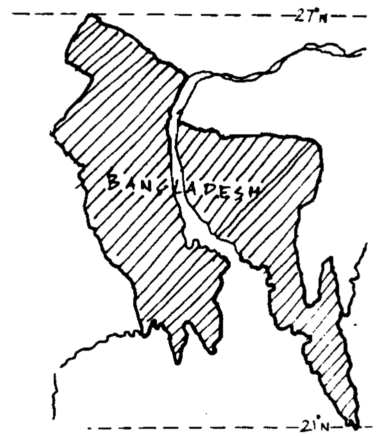

Fig.2.19
Map of Bangladesh

Bangladesh lies in a flat delta plain formed by the confluence of two rivers, the Ganges and the Brahmaputra. A third of the country is flooded every year. This has led to the construction of settlements on higher ground. But the vernacular architecture has not developed building on stilts as in the South Eastern countries. Since ancient times, predominant building materials have been earth, bamboo, timber and grass. In this study, the ventilation features used in the traditional rural 'Bengali' houses will be discussed.

2.5.1 The 'Bengali House'

A traditional rural 'Bengali House' in its basic form is a cluster of small shelters around a central yard, locally known as a *Uthan* (Fig.2.20).[26] The role of climate in shaping the dwelling in this traditional form appears to be less deterministic compared to other factors such as culture. The introverted layout of the house around an inner court

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[25] King; 1976, p.28
[26] Mohammed A Muktadir and Dewan M Hasan; 'Tradition house form in rural Bangladesh - a case study for regionalism in architecture', Regionalism in Architecture

might not appear to be suitable to a warm and humid climate, and yet this pattern has proven popular in this region. The house has two distinct parts, the inner house and the outer house. The family functions are housed in the former while social and public functions take place in the latter.[27] The inner house, which is inhabited at all times by the family, is sensitively designed for human comfort. The roof form, typical of this region, slopes on all four sides with the eaves curving downwards at each corner of the roof (Fig.2.21).

Ventilation strategies

The dwellings are usually single roomed, detached and loosely spaced around a courtyard so as to take maximum advantage of prevailing winds. The adverse effects of the sun due to unfavourable orientations (as is often the case in courtyard houses) are considerably reduced because of the low height of the structures, their projecting roof overhangs and the presence of abundant vegetation for shade. The high roof provides for convective movement of air and is covered by a thick thatch, carefully woven and of a low thermal capacity.

The porousness of rural house structures, the inherent coolness of shaded mud walls and the insulating capacity of thatch roof contribute to a good thermal character (Fig.2.21). In the construction of a traditional Bengali house, the plinth, made of rammed earth, is the first element to be built. The walls are of two basic types: the mud wall, and the bamboo and reed wall. Mud walls are thick and monolithic, and window openings are

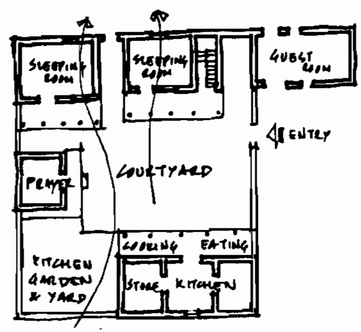

Fig. 2.20
Typical 'Bengali house' layout
(Source: Ghosh, 1988, p.83)

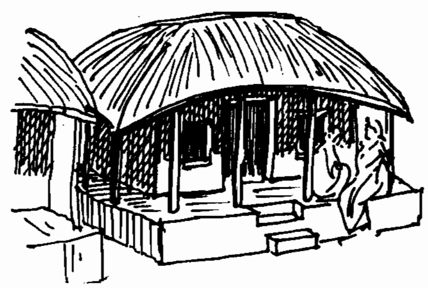
Fig. 2.21
Bengali house *(Source: Ghosh, 1988, p.84)*

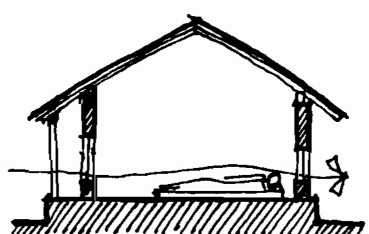
Fig. 2.22
Typical Bengali house section
(Source: Ghosh, 1988, p.84)

[27] Subrata Ghosh; from excerpts of thesis in 'The Bengal Home' in Architecture + Design, vol.4, no.4, 1988.

placed low, at the activity level (Fig. 2.22). The bamboo and reed walls are formed in panels and are fastened to the structural framework of bamboo poles or timber logs erected vertically along the periphery of the plinth and tied together with horizontal cross members (Fig.2.23). These bamboo panels 'breathe' and provide a constant air change to the interior spaces while blocking out insects.

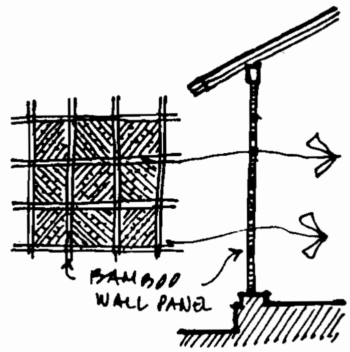

Fig. 2.23
Bamboo wall panels
(Source: Muktadir, 1988, p.85)

2 . 6 Traditional Filipino house - *Bahay na Bato*

Climatic characteristics of hot humid regions of Philippines

Location: Between latitudes 6° and 18°N

Mean Maximum Temperature: 32°C, absolute high 38°C

Mean Minimum Temperature: 22°C, absolute low 14°C

Uniformly warm all year; coolest from December to March

Average Humidity: High, 70% - 80%

Average Annual Rainfall: Moderate, 1000 to 2000 mm

Monsoon months: July to October

Wind speed: Low: less than 4 m/s

High glare and radiation from the sky:

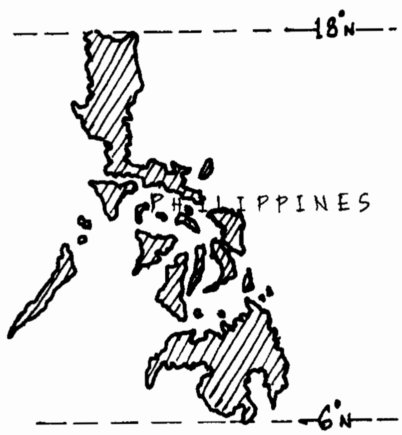

Fig.2.24
Map of the Philippines

The traditional Filipino house, the *bahay na bato*, is a product of evolution. It stems from its native ancestor, the *bahay kubo*, which is a nipa palm leaf roofed hut which existed before the Spanish invasion. Under the Christianising Europeans and the influence of Islamic traders, the *Bahay na bato* evolved into a cross-cultural, efficient response to climate. One of the salient features of this dwelling type is the openness of space which flows from one room to another through vast windows that stretch from wall to wall.[28] Traditionally, the Filipinos have always dreaded the dampness of the ground and hence

[28] Fernando N Zialcita et al; in Philippine Ancestral Houses, (Manila: Capitol Pbishing Inc., 1987) p.73

preferred to live on upper floors. Even today, with land at a premium, people prefer to live on mezzanines and raised floors.

Ventilation strategies

The ventilation devices used in the *bahay na bato* employ different elements of the structure. The roofs are hipped and the floor to ceiling height ranges from 3m to 4.5m. This helps in the convective movement of air, letting the rising hot air be displaced by the cool air from the windows at lower levels.

Gable vents are a common feature in roofs. The gable ends have a gentle inward slope and frame the vents which allow wind to pass through continuously. Another means to provide solar control and ventilation is to increase the length of roof rafters and thereby make the eaves wider. In order to allow wind to pass into the roof and remove the hot air, the eaves are not boarded up completely. Floral silhouettes and slats at regular intervals facilitate this air flow (Fig.2.25). In addition, they prevent large insects and rodents from entering through the gap between the roof and wall.

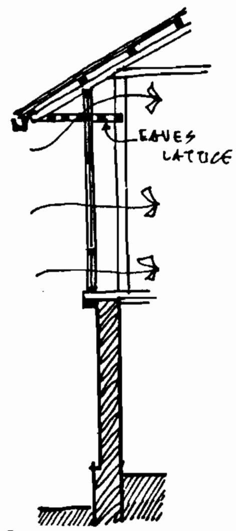

Fig. 2.25
Typical wall section of *Bahay na Bato*
(Source: Zialcita et al, 1987, p.57)

The windows are elaborate devices. To catch the wind, windows are about 1.8 m high and 5.4 m wide. Divided in two halves, the upper half acts as a main window while the lower half below the window sill, the *ventanilla*, is smaller and lets in more air through its elaborate iron grille or wooden balusters. Both top and bottom halves of these sliding windows consist of two kinds of panels.

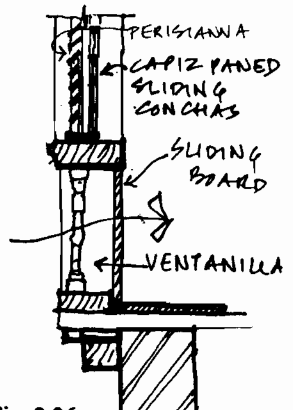

Fig. 2.26
Ventanilla
(Source: Zialcita et al, 1987, p.57)

Apart from the main windows and the *ventanilla*, there are sliding panels which shield the windows from sun and rain. When there is too much wind, as during a storm, and daylight is needed, *conchas* or latticework panels with *capiz* (oyster shell) panes are drawn to shield the main window (Fig.2.26). The *ventanilla* are often covered by blank boards which slide in grooves in the floor.[29] *Jalousies,* or *persianas*, block out the sun while letting in air. They consist of framed slats that can be opened or shut with a herringbone shaped rod that runs across them from top to bottom.

Floors often take the form of slats with gaps in-between. This facilitates air currents into the rooms above. The air coming into the house thus is already cool as it is passing through a shaded space. This method of ventilation is seen in other parts of the south-eastern region.

2 . 7 Traditional houses of Southern China

Climatic characteristics of Southern China

Location: Between latitudes 21° and 29°N

Mean Maximum Temperature: 30°C, absolute high 36°C

Mean Minimum Temperature: 20°C, absolute minimum 14°C

Summer : May to August; Winter : December to March

Average Humidity: High, 80%

Average Annual Rainfall: High, 1500 mm

Monsoon months: April to September

Wind speed: Low: less than 5 m/s

High glare and radiation from the sky

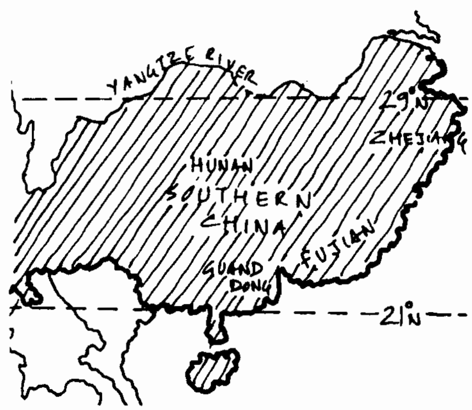

Fig.2.27
Map of Southern China

Chinese dwellings display a strong regional diversity and sensitivity to local environmental conditions. China encompasses a variety of climatic conditions. The regions situated southward from the valley of the Yangzi river, such as Zhejiang, Fujian, Guangdong, and Hunan can be classified as warm and humid. The Chinese prefer to build their houses on the ground rather than raise them on stilts. Typical Chinese houses are built with roofs pitched at angles of about 30°, in response to the heavy rainfall in summer. Roofs of thatch and baked tile are common.

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[29] Zialcita et al, 1987, p.81

Ventilation strategies

High humidity levels make living conditions very uncomfortable. The houses are oriented to the south or south-east to take advantage of the steady wind patterns experienced in coastal China. Small and high windows are used on the facade which block the direct rays of the sun and reduce ground radiation. Although the exterior windows are limited in number, the introduction of skywells and verandahs help to direct ambient breezes into the house (Fig.2.28).[30]

Skywells are sunken spaces which act as open shafts that capture breezes. They are abutted by verandahs which act as transitional spaces between the enclosed rooms and the open skywell. Substantial overhangs prevent direct sunlight from penetrating any of the rooms. Open latticed and louvred windows give onto verandahs and help ventilate the rooms.

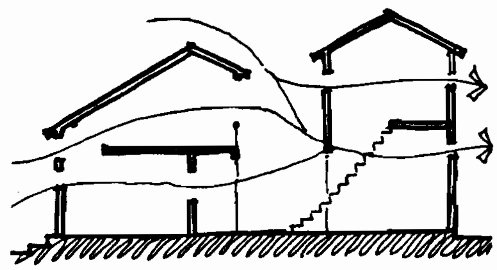

Fig. 2.28
Typical section through traditional house
(Source: Knapp, , p.18)

2 . 8 Traditional Southern Nias house, Indonesia

Climatic characteristics of Nias island, Indonesia

Location: Between the equator and 2°N

Mean Maximum Temperature: 31°C, absolute high 36°C

Mean Minimum Temperature: 23°C, absolute low 15°C

Uniformly warm all year, warmest from February to April

Average Humidity: High; 80%

Average Annual Rainfall: Very high, 1300 - 4000 mm

Monsoon months: December to March, May to September

Wind speed: Low; less than 5 m/s

High glare and radiation from the sky

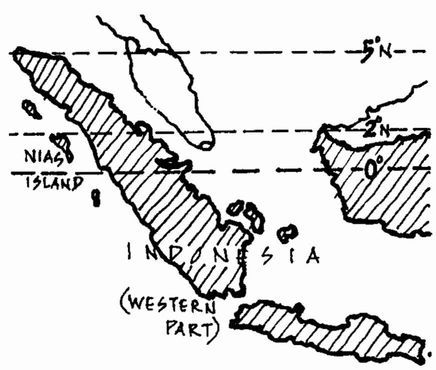

Fig.2.29 ———— 11°S
Map of Indonesia (part)

[30] Ronald G Knapp; The Chinese House, p.18

The island of Nias is located about 120 kilometres off the west coast of Sumatra in the Indian Ocean. It is part of a chain of islands which form the extreme limit of the Indonesian archipelago. The hilly terrain is covered by secondary forest, grassland, rubber and coconut trees. Important linguistic, cultural and architectural differences divide the island into three areas: southern, central and northern.[31] This section of the thesis will discuss the architecture of the south of the island.

2.8.1 The house

The houses are generally rectangular in plan with the narrower side facing the street. They are divided into a communal or public front section, and a private rear section (Fig.2.30). The Nias house is raised on stilts and has a vertical tripartition: lower frame, domestic nucleus and an upper frame. While the lower frame below the floor is used as a storage space or enclosure for domestic animals, the upper frame is not used. The traditional houses are entirely constructed of locally available materials. Timber is used extensively and different pieces of the structure are assembled and pegged together without the use of nails and screws. Bindings are confined exclusively to roofing.

Houses are joined together in groups of two with a common wall along the length. A common footbridge gives access to both houses. At the entrance is the public section of the domestic nucleus. The room is lit by narrow longitudinal openings in the facade. The corbelling of the facade is translated into the interior in the form of timber platforms (Fig.2.31). The lowest, the *bato*, serves as a sleeping platform for guests. The middle bench, *farakhina*, is used as a back and arm rest while the topmost shelf, the *harefa*, gives access to a flap-like opening in the roof.

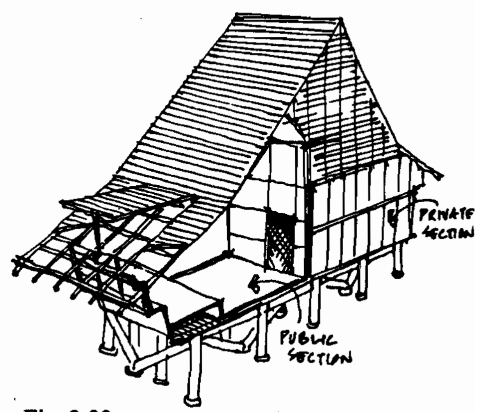

Fig. 2.30
Axonometric of typical Nias house
(Source: Viaro, 1992, p.117)

[31] Alain Viaro, Architectures of Indonesia: Nias island, Spacio E Societa, 1992, No.58, p.111

A wall with a door separates the public and private domains of the house. The layout and size of the private zone varies depending on the economic standing of the owner. Traditionally houses were not furnished although now the use of tables and chairs in the western manner is spreading.[32]

Ventilation strategies

The interior volume is well ventilated. Flap like openings in the roof, *lawalawa*, provide ventilation. These flaps are adjustable, giving the residents the ability to regulate the amount of air and light in a house (Fig.2.31). The openings on the lateral walls also provide air flow. The free space below the posts ensures ventilation of the lower part of the house. The large volume of interior air circulates constantly thus avoiding stagnation of masses of warm air.[33]

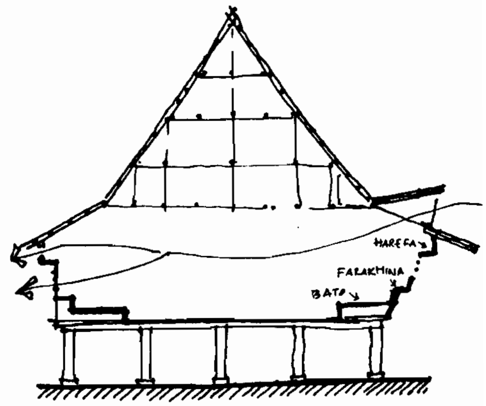

Fig. 2.31
Typical section of Nias house
(Source: Viaro, 1992, p.117)

2 . 9 Circular house forms, Nigeria

Climatic characteristics of hot humid Nigeria

Location: Between the latitudes 4°N and 12°N
Mean Maximum Temperature: 30°C, absolute high 37°C
Mean Minimum Temperature: 23°C, absolute low 14°C
Uniformly warm all year, warmest from March to May
Average Humidity: High; 75%
Average Annual Rainfall: Fairly high, 1200 mm
Monsoon months: April to June
Wind speed: Low; less than 4 m/s
High glare and radiation from the sky

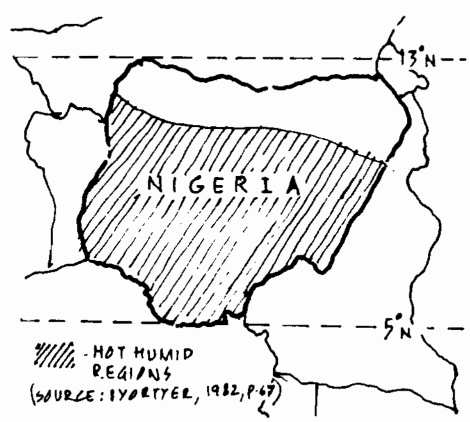

Fig.2.32
Map of Nigeria

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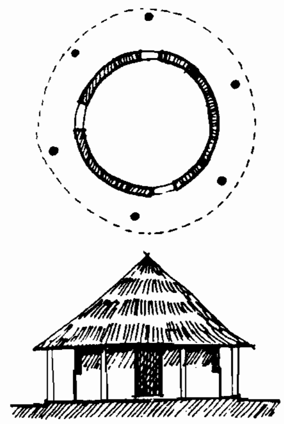
[32] Viaro; 1992, p.117
[33] Viaro; 1992, p.119

Although there are dry periods of heat, the Nigerian Savannah is predominantly hot and humid. House form in the Nigerian Savannah is diverse. There are houses on stilts, houses made of mud or vegetable material, and houses of rectilinear or curvilinear shapes.[34] Among the many house types, this section discusses circular house forms. The house plan is circular with its diameter equal to or greater than its height (Fig.2.33). Walls are built monolithically in horizontal courses of puddled mud. Palm fronds, bamboo or woven grass are also used for walls. Roofs are conical and are thatched in rings. Sometimes, the house is encircled with a verandah. The buildings are arranged in clusters surrounded by a compound wall.

2.9.1 Ventilation strategies

The dwellings are laid out in loosely arranged clusters which permit air flow through the structures. The circular plan with openings on all sides ensures air movement in the house.[35] Circular dwellings provide less obstruction to incident winds than rectilinear dwellings. Streams of wind closest to a curvilinear form flow with a high velocity.[36] Providing openings all around the house would result in air getting sucked into the dwelling, because of the pressure difference between indoor and outdoor air (Fig. 2.34). Sometimes, a gap of about six inches is provided between the top of the wall and the roof, which facilitates passive air circulation in the house.[37]



33
t circular house plan, elevation
e: Danjuma, 1988, p.35)

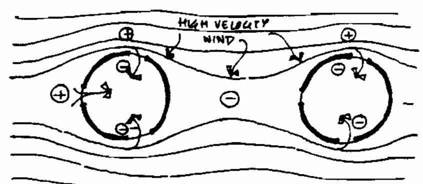


Fig. 2.34
Air flow
(Source: Danjuma, 1988, p.116)

[34] Philip Iyortyer, Tropical Urban Housing Design Considerations - with special reference to Nigeria, M.Arch. Thesis (Montreal: McGill University Press, 1982), p.30
[35] Benjamin Danjuma, House for in Nigerian Savannah, M.Arch. Thesis (Montreal: McGill University Press, 1988), p.118
[36] Olgyay, 1963, p.50 - The author discusses the effect of wind around small circular hillocks. The principle has been used in this case by Danjuma, 1988, p.116
[37] Kaj Blegvad Anderson; African Traditional Architecture, (Nairobi: Oxford University Press, 1976), p.156

Summary

The case examples studied were either loosely arranged (rural) or tightly packed (urban) settlements (the case study in Madras is also situated in a tightly packed traditional settlement). However, in this thesis, the particular ventilation strategies and devices are considered irrespective of the settlement type.

The devices and strategies are graphically summarised in Matrix I (Appendix II). Each strategy is represented with a code number (for ready reference) along with a brief description. The strategies are summarised with respect to the external and internal factors that affect ventilation in dwellings. Among the external factors, strategies with respect to siting of built form, vegetation, physical form, and plan have been discussed.[38] Among internal factors affecting ventilation, building elements, namely, roofs, walls and floors, openings and their shading devices[39] and other ventilating devices have been considered.

This matrix forms the first part of the identification stage of the transfer process. The second part of this stage is the identification of the context in Madras, which is discussed in the next chapter -- 'Context of the Transfer -- Madras'

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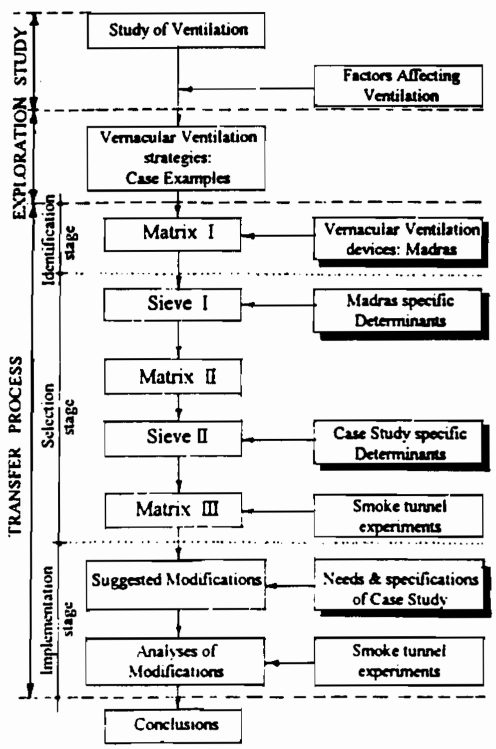
[38] The external factors of wind movement and orientation have not been discussed because in most cases, dwellings are oriented with respect to the wind direction. In the study conducted, no special strategy in this regard was found, to harness favourable winds.

[39] The factor of cross ventilation has been integrated with the factor of openings and their shading devices.

Chapter III

Context of the transfer - Madras

This chapter constitutes the field study conducted in Madras. It forms the second part of the identification stage -- the identification of the specific context where the transfer is to be effected. The chapter is divided into two parts. Part I discusses the context of the transfer -- the city of Madras and the traditional dwelling chosen as the site of a possible transfer. Part II includes a collection of vernacular ventilation devices found in the hot and humid climatic regions in and around Madras. These devices are incorporated into Matrix I which is then used as a 'base palette' for choosing devices to be transferred.



<u>Part I</u> - The Context - Madras

Climatic characteristics of Madras

Location: Latitude 12°59'N

Mean Maximum Temperature: 35°C, absolute maximum 42°C

Mean Minimum Temperature: 22°C, absolute minimum 18°C

Summer months: April to August; coolest months November to February

Average Humidity: High; 75%

Annual Rainfall: Fairly high: 1275 mm

Monsoon months: North-east monsoon-October to December; South-west monsoon July, August

Wind direction: Predominant wind direction - South. During summer months, sea breeze blows from early afternoon.

Wind speed: Low; less than 5 m/s, going higher than 8.5 m/s on 1.2% days in a year (about 5 days). Cyclonic storms occur during NE monsoon with squalls ranging from 50 to 90 km/h.

High glare and radiation from the sky.

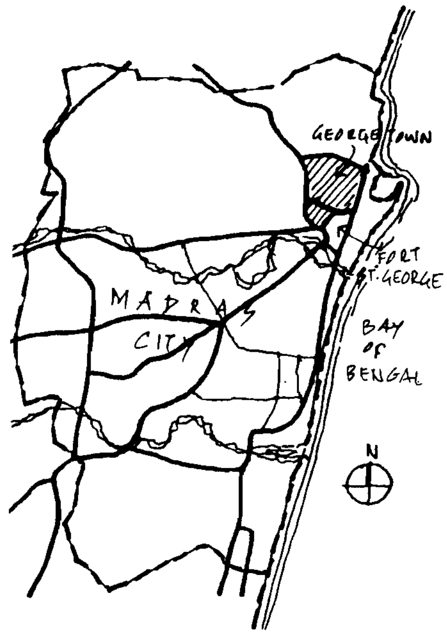


Fig. 3.1
Map of Madras

Part I of this chapter focuses on the particular context that has been chosen for the transfer -- Madras, the capital city of Tamil Nadu, a southern state of India.[1] The city of Madras came into being around 350 years ago with the advent of the British, who ruled India until the middle of the twentieth century. The city was originally a coastal strip of verdant land, interspersed with villages and agricultural fields.[2] After the British established Fort St.George on the coast in the seventeenth century, there was an influx of immigrants from neighbouring areas in search of employment and better trade prospects. They settled close to the Fort in a settlement called the 'Black Town' by the colonisers which was later renamed George Town.[3] Traditional villages that existed before the British came also started to evolve, although with less interaction with the foreigners. As a result, the majority of the Indian community lived in two distinct settlement types: first, in the dense Indian urban core adjacent to the Fort, and second,

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[1] Refer to Appendix I, Figure A -- Location of Madras in Map of India
[2] Philip Davies; <u>Splendours of the Raj - British Architecture in India: 1660 - 1947</u> (London: Murray, 1985)
[3] S.Muthiah; <u>Madras Discovered</u>, (Madras, Affiliated East-West Press, 1981). p

in rural settlements relatively isolated from Colonial influence.[4] The British initially lived in the Fort itself and later in typically British 'garden houses' (bungalows), situated a little way from the Fort, which were adopted by prosperous Indians from the early twentieth century.

All three dwelling types are prevalent to this day. However, now there are other house forms too that are becoming part of the vernacular of Madras. The last three decades have seen the emergence of the three to five storey apartment building type which is popular because of its increased land use efficiency and cost benefits.[5] Although there are no villages in Madras, there are many regions along the outskirts of the city which show a distinct rural character. The increasing number of rural migrants into the city, and their informal methods of housing also show a rural character. Today, all these dwelling types exist together as part of the vernacular of Madras.

In this research, the discussion is limited to the study of a traditional dwelling in the urban core of George Town. This dwelling has been chosen to explore the possibility of effecting a transfer of technology in order to improve its indoor ventilation. The main criteria for choosing this particular dwelling are: (a) the indoor environment (in terms of air movement) is not satisfactory, (b) the dwelling has been in existence since the turn of the century and is part of the existing vernacular of Madras, (c) the history of the dwelling is known and also some information about the indoor environment of the house over the years is available.

The house at 89 Ramaswamy Street, George Town, (Fig.3.2), was built according to the traditional principles of *Vaastu Saastra*. Some of the former residents of the house were able to throw light on the house plan in the early 1930s and the air flow within the house at that time. This enabled the researcher to reconstruct the older plan form and its ambient indoor environment, discussed in a following section.

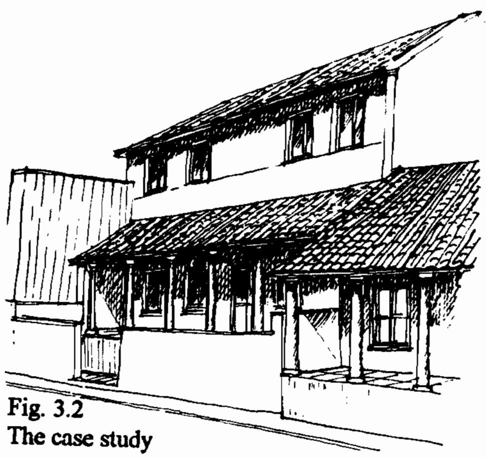

Fig. 3.2
The case study

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[4] Norma Evenson; The Indian Metropolis, (London, Yale University Press, 1989), p12

[5] With the real estate boom in the city, promoters and developers buy property, demolish existing structures and build apartment buildings which accommodate the erstwhile property owner and many other people. This is financially advantageous to the house owners too. The indiscriminate appearance of these structures and the increase in number of residents per lot adversely affects (1) the air movement in the region and (2) depletes the ground water of the region due to a sudden increase in water consumption.

3.1 Traditional dwelling typology

The traditional knowledge and practice of architecture in India is present in the form of texts as well as in oral knowledge and skills that are passed down through generations. The basic premise that is followed in the traditional systems of architecture is that the built form is an extension of man's physical and metaphysical existence in this world. According to an interpretation of these texts by Ananth, "man does not inhabit this earth alone. He lives amidst other natural forms and is in touch with energies in outer space, the energies on the earth and the energy within all living creatures that are vibrating and alive." The aim of the *Vaastu Saastra* is to achieve a consonance between these energy forms by providing a built environment which is utilitarian (*bhogadayam*), aesthetic (*sukhadarshanam*) and provides psychological well-being (*ramyam*). [6]

The traditional dwelling in the Madras region is usually the street house. This rectangular house form is symbolised as the body of a man lying down. The most significant points in the plan form are the centre, known as the *Brahmasthanam*, and the four cardinal directions (in which the east-west axis is known as the *Brahma Sutram*, and the north-south axis is known as the *Soma Sutram*).[7] The point at which the two axes meet is the most important part of the house and falls in the *Brahmasthanam* (the divine space) and is always left uncovered. Ideally, this place open to the sky, but in the worst case, it can be covered provided there is adequate provision for light and ventilation in that space.

In George Town, the traditional street houses are seldom more than two storeys high and share common walls with adjacent units. The entrance verandah, which often abuts the street, is raised from the road level by more than two feet, leaving only the entrance bay with steps for access to the house. This raised verandah (*thinnai*), is essentially a raised platform on which people can gather.

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[6] Sashikala Ananth; Vaastu Vignanam - a study of documentation of the Vaastu principles in housing by RASAM - sponsored by the National Housing Bank, (Madras, due for publishing)
[7] Madhu Khanna; ' Space, Time and Nature,' Spacio E Societa, 1992, no.6

The entrance door is always placed off-centre to the spine of the house (*Madhya Sutram*).[8] On the *Madhya Sutram* lies the 'lifeline' or 'air funnel' (*Vamsamoolam*) of the house (Fig.3.3). The entrance door leads to the *rezhi*, the entrance lobby of the house. The *rezhi* is flanked by rooms which overlook the street. The *rezhi* leads to a verandah (*alindram*) which runs around a courtyard (*anganam* or *muttram*). This courtyard could have verandahs on two, three, or on all four sides. Apart from the rooms grouped around the courtyard, invariably there is an extended verandah (*koodam*) which is the main living space in the house. Most of the daily activity goes on in the *koodam*, which draws air and light from the courtyard.

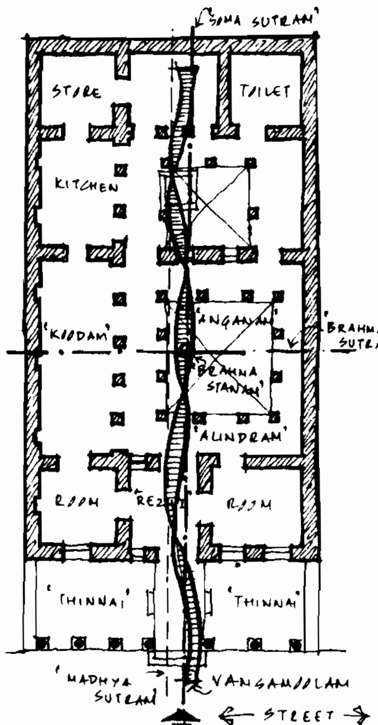

Fig. 3.3
Traditional street house

The courtyard itself is a very important activity space in the dwelling. It is a private open space which has many functions. It serves as a play area for children, an extension to the kitchen for food preparation, a space for ritualistic activities and for family gatherings.[9] The cooking area, store and prayer room (*pooja*) are situated beyond the courtyard of the house. The rear yard is generally used for washing and drying of clothes and cooking related chores. The toilets are usually placed at the far end of the yard.

In a traditional dwelling, the guiding principle is to effect cross ventilation through a series of openings from the front entrance through a central courtyard and out through an opening at the rear (Fig.3.3). This forms the 'air funnel' (*Vamsamoolam*) of the house. The incident wind passes through the *vamsamoolam* and is focused on the courtyard, which in turn ventilates the living areas grouped around it. The courtyard symbolises the *Brahmasthanam* and is almost always left uncovered. In some cases, when the *Brahmasthanam* is covered, the roof is raised and provided with ventilators or windows to let in air and sunlight. The courtyard, which acts

[8] Ananth; p.
[9] Amita Sinha; "The centre as void - courtyard dwellings in India", Open House International, vol.19, no.4, 1994, p.28

as a 'lung' of the house, is considered by the *saastras* to be a major source of energy transfer from inside the built space to the outer open space.[10]

It is important to note here that although the *Mayamata* and *Manasara* [11] advocate these design principles, local practice often modifies them to suit existing conditions. For instance, for reasons of security or to facilitate expansions to a house, the courtyard may become smaller or be covered with iron grills or even totally sealed. In many cases this could hamper the ventilation of a house. Often, due to shared inheritances or partitions in a family, a house may undergo changes which could inhibit the free passage of air in the *vamsamoolam*. In the field study, the author rarely encountered a house that had not undergone changes.

3 . 2 Climatic and Environmental considerations for a dwelling [12]

Besides the requirement of ventilation, there is additional need for protection from the sun in Madras. Given its location between the Equator and the Tropic of Cancer and because the maximum overheated period in Madras is between 8:30 a.m. and 3:30 p.m. for most of the year, shading must be considered for both the north and the south walls..

Between April and August, the sun is on the northern side of the building.[13] During the hottest months (May to July), the sun is virtually overhead around noon. For the north wall, the most critical wall azimuth angle of the sun is about 62°. This implies that a horizontal shadow angle [14]of 62° is required to cut off the sun with the use of vertical shading devices (Fig.3.4). In the triangle formed by the critical wall azimuth angles, the most intense altitude of the sun is 40°. A combination of the horizontal shadow angle

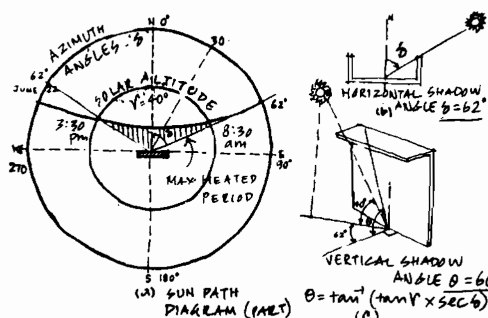

Fig. 3.4
Sun protection requirements - North wall

[10] Sinha; 1994, p.24
[11] Other known texts pertaining to traditional Indian Architecture, supposed to be written around the 2nd century AD
[12] This section deals with critical solar angle calculations for dwellings in Madras. As mentioned in the Scope and Limitations of the thesis in the introductory chapter, a detailed explanation of the solar calculations are not indicated. Only the critical horizontal and vertical shadow angles that are necessary for the design of shading devices are discussed.
[13] Refer to Appendix I, Figure D -- sun path diagram for Madras.
[14] Horizontal shadow angle = Solar azimuth - Wall azimuth. For the North wall, wall azimuth is 0°; for the East, South and West walls, the wall azimuth is 90°, 180° and 270° respectively.

and the critical altitude of the sun results in the vertical shadow angle.[15] It is necessary to block this angle (60° for the north wall) with a horizontal shading device (Fig.3.4).

The sun falls on the southern wall in the slightly less warm months, between September and April (Fig. 3.5). The angle of the sun is lower than on the northern wall and hence a greater wall area is exposed to the sun. The critical altitude of the sun is around 30°, while the critical azimuth angle of the sun is about 240° which indicates that the horizontal shadow angle required is 60° and the vertical shadow angle is 45°.

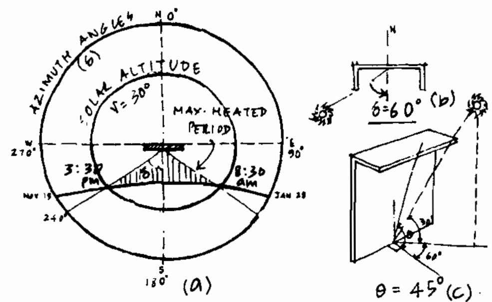

Fig. 3.5
Sun protection requirements - South wall

The eastern and the western walls are exposed to the sun on every day of the year. Although both walls have similar requirements, the western wall is crucial as insolation occurs during the hottest parts of the day. The critical period is between February and November. The critical altitude of the setting sun is about 20° and the critical wall azimuth is 25° (Fig.3.6). The horizontal shadow angle required is 25° and the vertical shadow angle is 20°.

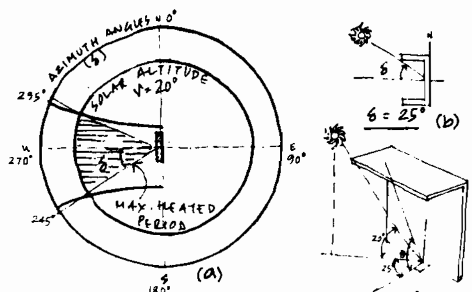

Fig. 3.6
Sun protection requirements - West wall

Madras has a severe mosquito problem. Except for the hottest months (May to July), they are active throughout the year. There have been several eradicative measures by the Health Authorities to stop this menace, but of no avail. Mosquitoes are active from late evening to early morning. The most effective measure to date has been the use of plastic perforated screens on windows which, to a large extent, prevent the entry of mosquitoes and other insects.

3.3 Street house in George Town : a case study

The house chosen for study is at least a hundred and twenty years old. This two-storey house is situated on an exclusively residential street of George Town, about three kilometres from the

[15] Vertical shadow angle , is calculated as follows: $\tan\theta = \tan\gamma \times \sec\delta$, where 'θ' is the shadow angle, 'γ' is the altitude of the sun and 'δ' is the horizontal shadow angle (Figure 3.4 indicates these angles graphically)

sea front.[16] It is a north facing house which shares walls with both adjacent lots. On the west side is a single-storeyed dwelling while on the east side, the house abuts a temple compound wall. Window openings on this wall are strongly discouraged. The ambient wind direction is from the south side, the rear of the house.

The exact date of construction of the house is not known, but a deed issued by the British authorities in the name of a former resident's father was dated 1892. The resident, who was interviewed, was born in the house in the early 1930's and lived there until 1942 when the property was sold. Until that time, the house was occupied by a single family who lived on the lower floor while the upper floor was used occasionally for guests or visiting relatives. The house has changed hands since, and the current owner, an insurance agent, has let out the first floor to a relative.[17]

The house is narrow fronted and rectangular, twenty five feet wide by forty feet long (Fig.3.7) with a five-foot-wide brick-paved set back from the street and a five-foot-wide rear yard.[18] The entrance verandah of the house is four feet wide with a *thinnai* on both sides. The verandah is divided into five equal bays, with entry being effected from the second bay from the right (Fig.3.7), leading to the entrance door of the house which opens into the entrance lobby, the *rezhi.* This leads on to a verandah, the *alindram*, which runs around a courtyard, the *muttram*. There are rooms around the *muttram* and a single flight of stairs lead to the upper floor.

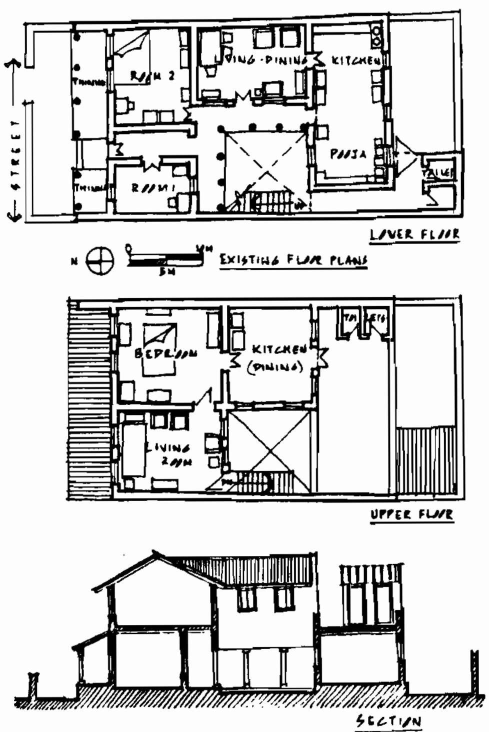

Fig. 3.7
Floor plans, section of case study today

The rooms adjoining the entrance verandah are used as bedrooms, Room 2 for the married son and

[16] Refer to Appendix I, Fig. C – Detailed map of George Town.
[17] The lower floor has a total of six inhabitants: the owner, his wife, two sons and a daughter. The oldest son is married and his wife also lives in the house. The upper floor is inhabited by a distant relative of the owner, his wife, their six year old daughter and the wife's brother.
[18] The frontal set back is not a standard feature, as most of the houses here are directly on the street. It is not clear why there is a set back but the most plausible reason given by the residents of the house was that there might have been a tree within the lot and the original house owner may have wanted to preserve it.

Room 1 for the other son. Originally, the rooms had openings on three sides in the form of windows or doors (Fig.3.8). The *koodam*, which was an extended verandah, is now an enclosed and furnished living and dining room. The kitchen and *pooja* are beyond the *muttram* with a passage along the western wall leading to the toilet. These two rooms were separate entities originally, on either side of the *vamsamoolam*. Later, probably due to security and spatial constraints, both these rooms were amalgamated and the rear door on the *vamsamoolam* was replaced by a small window.

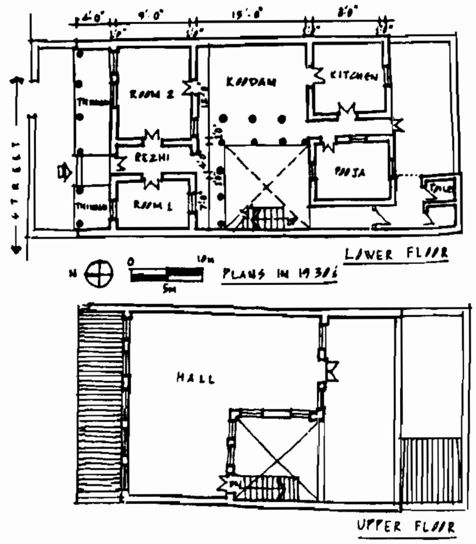

Fig. 3.8
Floor plans of case study in 1930s

On the upper floor, a large hall was replaced by rooms that were built about thirty years ago. The three rooms are interconnected. A living room leads on to a bedroom and then to a kitchen. To access the toilet, one goes through the kitchen.

The use of spaces in both households is both traditional and modern (Fig.3.9). On the lower floor, while the sons prefer to dine at a table, the house owner, his wife and daughter eat in the kitchen, in the traditional fashion (Fig.3.9a).

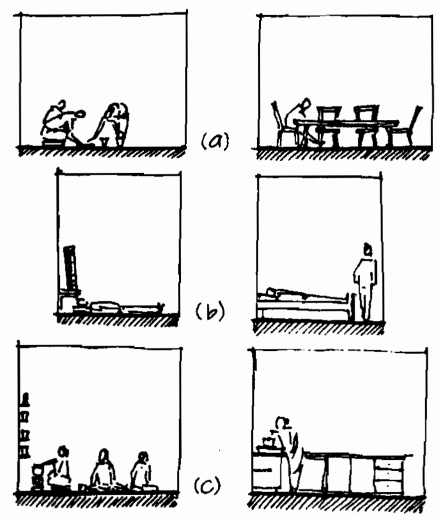

Fig. 3.9
Internal spatial use

The sleeping arrangements vary from person to person. While the elder son and his wife sleep on cots, the other members of the family sleep on traditional woven cane mats (*paai*) on the floor (Fig.3.9b). Cooking is done on a counter-like working platform. On the upper floor, the residents sleep on cots, while cooking and dining is done in the traditional manner (Fig.3.9c).

3.3.1 The indoor environment

Originally, as described by a former resident, the house was well ventilated with air flowing through the *vamsamoolam*. The openness of the plan form, with one room opening into another, would have facilitated good air movement in the dwelling. Every room had at least three walls with openings to draw air from one another. The open *koodam* would have been an important factor in affording a cool interior. According to the resident, the rear door (which was the mouth of the *vamsamoolam*) was kept open most of the day. It had a grilled top half which let in the breeze even when closed, issuing an uninterrupted air flow through the courtyard and the *rezhi* through a fixed grille fanlight above the entrance door. Another source of air flow was through the corridor along the west wall leading to the toilet. The door in the corridor was similar to the rear door, which allowed air flow even when closed.

Today, there is a lack of air movement on the lower floor. Even if there is an ambient breeze in the rear yard, it is not felt strongly inside the house. The main reason could be the lack of sufficient openings to effect cross ventilation and the blocking of the *vamsamoolam*. Room 2, in particular, has an uncomfortable indoor environment. For reasons of privacy, the door to the room is kept shut and so are the windows on the north wall. The openings to the *rezhi* and the *koodam* are also sealed. The room is also over furnished with two large storage cupboards and a large cot. Room 1 is relatively unchanged in its plan form. The living/dining room is fairly well ventilated because of its proximity to the courtyard. In the rear part of the house, the door to the kitchen from the courtyard, which is on the original *vamsamoolam*, is kept closed most of the time. The openings in the store/*pooja* part of this room facilitate a better flow of air. However, a large pile of boxes is stored on the southern wall covering most of the window, inhibiting the flow of air.

The upper floor receives very high insolation and radiation from the roof. Hence it is very important to remove hot air at the roof level. Unlike the lower floor, which is well shaded from insolation because of the insulating floor above, radiant heat from the roof in the upper storey increases the indoor temperature of the rooms. Since the roof is composed of simple clay tile over timber battens, without a ceiling of any sort, thermal insulation is low and hence the temperature of the rooms remains high.[19] Also, while the walls of the lower storey rooms are well shaded with verandahs on the north side and along the courtyard, the walls of the upper floor rooms are exposed to the sun. As a result, although the ambient air movement at the

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[19] According to a study done by Koenigsberger et al, a red clay tile roof produces excess of ceiling temperature over indoor temperature by about 8°C - Otto Koenigsberger et al, Roofs in warm humid tropics, (London, Lund Humphries, 1969), p. 25

upper level is greater, the windows have to be kept closed due to inadequate protection from the sun. This is true particularly in the living room which has windows facing the south wind.

Often, the wind flowing from the south is heated while passing over the terrace above the lower storey, which is insolated all day. The kitchen/dining room of the upper floor has an unshaded south facing wall but the location of the toilet block and the pot wash of the kitchen just outside one of the windows has eliminated its use. Windows of the west wall of the kitchen are kept open only during the morning hours. The bedroom is the most uncomfortable room in the house. With no wall exposed to the windward side, the room has to borrow air from its neighbouring rooms. During the summer months, windows on the north side are kept closed for most of the day. In both levels, all windows are timber panelled and side hung with a sill of 3' 0" above floor level, irrespective of the activity levels in the room.

3.4 Existing material resources in Madras

To effectively import strategies, it is important to understand the local building resource base, and devices and strategies will have to be modified based on the available material and skills available in Madras. The most commonly used building materials in Madras today are brick, concrete, steel, country timber, clay tiles and thatch. Traditionally, there was extensive use of lime and timber (teak wood and jackfruit wood) but over the years, cement has replaced lime and scarcity of timber has resulted in a ban against widespread use of timber. Considerable research and experimentation is being conducted in pursuit of alternative building materials. Materials such as compressed wood-cement panels,[20] ferro-concrete, micro-concrete and stabilised mud blocks are being increasingly used in building construction. In this research, the above mentioned materials will be considered, but not their detailed chemical composition or material strengths.

Bamboo is seen as an important building element in the future because it is cheap, flexible and easily replenishable. HUDCO (Housing and Urban Development Corporation), a government organisation, has conducted considerable research on bamboo and has suggested ways of treating it to make panels of woven bamboo for doors and partition panels. Private

[20] Compressed wood-cement is a building material recently introduced in Madras. It is available in panels of varying sizes and can be plastered, glued, screwed on, sawed or jointed in a similar manner to timber, the main difference being that compressed wood-cement is heavier.

entrepreneaurs are using bamboo for making building components, furniture and artifacts. There is a widespread use of bamboo in the country and the skill to work with it is also becoming increasingly prevalent. In and around Madras , split bamboo has traditionally been used for making mats and sun screens. Awareness of the variety of uses of bamboo is on the rise among the local craftsmen of Madras.

Among roofing materials, clay tiles and thatch are most prevalent in this region. Among clay tiles, the 'mangalore tile' is most widely used and is fixed on a timber sub-structure or grouted directly onto a concrete roof. Thatch is considered a low cost and 'impermanent' roofing material. Although most people look down upon this material, it seems to be enjoying a revival initiated by some professionals due to its thermal efficiency. There are different kinds of thatch available in this region, most common being coconut palm thatch and the black marsh reed thatch. The latter is a black reed which has the property of swelling up when wet and thus preventing water penetration. Layers of these reeds are lashed together to create a roof thicknesses that varies from three to six inches. The reed also has the inherent ability to 'breathe' which creates air pockets that further insulate the spaces below.

Among other roofing methods, the Madras terrace roof has traditionally been used widely. This roofing technique involves placing timber rafters (10cm x 15cm) across the shorter span of the roof at a spacing of about a foot from centre to centre. Layers of bricks (generally two) are laid diagonally over the rafters with a lime mortar bed over the bricks. Today, these roofs are seldom used because of the unavailability of timber (although steel is replacing timber rafters). These roofs, combined with high ceilings, are thermally well suited for the climate due to the thickness of the roof layer.

Part II - Existing vernacular ventilation devices in the region

This section discusses vernacular ventilation devices in use in and around Madras. The majority of ventilation devices used in this region are found predominantly in roofs and walls. The roofing systems in hot humid Tamilnadu vary from the coastal regions to the interior. Depending on the amount and intensity of rainfall, the roofs are either sloped or flat terraces. The material used for construction largely depends upon available resources. The walls are predominantly brick masonry. The following sections discuss the various ventilating devices in sloped roofs, flat roofs and walls.

3.5 The devices in sloped roofs

Traditional timber construction is used for sloped roofs. The main supporting rafters run along the slope of the roof with clay tiles or thatch fixed to purlins running across the main rafters. Bamboo is also used in some regions for roof frameworks. Sloped roofs occur in both urban and rural areas. The roof slope angles vary from region to region (from 25° to 40°). Due to the slope, these roofs have high ceilings, which allows warm air to rise above the living zone. Described below are some ventilating devices that occur in roofs in this region.

3.5.1 Ridge vent

Among devices seen in sloped roofs, the ridge vent is very common, especially in regions with high rainfall (Fig.3.10).[21] But in the Madras region it is less prevalent due to the relatively lower levels of rainfall. The ridge vent of a roof typically runs parallel to the direction of the wind and is sometimes raised higher than the normal slope.

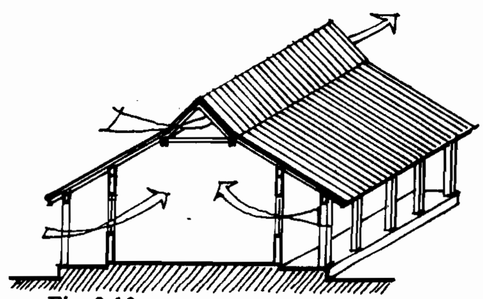

Fig. 3.10
Ridge vent

The pressure at the windward opening of a vent is far greater than at the leeward end.[22] As a result of this pressure difference, a flow of air is generated through the vent. As wind passes through a vent at high pressure, air is sucked out of the spaces below, hastening the stack effect in a dwelling, resulting in a faster air exchange in lower living spaces. The

[21] It can be seen in the hot and humid regions in Bangladesh, Philippines, Indonesia: see sections 2.5, 2.6, 2.8

[22] Refer to section 1.5.2, p.20

construction of a ridge vent involves an extension of the ridge on the ends creating a triangular gable above a hipped roof slope. The gable ends of a vent are traditionally boarded by timber with small ornate openings in them. By reducing the size of these openings, the velocity of the wind passing through the vent is enhanced.[23] The openings are sometimes meshed to prevent birds from nesting in the roof.

3.5.2 Smoke tile (*Pugai Odu*)

A unique ventilating device, the *pugai odu* is found in many parts of Tamilnadu. As the name suggests, the tile is used to exhaust cooking fumes. This tile is a modification of the mangalore tile (Fig.3.11). There is a rectangular gap in the tile which is covered by a tapering hollow cylinder cut in half.

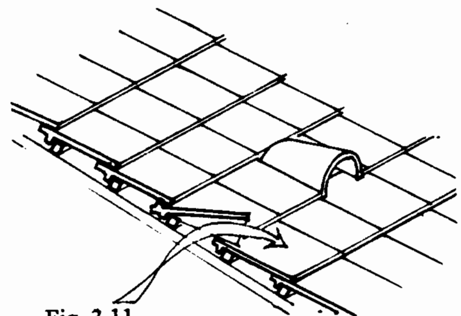

Fig. 3.11
Smoke tile (*pugai odu*)

It is generally placed on the leeward side to facilitate the easy removal of fumes without the interference of an incident wind. The *pugai odu* is also used to take the warm air out from the living areas. An increased number of these tiles can increase the air movement in a dwelling.

3.6 The devices in flat roofs

The devices used for ventilation in flat roofs are usually passive, primarily used to exhaust smoke and hot air.

3.6.1 Smoke exhaust (*Pugai koodu/pokki*)

Most common among these devices are the *pugai koodu* (smoke chamber) and the *pugai pokki* (smoke exhaust). These smoke exhausts are not unlike conventional chimneys (Fig.3.16). They also bring in daylight. The structure of the exhaust is a raised chamber of varying sizes (depending on users and local practices) and is usually made of brick. There are slits and gaps in the walls of the exhaust. This chimney is usually covered with a stone slab. In the case of a larger *pugai koodu*, timber battens span the chimney with bricks laid diagonally and a lime screed laid on top.

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[23] Venturi effect

Although primarily a passive ventilating device, the *pugai koodu* is also used as a dynamic device. It has long narrow slits in all four walls to catch wind from any direction, drawing the warm air out of the koodu. Often, rain enters the *koodu* through these gaps. Today, insect protection is an important measure that the *pugai koodu* has to incorporate.

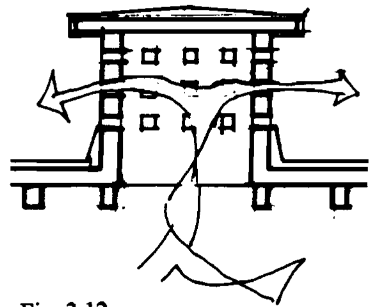


Fig. 3.12
Smoke exhaust (*pugai koodu*)

3.6.2 Smoke hole (*Pugai ottai*)

Pugai ottai is a passive device to remove smoke from cooking areas and prayer rooms where incenses and oil lamps are burned. They also bring in daylight. The pugai ottai is a hole, invariably circular in shape, and usually not more than 12" in diameter (Fig.3.13).

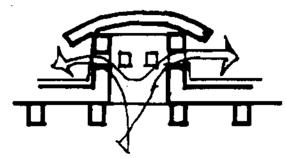


Fig. 3.13
Smoke hole (*pugai ottai*)

Except during rains, these holes are left open, to bring in daylight and let out smoke. When it rains, terracotta or clay cowls are used as to cover them to prevent the rain from getting in. To do this, one has to go up to the terrace as it is not operable from within.

3.6.3 Raised roof vent

The raised roof vent essentially works like a clearstory. One portion of a flat roof, along the span, is raised by about 2' 0", with a provision for small ventilators on the sides (Fig.3.14). These ventilators were screened with ornate stone lattices which were later replaced by iron grills. This device allowed for the escape of warm air rising from living spaces. It also brought in daylight. In recent times, most such vents are being closed off for security reasons and to prevent rain water from entering. There are constructional problems too, with respect to roofing techniques. It was easier to lift a part of the roof slab in the Madras terrace roofing system by resting the roof vent on two rafters. Today, most flat roofs are concrete slabs which afford less flexibility in providing this device.

The raised roof vent is seen in the dense urban settlements, where due to common side walls, the roof is the only source of light and ventilation for inner rooms. According to some of the residents of traditional dwellings, these vents do not cause great air movement within rooms but are more of a passive ventilating device. This result could be due to the fact that the vents were not raised high enough above the terrace and parapet walls, preventing a greater flow of air into these vents.

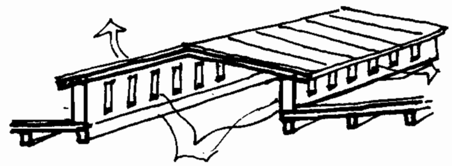


Fig. 3.14
Raised roof vent

3.7 Ventilation devices in walls

Traditionally, walls were treated more as enclosures affording privacy and security. Narrow horizontal openings, *palakani* or 'many eyes', with stone latticed grills were inserted high up in walls. These openings ensured air movement within the house and at the same time afforded privacy and daylight. These stone lattices were later replaced by thick timber lattices and iron rods. Windows, as such, emerged later through cross cultural influences. Some of the common devices used in walls are discussed below.

Honeycomb brickwork openings (*jallis*) are permanent ventilators, commonly found in urban and rural areas. They are gaps created during the construction of a masonry wall. They afford privacy to residents while providing constant air exchange within a dwelling.

Another common practice is leaving gaps at the junctions of walls and roofs. This ensures constant air movement at the level of the eaves (Fig.3.15). Just below the rafter that rests on the wall, gaps of about 6" (two brick thickness) are left, which let in air that is shaded and cooled by the deep overhangs. They act as passive warm air removers.

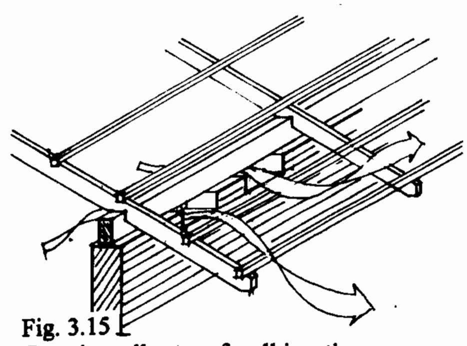


Fig. 3.15
Gaps in walls at roof-wall junction

A less expensive wall construction technique is the use of interwoven palm thatch panels for walls. This technique is used in rural as well as in urban settlements. The fine gaps in the interwoven panels let air in constantly. Since thatch is a poor conductor of heat, these panels do not retain heat and hence provide a cool medium for air passing through.

Gable ventilators in masonry walls seem to be inspired by colonial architecture in India (Fig.3.16). They are quite common in urban settlements, and are effective in letting incident winds in a dwelling. Since a gable ventilator is placed close to the ridge -- the highest part of the roof -- it removes the warmest air in the room, thus enhancing the stack effect drawing air into the dwelling through openings at lower levels.

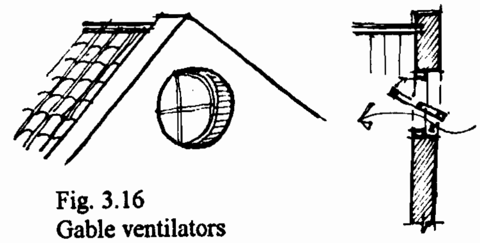


Fig. 3.16
Gable ventilators

Double windows are common all over Tamilnadu (Fig.3.17). They are usually wood panelled windows without glass panes. While the lower panels can be closed for privacy, the upper panels are left open most of the time. When the glare of the sun is too much, both are closed, keeping the interiors cool. These are effective windows but do not have the same widespread use today due to the amount of timber and ironmongery necessary for their construction.

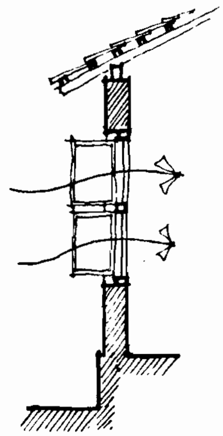


Fig. 3.17
Double windows

Louvred windows and fixed louvres are also most probably a colonial influence and are also widespread in urban areas. Wooden louvres are now losing popularity due to the non-availability of timber.

3.8 Wind Pavilion (*Kattru Pandal*)

The *kattru pandal* (wind pavilion) is a unique ventilating device (Fig.3.18) found in the coastal regions of Tamilnadu. It was used in rural settlements in the Madras region until the early part of the twentieth century but is no longer prevalent. The *kattru pandal* is a pavilion supported on (inexpensive

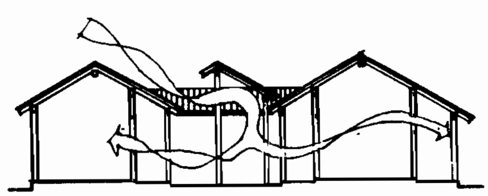


Fig. 3.18
Wind Pavilion (*kattru pandal*)

and readily available) country timber *ballis*,[24] and is sloped in one direction.

The roofing material is palm thatch (or available grass or reed). This pavilion is located in courtyards and is sloped upward, towards the wind (the south wind is the primary wind direction). The wind hits the underside of the thatch roof and is directed downward and into the rooms adjoining the courtyard. The slope virtually cuts off unfavourable cold and damp monsoon winds coming from the north and the north-eastern directions. It is always a temporary structure and is replaced every two or three years. During the summer months it cools the interiors by bringing in a cool south breeze which comes from the sea. The use of thatch as the roofing material further cools the air coming into the dwelling.

Summary

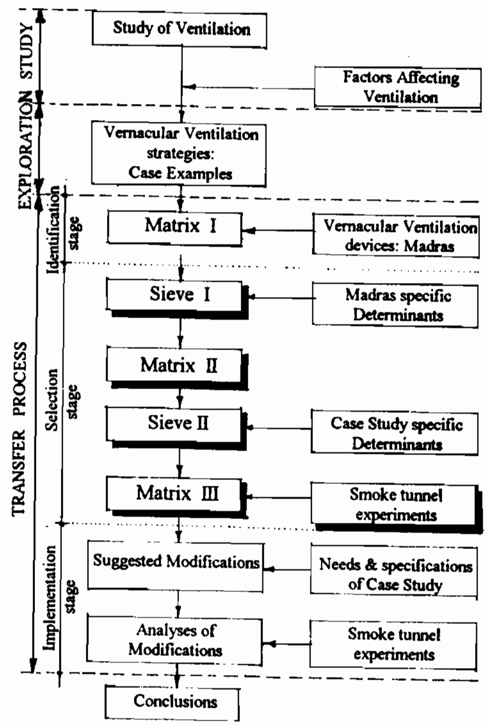
Chapter III completes the identification stage of the transfer process. In Part I, the context of the transfer was identified and in Part II the vernacular ventilation devices in the region were documented. These devices are incorporated into Matrix I (Appendix II) which forms the base for the selection stage of the transfer process, discussed in the following chapter - 'Establishing a selection process.'

[24] *Ballis* are country wood poles, usually of a circular cross section, used as scaffolding material as well as for cheaper and temporary construction.

Chapter IV

Establishing a selection process

The identification stage of this thesis has developed Matrix I, the 'base palette' of strategies from which appropriate devices will be chosen. To identify the most suitable devices for a transfer, a selection process has to be developed. This chapter establishes which generic devices and techniques from Matrix I are most suitable for a transfer to the context of Madras and the dwelling chosen.



4 . 1 Selection process : a sieve

The proposed selection process works like a sieve. Just as a sieve lets through acceptable sizes of particles through its holes while retaining oversized particles, the proposed selection process would seek to choose devices from Matrix I for an appropriate transfer to the chosen context in Madras. In this process, some of the devices can be accepted directly while some require modifications. Some devices do not relate to the context of the transfer for various reasons (which will be discussed later in the chapter) and are rejected. The 'holes' of the sieve-like selection process are the determinants that form the basis for the acceptance or rejection of a device.

The proposed selection process comprises two stages (Fig.4.1). The first stage, Sieve I, establishes certain socio-cultural, environmental, functional and economic factors that form the basis for determining the acceptance or rejection of the vernacular ventilation devices from Matrix I in the specific context of Madras. The devices that pass through this sieve comprise Matrix II, which presents the devices that are most appropriate for a transfer to Madras.

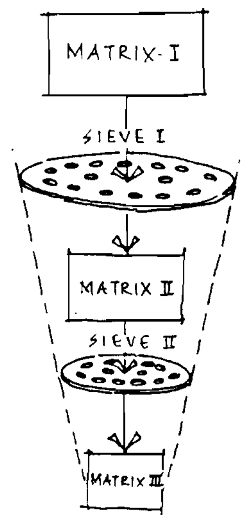


Fig. 4.1
The Selection process

The second stage is a narrower selection process and is specific to the particular dwelling in which the transfer is to be effected. Since this research concerns the enhancement of the indoor environment of an existing dwelling, the determinants of Sieve II consider the viability of any transfer to this specific case. The 'sifting' of the devices from Matrix II through Sieve II results in a further filtered set of devices creating Matrix III, which presents the devices considered suitable for a transfer to this dwelling.

Scale models of appropriate ventilation devices have been tested in a smoke tunnel. The objective of this exercise is to identify the patterns of air flow effected by each device in its indigenous state. These models attempt to simulate, rather than replicate, the principle behind each vernacular device. The sieve-like selection process will be discussed stage by stage in the following sections.

4.2 Sieve I

In the various vernacular devices studied, ventilation occurs through devices in roofs, walls and floors or by virtue of the physical form or plan form of a dwelling. To select any device for a transfer to the context of Madras, one has to study its appropriateness. The appropriateness depends upon certain contextual considerations or determinants. There are essentially three main determinants, discussed in the following section, which any device must satisfy. They are: (i) the cultural compatibility of a device, (ii) the functional performance of that device, and (iii) the material resource viability in the new context.

4.2.1 Determinant I - Cultural compatibility

The cultural compatibility of a ventilation device depends upon two parameters: (i) the acceptance of its physical appearance within the new context and (ii) its compatibility with local lifestyle. Both these parameters are essential in establishing the cultural compatibility of any device. The acceptance of the physical appearance of a device implies that the appearance of the new device must bear a resemblance to images in the cultural memory of the residents.[1]

For instance, the dwelling type raised on stilts is widely prevalent in hot and humid regions. It is designed to prevent water penetration, prevent insects and rodents from entering and to increase air movement, unhindered by neighbouring bushes and shrubs. In some cases the space between the floor of a dwelling and the ground also facilitates air movement through the floors.[2] In other cases, this space can be used for storage while in some others it can act as a livestock shelter.[3] But this house type is not found in the Madras region. Culturally, people in this region use open spaces and yards within and adjacent to dwellings, as an extension of living spaces (as discussed in the previous chapter). In this context, having a raised and stilted floor reduces the ease of access to the

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[1] Since we are trying to integrate a device into the vernacular of the Madras context, the term 'cultural memory' essentially means the traditional forms of architecture that are ambient in the region over the last century or so. The underlying assumption is that these dwelling forms constitute the vernacular architecture of the region. This does not mean that new forms will never be accepted. What it implies is that a more familiar built form will be more largely accepted than a new form.

[2] Refer to Thai houses, section 2.3.1, p.33

[3] Refer to Nias house, section 2.8, p.44, and Thai houses, section 2.3.1, p.33

ground and would entail a major change in the relationship between indoor and outdoor space. Moreover, the absence of this typology in this region could be a result of the large amount of timber that is required to build a structure on stilts in a region where wood has always been in short supply. Hence this house type does not pass through the 'sieve,' and in the graphic representation, an empty circle indicates the rejection of this house type.

Some other devices, like the roof forms of the conical dwellings[4] of Southern Najran, Saudi Arabia, also do not pass through Sieve I.[5] This is because such a physical form does not fit in with the use of living spaces in Madras, where traditionally there is a distinct delineation of a roof and a wall. As a result, a dwelling form such as the Najran house, which does not have a definite division between the roof and the wall, is not appropriate. On the other hand, a house on a raised plinth with outer verandahs is an already acceptable house type, as similar dwellings are found in this region.[6] The verandah, besides being a climatically suitable device, is an integral part of the local life style. Graphically, an opaque circle appears against this type in Sieve I to indicate its acceptance.

Two important concerns in the lives of the people in Madras are privacy and security and these require special attention when discussing the cultural compatibility of devices for this region. In this manner, the cultural compatibility of a device is established, based on the acceptability of physical form and suitability to life style.

4.2.2 Determinant II - The functional performance

Apart from their ventilating functions, devices are judged on how certain environmental factors are addressed in the context of Madras. Often, although a device may induce good ventilation in a dwelling, it may provide inadequate protection against certain environmental factors. The functional performance of devices is judged by the protection they afford against environmental factors such as sun and glare, insects and rodents and rain. For instance, in the central Thai house, a window from the floor to the

[4] The use of terms like 'conical house forms' and 'stilted house types' are used in this thesis purely for ease of classification. The author is fully aware that by giving such generalised terms, one undermines the existing variety in these house forms. However, since the emphasis is on the 'physical principle' of the house type and its response to wind movement, such terms are being used. (Also mentioned by Oliver; 1987, p.57)

[5] Refer to section 2.4.2, p.37

[6] Refer to Malay house, section 2.1.1, p.29, Bengali House, section 2.5.1, p.39

sill level is louvred and top hung.[7] Since the roof overhang does not always shade the window from the sun, the louvres themselves act as a self-shading device while allowing air flow to the interior. So this device, while providing for ventilation also acts as a sun-shading device. In Madras, the primary wind direction is from the south side. But the south facade also has to be protected from insolation for six months of a year. This means that any device chosen must address this environmental condition in a satisfactory manner or be suitably modified to provide an acceptable solution.

4.2.3 Determinant III - Context specific material resource viability

The third determinant for the acceptance of a device is the context-specific material resource viability. It comprises three parameters, which are (i) availability of similar building materials, (ii) availability of similar building skills, and (iii) economic viability of a new device. All of the potential devices, in their traditional forms, are built using existing natural resources prevalent in their particular geographic locations. To make an appropriate transfer of a foreign device, there must be similar material resources available in Madras.[8] For instance, in the construction of the ventilating floors of the Thai house, large quantities of timber are used which are not abundantly available in Madras. This indicates that such a device is inappropriate to the context. Often, the construction of a ventilating device may require special skills. The creation of a wall section of a typical Nias house with its outward battered timber wall is not feasible for a local craftsman in Madras.[9] On the other hand, the wall panels made of woven bamboo or palm thatch used in Thailand and Bangladesh are common in Madras too, which indicates that the skill of their construction is available in the region.[10] The third parameter is the economic viability of a device to be transferred, which depends on the first two parameters. If the implementation of a device involves procuring building material from a distant area, or if the skill required for construction is very specialised, then that device is economically not viable. The *rowshans* of Jeddah, Saudi Arabia, require large quantities of timber, or a

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[7] Refer to Thai house, section 2.3.1, p.33

[8] 'Similar material resources' implies appropriate locally available materials that can be used to substitute the original material of construction, to perform a similar function.

[9] Refer to section 2.8.1, p.44

[10] Refer to section 2.3.1, p.33; 2.5.1, p.39

suitable material replacement, in addition to the necessary construction skill.[11] Together, these two factors make a *rowshan* economically non-viable in Madras.

4.2.4 The working of Sieve I

Sieve I is graphically presented in Appendix III. The first column in Sieve I indicates each device graphically with its coded number. The devices are graded against the three determinants and their respective parameters. A three tone grading indicates the devices as being 'appropriate', 'not appropriate' or 'appropriate with modifications.' In the graphic matrix, an opaque circle (referred to as 'full circle') indicates 'appropriate,' an empty circle indicates 'inappropriate,' and an opaque half circle (referred to as 'half circle') indicates that a device can be made appropriate with certain modifications. The devices are then graded, with full circles carrying two points, half circles carrying one point and empty circles carrying no points.[12] Each device is rated against each of the three determinants, each with their respective parameters, and the grades are indicated.[13]

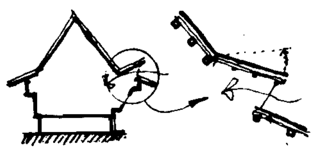
To illustrate the working of the selection process thus far, we can look at the roof flap of the Nias house, identified by the code R4. Evaluating the cultural compatibility (Determinant I) of the device, R4 ranks a half circle (one point) against the first parameter, physical appearance. This is because although roof vents and ventilators are found in this region, an adjustable flap on the roof slope is not prevalent here. So with some modification in form, the principle of an adjustable roof flap could be used in Madras. The second parameter, the compatibility of the device with the local life style, has three sub-criteria, namely, internal spatial use, security and privacy. R4 receives a full circle (two points) for compatibility with the internal spatial use, as traditionally dwellings in this region have had roof ventilators and people are accustomed to using the roof as a means

[11] Since the lattices of the *rowshan* cut off the glare of the sun as well as provide privacy, the design of the lattices require considerable skill which is salient to the culture.

[12] There is no particular logic for arriving at a 2-1-0 point system. It could well have been 1-1/2-0. A higher number does not reflect a superior quality of a device. It simply indicates that the device requires fewer modifications to suit this particular context

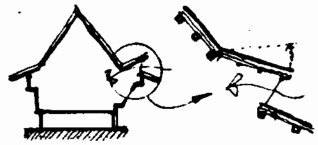
[13] It is important to note that if a device is found incompatible with any one of the three determinants, it is automatically rejected. However, Sieve I grades each device against each determinant because, even if a device is rejected, say due to cultural incompatibility, it may be a good sun shading device. For instance, the suspended lath-curtain wall in Papua New Guinea is culturally inappropriate in Madras because of the lack of privacy and security the wall affords. However, the device could be used as a sun shading device and this property could be utilised as a modification of another device.

of generating air movement and ventilation in their dwellings.[14] In its indigenous form no security grilles are provided. R4 would have to be suitably modified to meet this requirement and is hence denoted by a half circle (one point). R4's location on the roof slope, with its adjustable nature, could provide the required levels of privacy to residents. Against this sub-criterion, R4 gets a full circle (two points). This gives **R4** a total of six points out of a possible eight, a **performance index** of **0.75** for **Determinant I**. A high performance index indicates a lower level of modification required for a transfer.

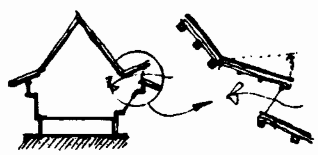
R4 Adjustable roof flap, Nias house, Indonesia  Fig. 4.2	**Determinant - I - Cultural Compatibility**			
	Physical Appearance	Compatibility with existing lifestyle		
		Internal spatial use	Security	Privacy
	◑ 1/2 Points	● 2/2 Points	◑ 1/2 Points	● 2/2 Points
	A total of 6/8 points : **Performance Index - 0.750**			

Similarly, R4 is evaluated for its functional performance, Determinant II, in the context of Madras. With regard to the first parameter, protection from sun and glare, R4 gets a full circle (two points) because it is an adjustable device. Against the second parameter, protection from rain, R4 gets half a circle (one point) since the device is open on the sides to rain water. This requires suitable modifications to render it appropriate to the context. Against the last parameter, regarding protection from insects and rodents, R4 gets a half circle (one point), as in its traditional form no protection is provided against insects. To be made appropriate, the device will have to be modified suitably, given Madras' mosquito menace. This gives **R4** a total of four points out of a possible six, a **performance index** of **0.667** for **Determinant II**. This indicates that a moderate level of modification is needed to make the device suitable for application in Madras.

[14] Refer to section 3.5, p.60

R4 **Adjustable roof flap,** Nias house, Indonesia	**Determinant - II - Performance with respect to Environment**		
	Sun/glare protection	Rain protection	Insect protection
	● 2/2 points	◑ 1/2 points	◑ 1/2 points
Fig. 4.3	A total of 4/6 points : **Performance Index - 0.667**		

R4 is now evaluated against the third determinant, context specific material resource viability. Against the first parameter, the availability of similar material resources, R4 gets a half circle (one point). This is because while the traditional roof flap in the Nias house is made of nipa thatch on a timber structure, in Madras, the flap could be made of locally available black reed thatch, tightly secured to a bamboo structure. Micro concrete or ferro-cement panels could also be used, but in small sizes, as they may be too heavy to be used as flexible roof flaps. The construction skill of such a device, the second parameter, is specialised but not uncommon in this region which abounds in different kinds of thatch construction and hence R4 gets a half circle (one point). A very important part of the skill component is devising a detail of R4's hinged joint and protecting the sides of the device from rain water. Against the third parameter, that of the economic viability of the device in Madras, R4 gets a half circle (one point). Since this parameter depends on the first two parameters, we find that the skill component required in adapting the device to this region may be high. But after an initial expense to establish the necessary details and construction training, the device may turn out to be viable. This gives **R4** a total of three points out of a possible six giving a **performance index** of **0.5** for **Determinant III**. This indicates that a greater level of modification is required for R4 against this determinant.

R4 **Adjustable roof flap,** Nias house, Indonesia	**Determinant - III - Context specific material resource viability**		
	Material availability	Skill of construction	Economic viability
	◑ 1/2 points	◑ 1/2 points	◑ 1/2 points
Fig.4.4	A total of 3/6 points : **Performance Index - 0.500**		

By conducting this exercise for all selected devices, a performance index is given to each device with respect to each of the three determinants. A Minimum Performance

Index for each determinant is also established.[15] Any device which has a lesser figure than the Minimum Performance Index (MPI) for any one of the determinants, does not pass through the sieve and is deemed inappropriate. The MPI for each of the three determinants, cultural compatibility, functional performance, and material resource viability, is 0.500.

As a result of the first stage of the sieving process, Sieve I,[16] a selected set of ventilating devices is obtained and presented in Matrix II. These are the devices most likely to be successfully transferred to the context of Madras. Matrix II can then be used as a starting point for the second stage of the selection process, Sieve II, to obtain a set of devices specific to the chosen dwelling in George Town, Madras.

The selection process indicated is linear. It evaluates a device with respect to one determinant at a time, whereas most often, the performance of a device depends on more than one determinant at a time. For instance, the *rowshan* addresses the aspects of privacy and sun and glare protection at the same time and it is important to evaluate both aspects simultaneously. Selection is actually a more complex process operating at different levels. Intuitively, this process of selection works in a non-linear and multi-dimensional manner, looking at different variables at the same time. Nevertheless, this thesis has placed its emphasis on the process of transfer and identified the importance of the three main determinants in the selection process.

The evaluation of the devices is very subjective and would vary from person to person. For instance, the rejection of the house on stilts on the grounds of incompatibility with the local lifestyle, may be acceptable to some others. It may be argued that people are now willing to live in apartment buildings which can be seen as extensions of 'houses on stilts.' However, the suggested evaluation of devices is based on the author's own experience, as a resident and practising architect of Madras.

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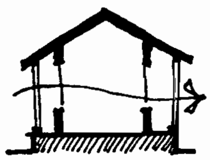
[15] Any device with a possibility of being accepted to the context with some modification passes through Sieve I. Hence, the lowest logical performance index among all the devices is taken to be a performance of a half circle for every determinant, which is half of the total possible points -- a value of 0.500. This is referred to as the Minimum Performance Index.

[16] Sieve I is graphically illustrated in Appendix III with a brief note on the logic of selection for each device.

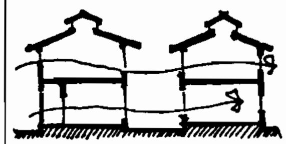
4.3 Matrix II -- the devices that are most likely to suit the context of Madras, after passing through Sieve I (S1, S2 and V1 have also passed through Sieve I but are not indicated in Matrix II due to spatial constraints).

A. Strategies due to Physical Form

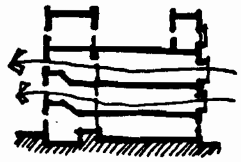
F2



F5

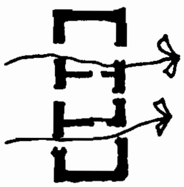


F6

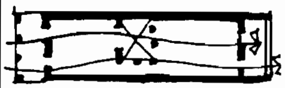


B. Strategies due to Plan Form

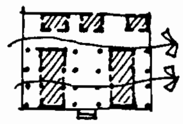
P1



P3



P5



C. Devices in Roofs

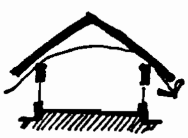
R1

R2

R3

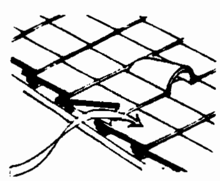
R4

R5

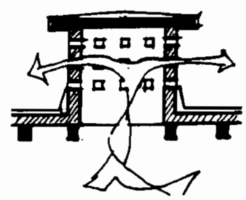


R6

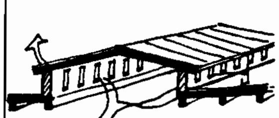
R8



R9

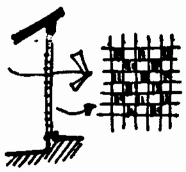


R10



D. Devices in Walls and Floors

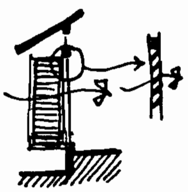
W3



W4

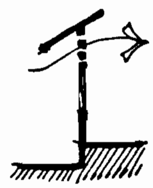
E. Wall opening devices

D1

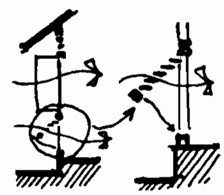


D2

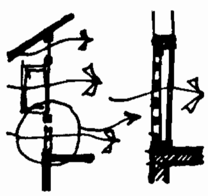
D3



D4

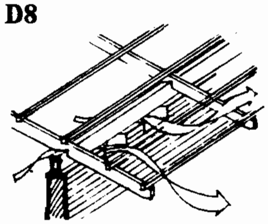


D5

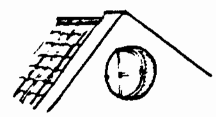


D7

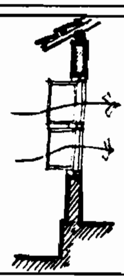
D8



D9

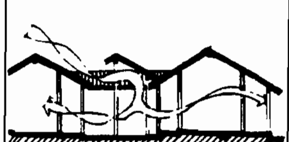


D10



F. Other ventilating devices

E1



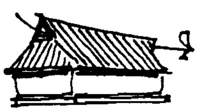
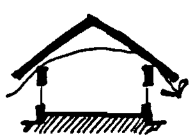
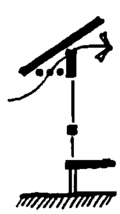
4.4 Sieve II

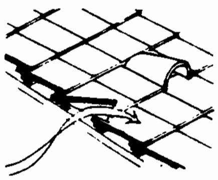
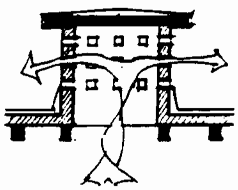
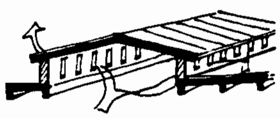
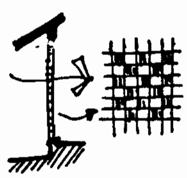
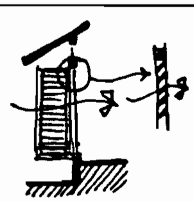
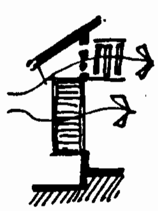
Based on the first part of the selection process, Sieve I, devices F1,3,4; P2,4,6; R7; W1,2; L1 and D6 are eliminated from Matrix I. The appropriateness of the remaining devices, presented by Matrix II, will now be evaluated in a more specific context -- the house at 89, Ramaswami street, George Town. The devices to be transferred need to be incorporated within the specific context of a specific house. The existing house has certain specifications that determine the possibilities for a transfer. For instance, the devices that function as an extension of the physical form of the dwelling (namely, S1-2, V1, F2,5,6; P1,3,5) are not applicable in this case since the existing dwelling already *has* a physical form. Hence, Sieve II considers only the opening devices in roofs and walls (the floor device was eliminated in Sieve I).

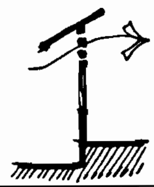
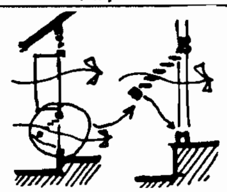
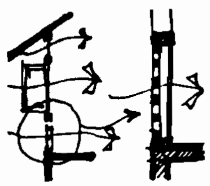
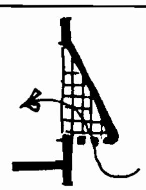
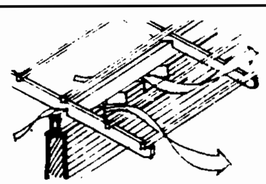
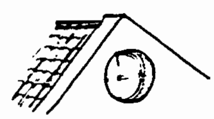
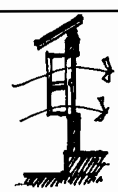
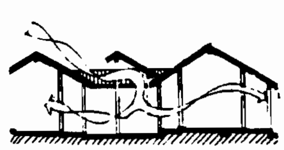
Sieve II evaluates the devices from Matrix II based on the level and extent of modifications involved. If the modifications required to implement a device involve extensive alterations to building elements, the whole exercise becomes non-viable. This can be understood in the graphic presentation in Sieve II where the roof, wall and other ventilating devices are mapped against the level of modifications involved in the transfer.[17] For instance, R1 is a device which causes ventilation through a split in the roof (found in Malay and Thai houses). At the point of separation, the roof requires a vertical structural support (ref. Fig.2.3). Also, spatially, it requires a justification like a verandah adjoining the main room. In this context, there is no spatial justification to introduce a vertical support in between the existing span. Moreover, the work involved is of considerable magnitude, since the entire roof structure would have to be changed. Hence, R1 is not a viable proposition in this context. In Sieve II, R1 gets an empty circle which indicates its irrelevance to the context. On the other hand, R6, which is a horizontal lattice of the *Bahay na Bato* of the Philippines, can be introduced at the eaves level of the roof by fixing the lattice and its support system without disturbing existing building elements. In Sieve II, R5 is given a full circle since it requires minimal modifications for implementation. The following table indicates the performance of the devices with respect to the levels of modifications required (Sieve II).

[17] 'Level of modification' indicates the degree of alterations that will be undertaken in order to implement a device.

Sieve II

Code	Graphic representation of ventilating device	Grade	Remarks - Level of modification
R1		○	R1 is a device which causes ventilation through a split in a roof. At the point of separation, this roof requires a vertical structural support. Also, spatially it requires a justification to introduce a vertical support in between the existing span. Moreover, the magnitude of the work involved is large since the entire roof structure has to be changed. Hence R1 is not viable.
R2		○	The ridge vent R2 runs the whole length of a roof. To introduce this vent would involve removing the roofing material and erecting a sub-structure for the ridge vent. The volume of work is again high and hence it is not viable.
R3		◑	The partial ridge vent is an accepted typology in Madras. The modifications involve opening up the roof at the area where the device is to be introduced, and this is not extensive.
R4		◑	The roof flap is normally placed on the windward slope of a roof. Installation would involve the removal of roofing material around the area of its installation. The modification involved would essentially be devising the assembly of an adjustable flap in accord with the environmental parameters detailed in Sieve I.
R5		●	The gap between the roof/roof rafters and the top of the wall is found in this dwelling. The only modification required for this device is the protection from insects.
R6		◑	The horizontal eaves lattice could be introduced at the eaves level of a roof and affixing the assembly would not disturb existing building elements.

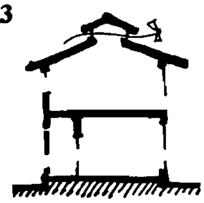
Code	Graphic representation of ventilating device	Grade	Remarks - Level of modification
R8		●	R8 is a device prevalent in the region. It requires minimum modification since it requires replacing some of the existing roof tiles.
R9		○	R9 is a device used in flat roofs and it cannot be used in the upper floor. For the flat roof over the lower level kitchen area, breaking the roof and introducing this device is a very high level of modification and is inappropriate.
R10		○	This device again occurs in flat roofs and is hence not relevant to the context.
W3		○	As wall panels, the woven bamboo panels require elaborate security arrangements. However, they can be used as sun and glare shading panels or insect protecting screens.
W4		◑	Permanent grilles as fixed panels in walls (made of honey-comb brick work, timber, terra-cotta or concrete lattices) are a common typology in Madras. However, introducing these lattices in an existing wall involves breaking and rebuilding parts of the wall which is a major modification.
D1		◑	The louvred window is not uncommon in Madras. Any modification required is in terms of the material of construction since timber is not easily available.
D2		◑	A full length opening would require a high level of modification. However, since it goes unto the top of the wall, a lintel is not required. The safety grilles and insect protection screens needed will be elaborate.

Code	Graphic representation of ventilating device	Grade	Remarks -- Level of Modification
D3		◑	This ventilating device is an opening between the lintel and the top of a wall. The modification required would involve removing the part of the wall above the lintel.
D4		◑	This opening device, below the sill level would involve breaking of the wall below existing windows. The existing windows could be retained.
D5		◑	This opening device below sill would be modified the same as above.
D7		◑	This device would involve replacing the existing window with a newly assembled window. The main modifications involved would be in the fabrication of the new assembly.
D8		●	This device requires less modification as it involves removing one or two layers of bricks from the top of the wall. These gaps would also require insect screens.
D9		◑	Introduction of this device would involve moderate modifications, provided the opening is small and high in order to avoid the use of a lintel. If the opening is large, the level of modification will be high.
D10		◑	The introduction of double windows is an expensive proposition because of the amount of timber it involves. If a suitable inexpensive alternative material can be used, these devices require a low level of modification.
E1		●	This device requires a low level of modification. It involves a new construction which traditionally takes about two hours and is inexpensive.

4.5 Matrix III -- the final set of devices that are most likely to suit the chosen dwelling, after going through the final stage of selection, Sieve II.

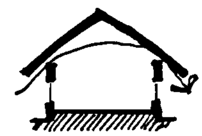
A. Roof and Wall Devices

R3

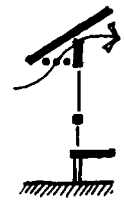


R4

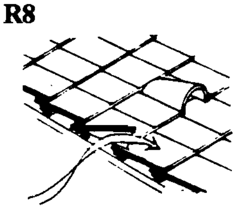
R5



R6



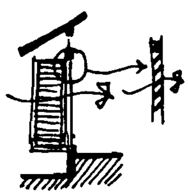
R8



W4

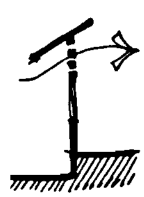
B. Wall opening devices

D1

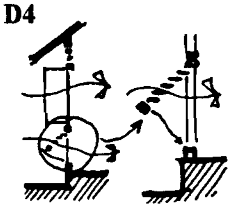


D2

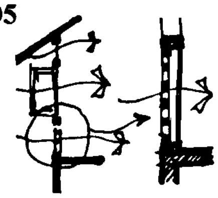
D3



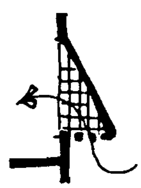
D4



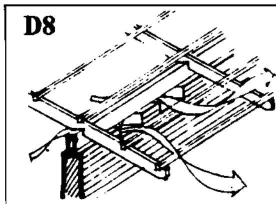
D5



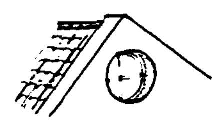
D7



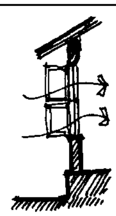
D8



D9

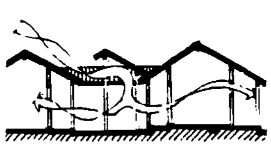


D10



D. Other ventilating devices

E1



4 . 6 Smoke tunnel experiments of devices from Matrix III

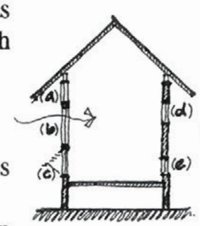
As a result of the sieving process, a set of devices that comprise Matrix III has been identified to effect an appropriate potential transfer of technology to the Madras context. Before going into the implementation stage, the research attempts to identify the air flow patterns effected by some of these devices in their indigenous locations. For this purpose, scale models, which simulate the working principle of each device, are made and tested in a smoke tunnel.[18]

Of the devices selected for the implementation stage, four devices have been chosen for testing in the smoke tunnel. The criteria for this selection have been the simplicity to replicate, and variety in physical form. The devices that will be tested are: (a) the windward wall section of the Central Thai house, (b) the windward wall section of the *Bahay na Bato* of the Philippines, (c) the 'magic eye' of Saudi Arabia and (d) the roof flap of the Nias house of Indonesia. All four models are essentially sections of dwellings, taken through the ventilating device. The depth and form of each room follows the proportions of its indigenous conditions as much as possible, given the proportional constraints of the smoke tunnel. Most of the openings on the windward and leeward walls of each model are 'detachable' or have the provision of being closed. This provides more options for studying internal air flow by using different combinations of openings.

The smoke tunnel generates white smoke from its linearly arranged nozzles at the bottom of the apparatus. Although the streams of smoke emerging from these nozzles do not replicate actual patterns of air flow, they, at best, simulate the flow of air. The following sections discuss graphically the experiments conducted.

[18] The specific details of the smoke tunnel experiments -- regarding air speed, modeling strategies, lighting and photography and practical constraints --are discussed in Appendix IV.

4.6.1 Central Thai house - Devices on wall



The windward wall has three sections (a), (b) & (c) while the leeward wall has two, (d) & (e). The experiment was carried out with different combinations of openings on both walls, observations of which are illustrated below.

Situation I
When all the openings on the windward and leeward sides were open, it was found that:
(i) the general tendency of the wind was to flow upwards in the house,
(ii) the gap between the roof rafter and the top of wall provided for air movement,
(iii) there was considerable air movement in the upper levels of the room, while in the lower levels air movement was comparatively less.
(iv) the air seemed to go around the louvred opening at (c) This is probably a limitation of the experiment since the space between louvres was too small and the air took the path of least resistance.

I

Situation II
When opening (e) was closed while all others were open, it was found that:
(i) the speed of air flow within the dwelling was reduced while the turbulence increased,
(ii) the air movement in the lower levels increased especially through opening (c), and
(iii) eddies were formed below the steeply sloped eaves which resulted in air movement through opening (a).

II

Situation III
When openings (b) and (d) were closed while all others were open, it was found that:
(i) there was maximum movement towards the bottom along with an increased speed,
(ii) there was a lot of turbulence in the room because both middle level openings were closed,
(iii) there was considerable movement through the opening at (a) and through the gap between the roof rafters and the top of the wall.

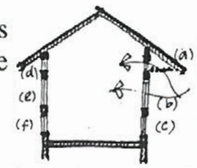
III

Situation IV
When the speed of the incident air was increased and openings (d) and (c) were closed (when (c) is closed, air passes through its louvres), it was found that:
(i) there was some movement of air towards the bottom; however, there was predominantly an upward flow of air.

IV

4.6.2 *Bahay na Bato*, Philippines - Devices on wall

The windward and leeward walls have three sections each -- (a), (b) & (c) in the former and (d), (e) & (f) in the latter. Section (a) is bisected by a horizontal eaves lattice. The experiment was carried out with different combinations of openings on both walls, observations on three of which are illustrated below.



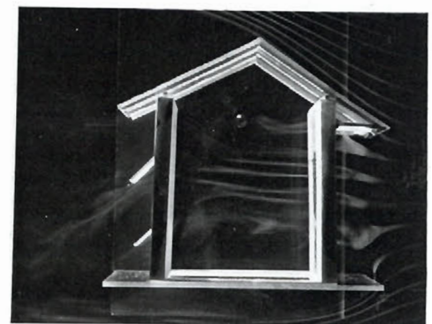
Situation I

When all the openings on the windward and the leeward side were open, it was found that:

(i) there was considerable air movement at all levels of the room (as with the Thai house), and the tendency of the air was to move horizontally,

(ii) the eaves lattice seemed to enhance air flow through (a) and through the gap between the roof and top of wall, and

(iii) the eaves lattice seemed to form a horizontal soffit which made the incident air flow horizontally into the room.

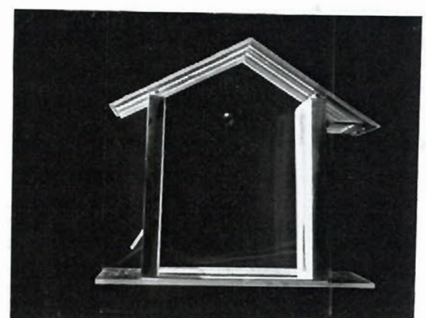


I

Situation II

When all openings except the lower ones, (c) and (f) were closed, it was observed that:

(i) there was a flow of air at the lower levels.



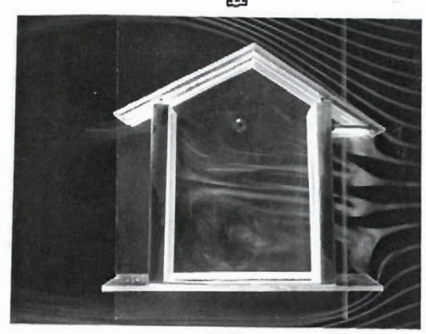
II

Situation III

When all the windward openings, (a), (b) & (c) were open, while the leeward openings, (e) & (f) were closed, it was observed that:

(i) considerable turbulence occurred in the room, particularly at the lower levels, and

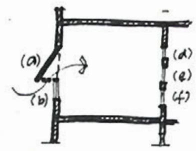
(ii) high air build-up at the eaves level resulted in air movement at higher levels and at a greater speed through (d). This can be seen in the way the air is coming out of (a).

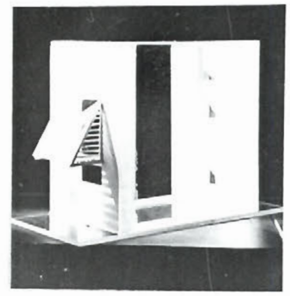


III

4.6.3 `Magic eye', Saudi Arabia - Device on wall

The windward wall has two sections (a) & (b) while the leeward wall has three, (d), (e) & (f). Section (a) is the 'magic eye'. The experiment was carried out with different combinations of openings on both walls, observations on three of which are illustrated below.





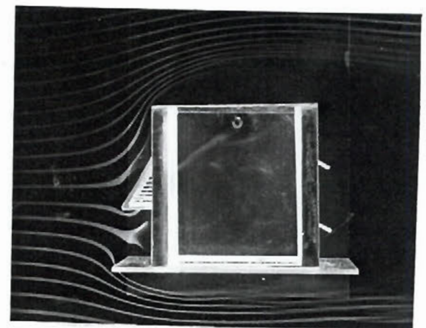
Situation I

When all openings on the windward and leeward side were kept open except (b), it was found that:

(i) there was an upward flow of air into the room,

(ii) turbulence in the room was created by this upward flow, and

(iii) air going out of the dwelling was not of a significant quantity.



I

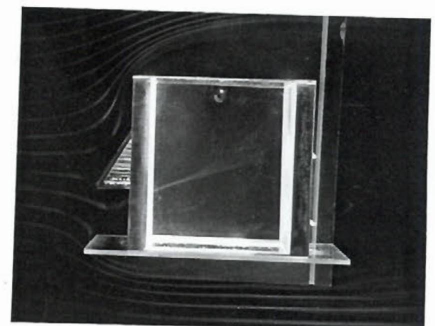
Situation II

When all openings on both the windward and leeward side were left open it was found that:

(i) the 'magic eye' was ignored and air went in through opening (b),

(ii) air had a tendency to flow upwards as in the case of the Thai house, and

(iii) air movement in the dwelling was not as much as in the other case examples.



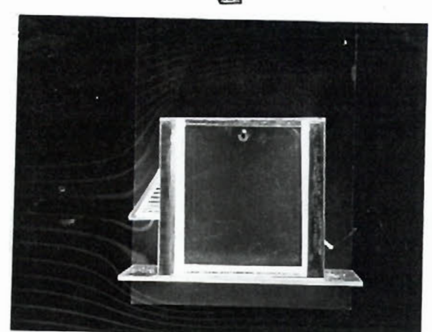
II

Situation III

When opening (a) on the windward side and opening (f) on the leeward side were open it was found that:

(i) air is directed through the 'magic eye', and

(ii) the air movement is reduced, as compared to Situation I.

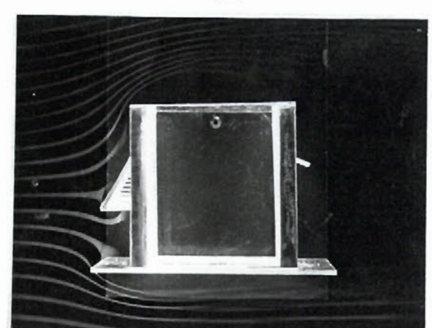


III

Situation IV

When opening (a) on the windward side and openings (d) and (e) were open, it was found that:

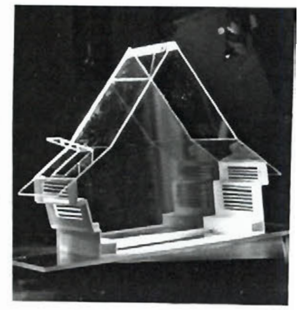
(i) although air moved into the 'magic eye', it was dissipated by the general turbulence in the room.



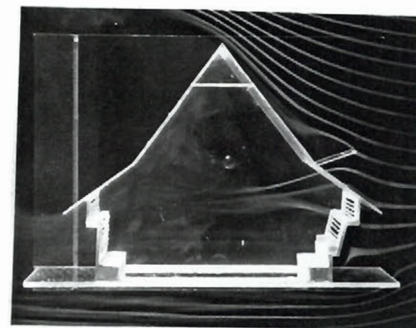
IV

4.6.4 Nias house, Indonesia - Device on roof

The windward and leeward wall have fixed latticed openings. The windward slope of the roof has an adjustable roof flap that is operable from inside. The experiment was carried out by studying the air flow with different angles of the roof flap. Observations on four situations are illustrated below.

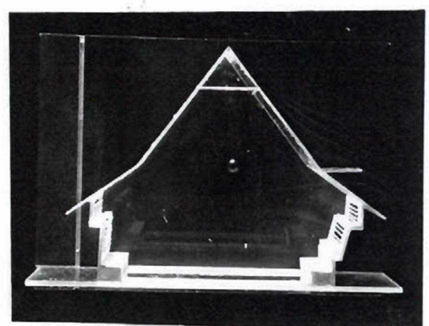


<u>Situation I</u>
When the roof flap opens upward, it was found that:
(i) the flap regulated flow of air downwards,
(ii) air passing through the lower level openings moved horizontally,
(iii) a considerable amount of turbulence was created at the lower areas at the far end of the room, and
(iv) at the roof level, turbulence is in the form of swirling clockwise eddies.



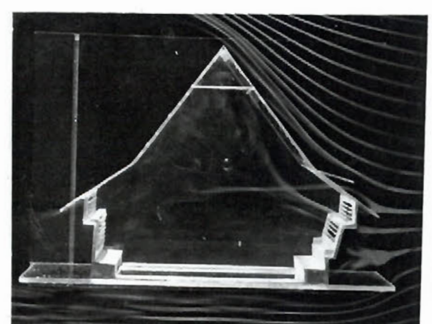
I

<u>Situation II</u>
When the roof flap is almost horizontal, it was found that,
(i) air flow was less than in the previous situation because of the reduced amount of air flow in the room, and
(ii) air flow in the room, as in the last situation, remained horizontal.



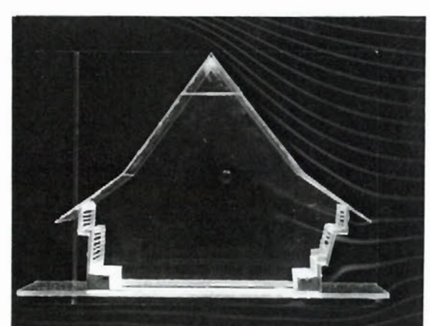
II

<u>Situation III</u>
When the roof flap is closer to the roof making a small angle to it, it was found that:
(i) the air flow through the flap was not so strong and tended to flow horizontally,
(ii) the air coming in from the lower openings moved upwards and was not modified by the air flowing through the flap, and
(iii) there was some turbulence in the room, but not as much as in Situation I.



III

<u>Situation IV</u>
When the roof flap is closed, it was found that:
(i) air movement is less than in other situations, and
(ii) air is directed upwards.



IV

4.6.5 Findings of the smoke tunnel experiments

The following are inferences drawn from the observations made in the experiments.

(1) In the typologies with full length openings (the Thai house, *Bahay na Bato*), there is certainly a greater air flow through living spaces.

(2) A sloped roof and its eaves tend to direct air upward in the living spaces as seen in the Thai house and the Nias house, whereas in the *Bahay na Bato*, the horizontal eaves lattice provides a break from the pressure build up below the eaves and ensures a more horizontal flow of air into living spaces.

(3) As seen in the Nias house, the roof flap plays an important role in the air flow within a dwelling. When opened wide, it catches more of the ambient breeze and directs the flow into lower living spaces at the opposite end. Moreover, this flow of air also regulates air flow through lower windward openings to the living spaces.

(4) The gap between roof eaves and the top of a wall is a good passive ventilating device. It also acts as an outlet to effect cross ventilation as seen in the *Bahay na Bato* experiment (Situation III).

(5) The 'magic eye' is a device that could be used to generate general air movement in a dwelling. While it does not directly cause air movement at the lower levels of human habitation in the rooms, it does generate some air movement in the whole volume of the room. This can be seen in the experiments where the whole room has a foggy appearance. Being a device that projects from the wall face, it could be placed parallel to the direction of the wind (such that wind passes through its sides) to test its facilitation of air movement.

(6) The openings at the lower levels on both the windward and leeward side provide for air movement at lower levels of human occupancy, as was evident in the experiments (*Bahay na Bato*, Situation I, III, Thai house).

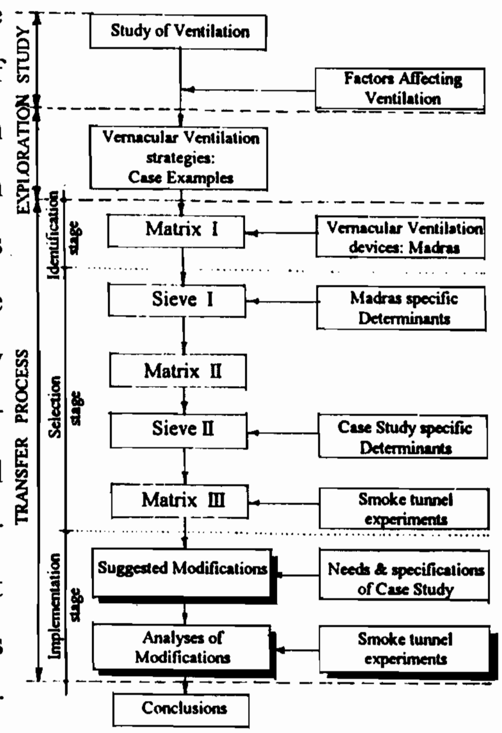
Summary

Chapter IV completes the selection stage of the transfer process. The selection was conducted in two levels of 'sieving.' The first level, Sieve I, selects devices that suit the context of Madras. These devices then go through the second level, Sieve II, which selects devices that suit the chosen dwelling in Madras, resulting in a final set of devices, Matrix III. The air flow patterns generated by some of these devices were tested and studied in a smoke tunnel. Matrix III forms the basis for the implementation stage of the transfer which is discussed in Chapter V: 'The Transfer -- Analyses and Inferences.'

Chapter V

The Transfer - analysis and inferences

This chapter marks the last stage of this research -- the implementation stage. The chapter begins with a brief summary of the requirements and needs of the chosen house of transfer (which was discussed in detail in Chapter III). The modifications to the selected devices and their suggested implementation in the house are graphically illustrated along with a body of explanatory text. These modifications are based on the particular needs and specifications of the dwelling. A scale model of the dwelling is tested in a smoke tunnel and the air movement in the dwelling is studied with and without the transferred devices. This is followed by an analysis of the suggested modifications in terms of their performance. Inferences are drawn which summarise the performance of the 'transferred' devices.



5 . 1 The dwelling at George Town, Madras -- A Summary

Originally, the house was considered fairly well ventilated, a fact corroborated by the previous residents of the house. The elongated plan form was oriented in a north-south axis and drew its ventilation from the prevailing south winds. All the rooms in the lower floor had at least three walls with openings and drew air from the central spine of the house, the *Vamsamoolam*. The passage of air was as shown in Figure 5.1. The upper level was seldom used by the family, except in the event of family functions or to entertain guests. The upper floor was used primarily in the evenings and nights which are cool. The main living areas were well shaded and cool as there was no direct insolation on any of the walls except at the rear.

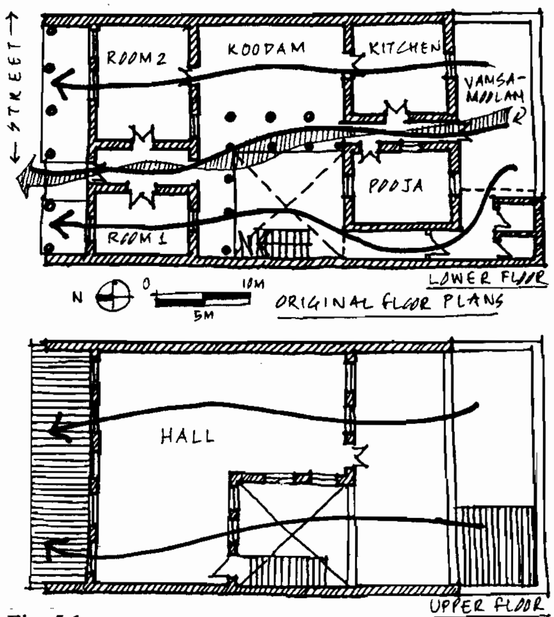


Fig. 5.1
Air flow in Case Study in 1930s

The existing dwelling has undergone many changes in plan form, use and physical conditions. Now there are two households occupying the building, one on each floor. Due to an increase in the number of residents and the changing lifestyles, the plan form underwent changes (Fig.5.2). Room 2 now has one access door and only one wall with windows and as a result is stuffy. The family space (*koodam*), which used to draw most of the incoming wind, is now an enclosed living/dining area. The rear rooms have been amalgamated into one room with the main opening along the spine, on the path of the incident wind, but has been reduced to a small window. The passage leading to the toilet is also closed now. The upper floor presents a poor indoor environment in terms of air movement. The once open hall space has been divided into three rooms. Although, by virtue of it elevation, there is more ambient breeze in the upper dwelling, the high insolation forces the residents to keep the windows closed. This makes the indoor environment warmer. The lack of a double roof/false ceiling causes an increase in the indoor temperature due to radiant heat.

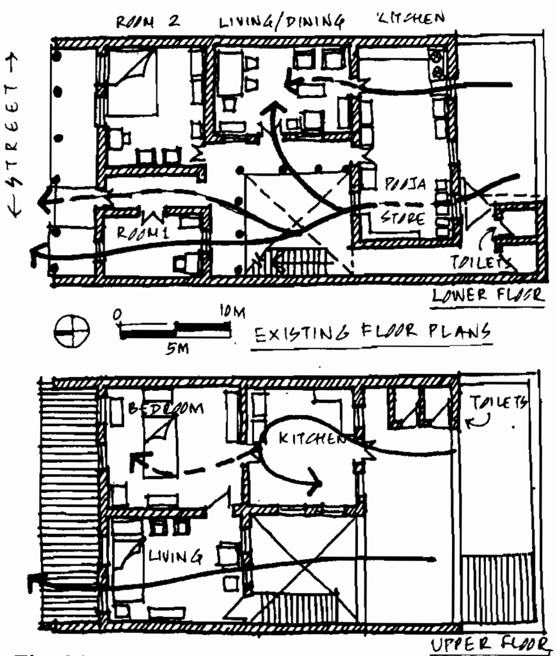


Fig. 5.2
Air flow in Case Study today

The following sections discuss some of the possible suggestions to improve the indoor air movement in the lower and upper floors, in that order.

5.2 Lower floor

Suggested modifications- building elements

The modified plan suggests ways of improving the air movement in the lower level of the dwelling. The first step would be to re-establish a spine or air funnel from which the surrounding rooms could draw air (Fig.5.3). This could be effected by enhancing the openings in the store/*pooja* which is in line with the entrance lobby. The openings in the *pooja* part of the room could be enhanced (Fig.5.4a,b). These openings could also be permanent (brick or prefabricated ferro-concrete *jallis*) to ensure a continuous flow of air through the dwelling.

The openings in the living/dining walls could be made larger to enhance the air flow in the room. There could, in turn, be more openings in the adjoining rooms to draw more air from this room.

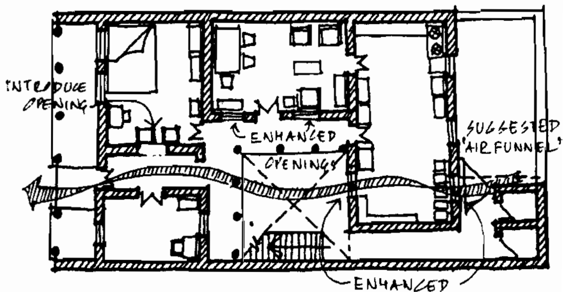


Fig. 5.3
Proposed 'air funnel'

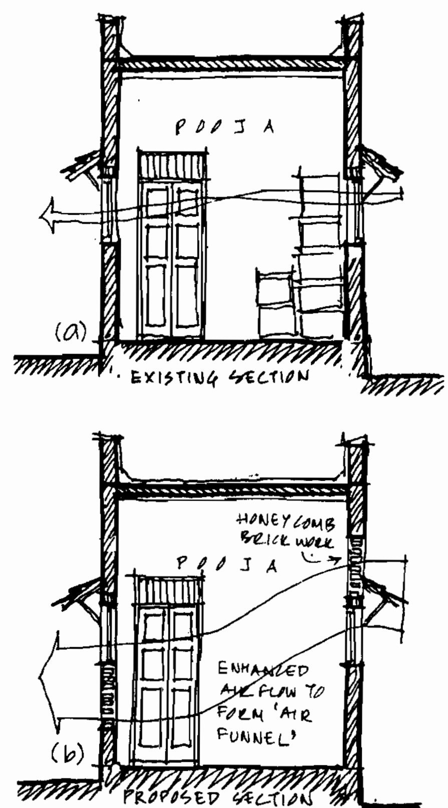


Fig. 5.4
Proposed modifications to *pooja*

5 . 2 Lower floor (*contd.*)

Suggested modifications- building elements

In the front part of the house, room 2 in particular has a poor indoor environment in terms of ventilation. The openings in the north wall of the room look into the entrance verandah (*thinnai*) of the house (Fig.5.5). For reasons of privacy, these windows are kept shut most of the time and so is the entrance door to the room (Fig.5.6). To improve this condition, the suggestion is to replace the existing window by a double window, the lower shutter being louvred. For reasons of privacy, even if the lower shutter is kept closed, air movement would be ensured through the louvred lower shutters and the open upper half of the window (Fig.5.8).

The common wall shared with the living /dining room could have latticed openings above lintel height to maintain an air exchange between the rooms. These openings could have shutters which provide aural privacy. Doors could have grilles or ventilators above them (an existing door type) to increase air movement in rooms (Fig.5.7).

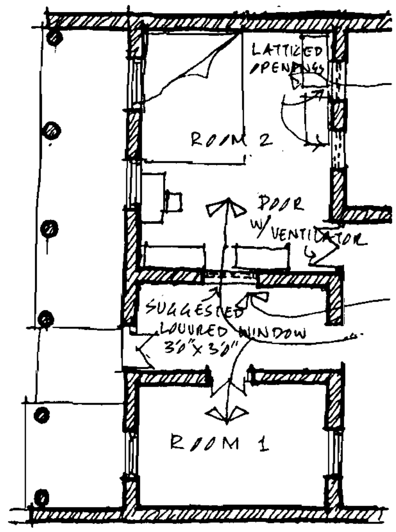


Fig. 5.5
Proposed modifications to Room 2

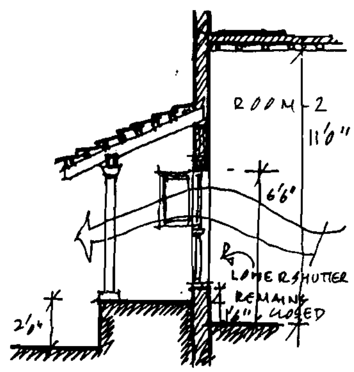


Fig. 5.6
Existing section through Room 2

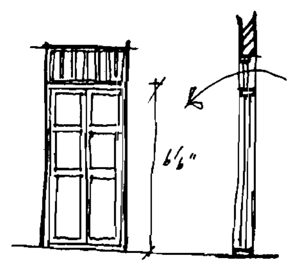


Fig. 5.7
Suggested door

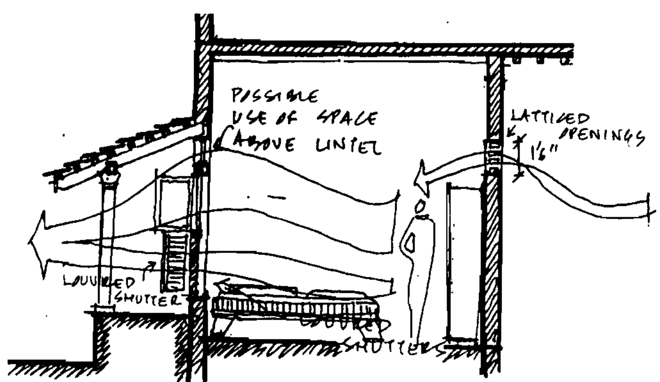


Fig. 5.8
Proposed section through Room 2

5.3 Upper floor - Living room

Specifications and needs of room regarding indoor ventilation

The living room is the best ventilated room on the upper floor so long as the openings on the south wall are left open (Fig.5.9). Due to the absence of a double roof or false ceiling, the radiated heat into the room causes increased discomfort. Hence there is a need for a device at the roof level to induce air exchange/stack effect. The device could be either passive or dynamic. There is a need to provide air movement in the dwelling to cover the human activity zones. It is also important for all openings to have. safety grilles and be protected from insects, especially mosquitoes.

High insolation on the south wall between the months of September and April forces residents to keep the windows closed for most of the day. Since the predominant wind direction is also from the south, it is important to make optimum use of the ambient wind. During the maximum heated times of the day (approximately between 8:30 a.m. and 3:30 p.m.) the altitude of the sun varies from about 30° to 90° (refer to section 4.2, p.58). The critical horizontal shadow angle of the sun is about 60°, i.e. 30 ° to the wall on the east and the west sides. While most of the azimuthal sun is cut off by the windows themselves when open (Fig.5.10 b), the vertical shadow angle of 45° has to be blocked. There is a need for full length openings that are suitably shaded from the sun and provide ventilation at all levels of human activity.

The north wall receives maximum insolation during the hottest months of the year - from mid April to the end of August. Between 8:30 a.m. and 3:30 p.m., the altitude of the sun varies from about 40° to 90° (refer to section 3.2, p.54). The critical vertical shadow angle is 60°. The critical horizontal wall azimuth is 62°. It is important for the windows on this wall to be well protected from the sun and glare while also facilitating air movement at all activity levels.

All openings have to be protected from rain which comes with the monsoon winds from either the north-eastern or south western directions.

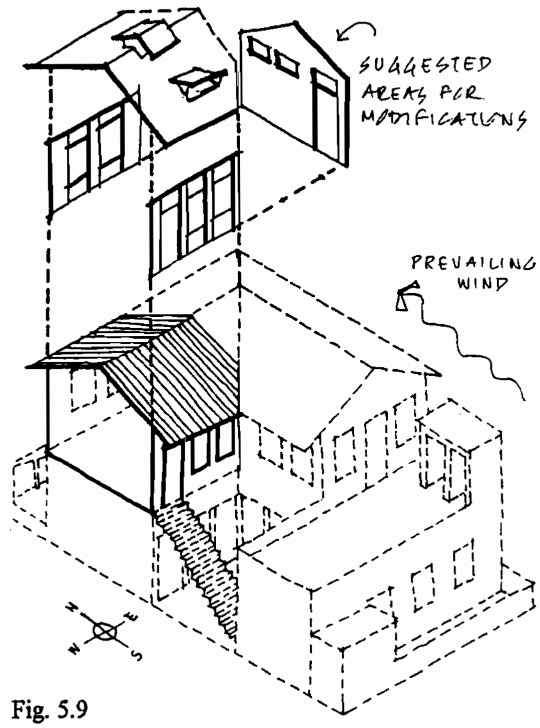


Fig. 5.9
Axonometric view
Suggested modifications to Living room

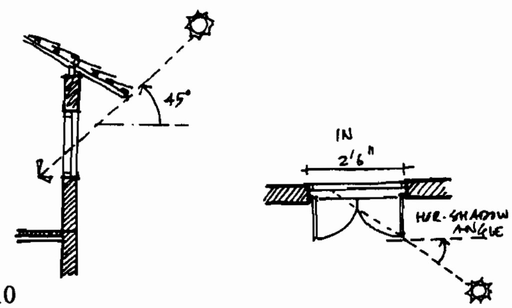


Fig. 5.10
Solar considerations - South wall

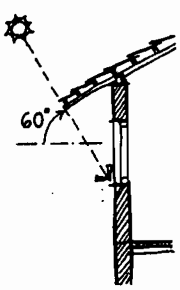


Fig. 5.11
Solar considerations - North wall

5.3.1.i Upper floor - Living room - South wall

Suggested modifications- building elements

Option 1

This opening is in three parts - floor to sill (c), sill to lintel (b) and lintel to top of wall (a). In the first option, section (a) of the opening, which is shaded from the sun and glare by the roof overhang, could be latticed (Fig.5.12). The lattice would provide security and prevent birds and rodents from entering the dwelling. The lattice could be a prefabricated terra-cotta *jalli* (available in this region), or of concrete, steel, bamboo or honey-comb brickwork. Protection from insects can be effected by fixing meshes to the insides of the openings.[1] At (b), the existing window could be maintained. The opening at (c) is introduced by removing the wall below the window. While the opening at (b) is shaded by the roof overhang for the lowest altitude of the sun (45°) during the hottest part of the day, the opening (c) is not shaded. Hence a self-shading opening device, like the side hung louvred window, could be introduced.[2] When closed, the louvres let in air but cut off the sun. The double window typology exists in this region, but louvred lower panels are rare.

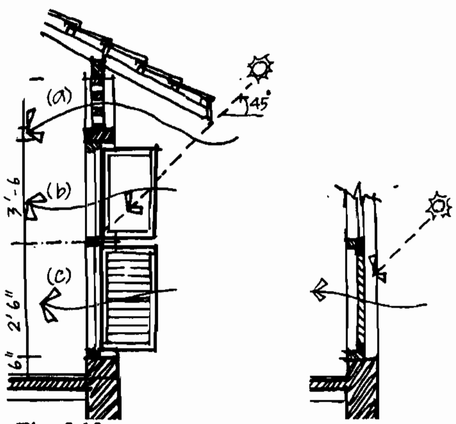


Fig. 5.12
Living room - South-wall section - Option 1

Option 2

In this option, while section (a) and (b) of the window are the same as in Option 1, a device inspired by the *ventanilla* of the Filipino *Bahay na Bato* (D5) is introduced for section (c). A lattice similar to the one in section (a) is introduced. A sliding shutter (which could be one of the commercially available compressed cement -timber panels) covers the opening as required (Fig.5.13a,c). But this device is not shaded from the sun. To effect this, a curtain of strong bamboo (using ropes of jute, coir, nylon or steel) is suspended from the eaves of the roof overhang. This device is inspired by the lath curtain walls of P. New Guinea. Spacing between the bamboos is worked out to beat the lowest angle of the sun (during the hottest parts of the day), in this case 45° (Fig.5.13b). The circular cross section of bamboo enables a wider spacing to facilitate greater air movement while affording view through the gaps. The curtain could be fixed by means of metal stays fixed to the window frame.

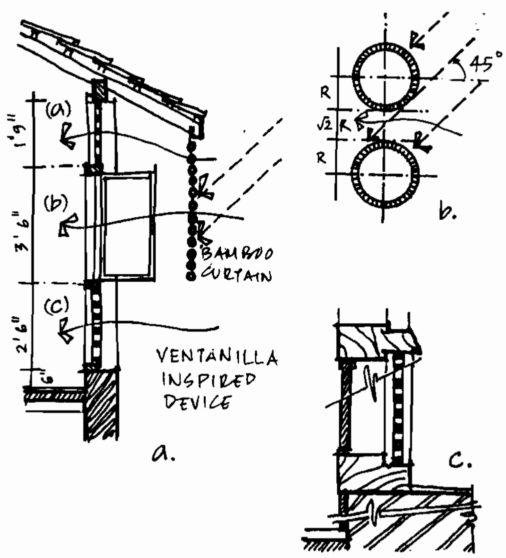


Fig. 5.13
Living room - South-wall section - Option 2

[1] There are many private enterprises in Madras that manufacture these meshes and fix them to the frames of openings
[2] D4: Device in Thai house

5 . 3 . 1.ii Upper floor - Living room - South wall

Suggested modifications- building elements

Option 3

This alternative has two variations from the previous two options. The first is in section (c) where a top hung louvred shutter is suggested. This device (D4: inspired by the Thai house) is a self shading ventilating device (Fig.5.14). When open, the louvres are almost horizontal and cut off the rays of the sun while letting air through. When closed, the louvres would still let in some air while providing shade from the sun. This opening could be fixed at any height required depending on the human activity zones within. For the louvres, flattened bamboo slats could be used instead of timber. The section (a) of the opening is just a gap left in the wall below the rafter. The gap could be six inches (two bricks thick) or nine inches (three bricks thick) wide. These gaps would need to be screened with insect proof meshes. To prevent rodents and birds from nesting in the eaves of the roofs, the eaves lattice of the *Bahay na Bato* (R6) could be introduced.

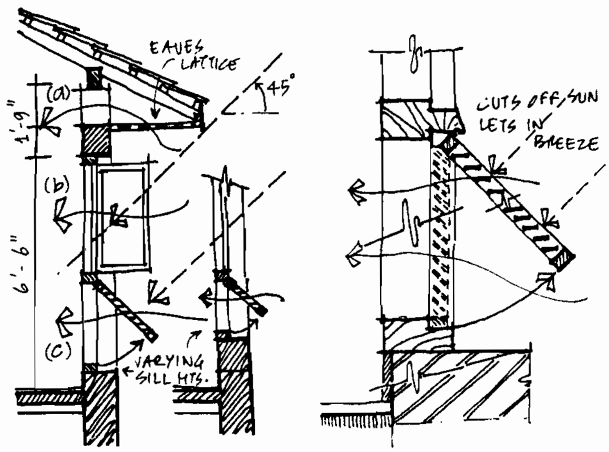


Fig. 5.14
Living room - South-wall section - Option 3

Two options are suggested for the lattice. In the first, a latticework is made of bamboo, suitably lashed together. Precast frames of ferro-concrete or compressed timber-concrete with a bamboo mat secured on top are fixed to the bamboo framework. This assembly can be effected using the gap left in section (a) of the opening from within the house (Fig.5.15a).

The other option for the eaves lattice involves the use of steel angles for a supporting framework. Precast lattice panels (of ferro-concrete, terra-cotta or compressed timber-concrete) are placed on the steel angles. If the section (a) of the opening has honeycombed brickwork, then this assembly can be done from outside (Fig.5.15b).

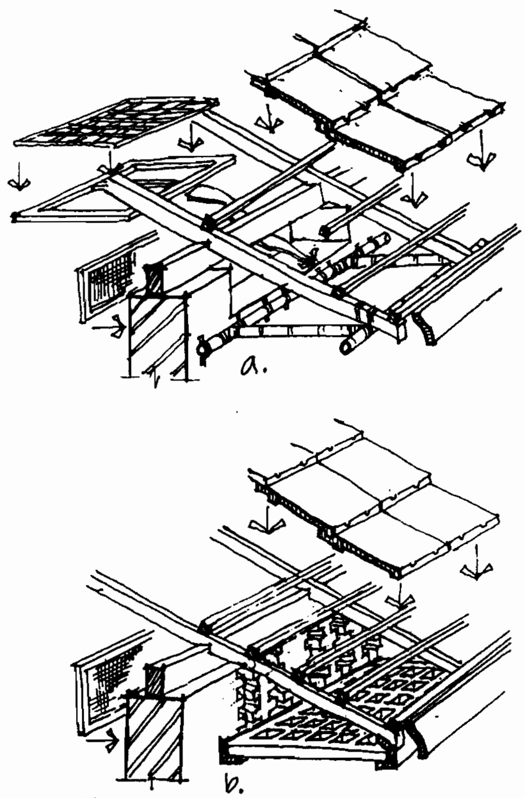


Fig. 5.15
Living room - Eaves lattice

5 . 3 . 1.iii Upper floor - Living room - South wall

Suggested modifications- building elements

<u>Option 4</u>

In this option, for section (b) of the window, the device suggested is inspired by the 'magic eyes' (D7) used in Saudi Arabia (Fig.5.16). The device consists of a roof incline at an angle of about 60° to the horizontal. The bottom and the side panels are perforated to let in any ambient breeze. The main functional feature of such a device is the effective shade provided from glare and the sun. However, the device restricts viewing out which is only possible through the sides and the bottom. The device has an additional advantage in that it shades the lower section (c) of the opening. The section (c) could be a *ventanilla*-like device discussed in Option 2.

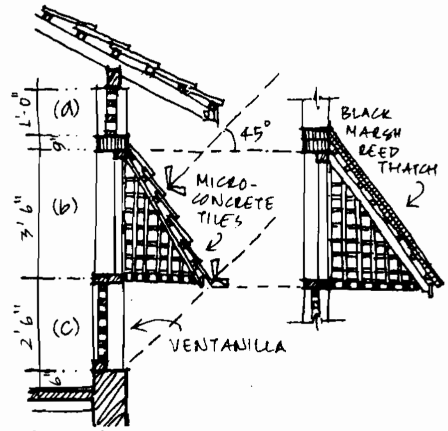


Fig. 5.16
Living room - South-wall section - Option 4

The suggested device is fabricated as follows. The framework could be made of sections of compressed timber-concrete. The side could have bamboo lattices (or ferro-concrete lattices or steel grilles). Two side-hung triangular window shutters can be provided (Fig.5.17). The bottom panel is fixed to the frame work. It could be a prefabricated latticed panel of ferro-concrete or compressed timber-concrete.

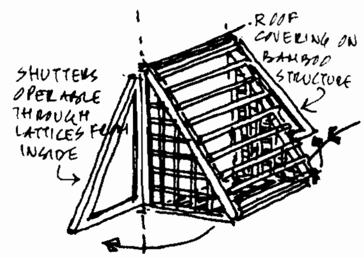


Fig. 5.17
Living room - 'Magic eye' with shutters

The roofing of the device could be thatch or micro-concrete roofing tiles. For both roofing methods, an under structure of bamboo could be used. The fixing details of the micro-concrete tiles are shown in Fig.5.18. They need to be well secured because of the steep slope of the roof.

Available black marsh reeds could be used in the thatching option. These reeds would have to be lashed tightly to the bamboo understructure. The thatch, about four inches thick, would have to be suitably flashed along the junction with the wall. The thatch option has the additional advantage of being a cool material which absorbs little heat.

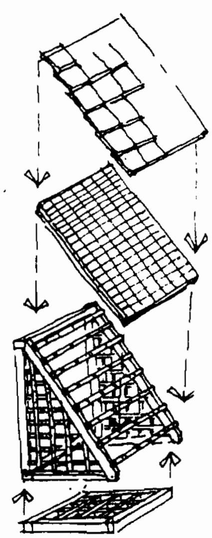


Fig. 5.18
Living room - 'Magic eye' - roofing options

5.3.2 Upper floor - Living room - Roof

Suggested modifications- building elements

Option 1

The first suggestion is the introduction of a partial ridge vent (Fig.s 5.19, 5.20). This typology (R3) is found in many of the studied vernacular examples. In essence, this is a redeployment of a traditional skill. This device involves raising a part of the roof, preferably in the centre of a room. The suggested vent is raised about one foot above the existing roofing and covers an area of two feet (wide) by three feet (long). The construction involves removing the tiles and curtailing the purlins area of the roof. Stub timbers support the vent and are placed on the main rafters of the roof and an understructure of country wood or bamboo could be used. Mangalore tiles and/or micro-concrete tiles could be used for roofing. The two gable ends of the vent could be closed using ferro-concrete panels. The windward openings would have to be screened with meshes for protection from insects. This device could act as a dynamic (as in the Malay shop houses) or a passive device.

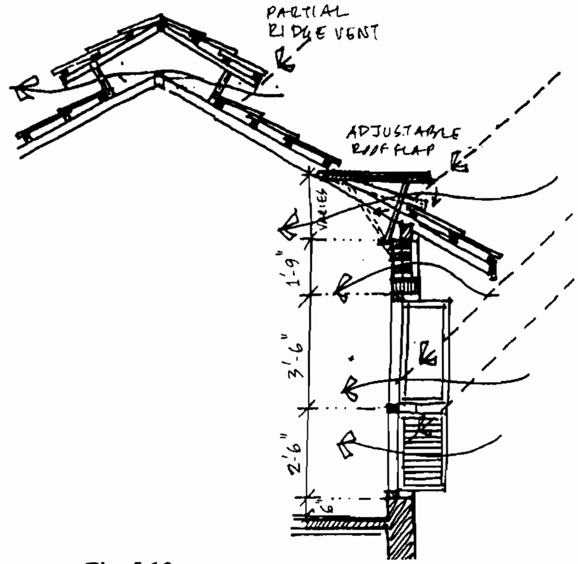


Fig. 5.19
Living room - Roof modifications - Option 1

Option 2

This device is inspired by the adjustable roof flap of the *Nias* house, Indonesia (R4). The device is placed on the windward slope of a roof, with the opening close to the top of the wall. The suggested device, about two feet by two feet, could be a ferro-concrete or micro-concrete panel. It could be fixed to a steel rod which in turn is fixed to the rafters, under the level of the purlins. This arrangement would allow the flap to pivot about the axis of the rod. The flap is at a slope less than the roof slope. The flap begins below the roof tile level and ends above the lower roof tiles in order to prevent water penetration. Two steel stays, which are pivoted in an axis parallel to that of the rafters, support the roof flap by hooking into notches (Fig.5.20b). A row of notches would help adjust the slope of the flap. However, the joint between the flap and the roof along the slope has not been resolved adequately and needs to be further detailed.

Option 3

The smoke tile (R8), as a possible dynamic device, could be incorporated in the roof on the windward slope (5.20a).

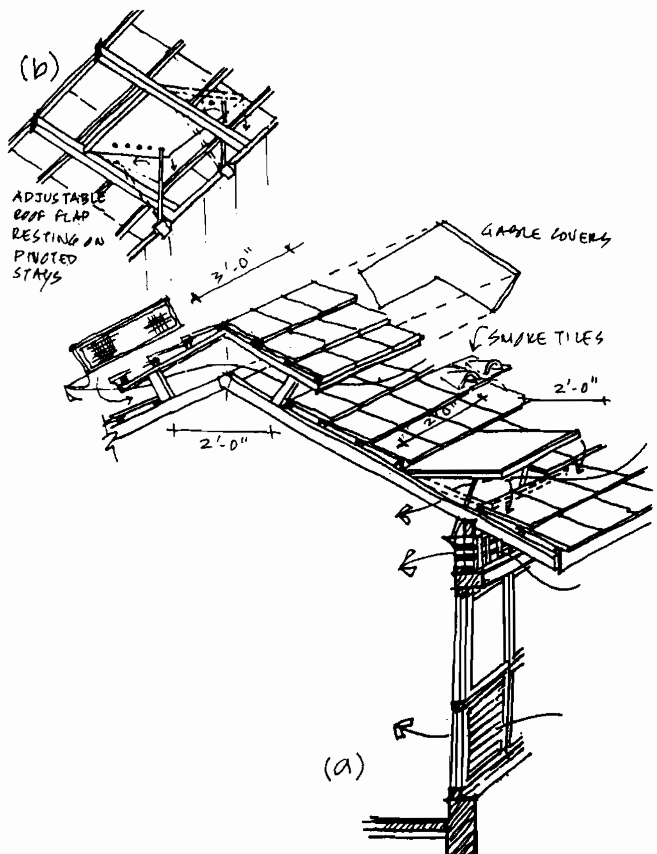


Fig. 5.20
Living room - Roof modifications - Option 2

5.3.3 Upper floor - Living room - North wall

Suggested modifications- building elements

Option 1
The north wall receives the highest insolation and during the hottest months. The first option is similar to the Option 1 on the south wall except that the section (c) of the opening has a higher sill because the use of the spaces immediately next to the window is higher than ground level by about a foot and a half (Fig.5.21). The opening is again for the full height of the wall to facilitate maximum cross ventilation.

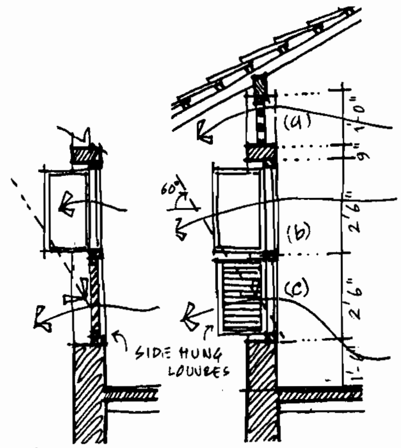


Fig. 5.21
Living room - North-wall section - Option 1

Option 2
This option is similar to the device in Option 3 on the south wall of the living room except that the sill of the section at (c) is higher, as mentioned above (Fig.5.22).

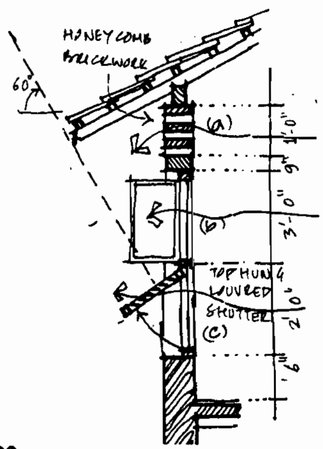


Fig. 5.22
Living room - North-wall section - Option 2

Option 3
This device is similar to the `magic eye' alternative in Option 4 on the south wall of the living room (Fig.5.23). Since the primary requirement of a ventilating device on the north wall is to provide adequate sun and glare protection, this device could be effective, particularly in a thatched roof option.

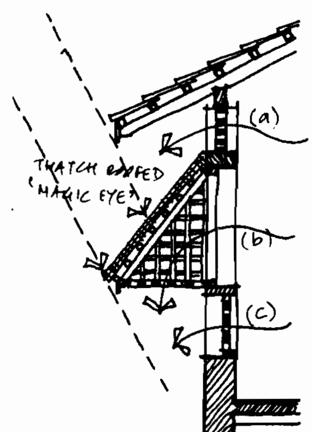


Fig. 5.23
Living room - North-wall section - Option 3

5.3.4 Upper floor - Living room - other devices

Suggested modifications- building elements

This is an introduction of the *kattru pandal* on the terrace over the pooja /store of the lower floor. The *kattru pandal* is found in coastal regions near Madras but has lapsed into disuse in the city. Traditionally, it is found in courtyards and directs the prevailing wind into the surrounding rooms. In this case, the device is placed on the flat terrace facing the south wall of the living room, the principle being to direct the prevailing south wind towards the south wall of the living room (Fig.5.24). Also, the thatched wind pavilion would reduce the reflected radiation from the terrace and cool the air passing through its shade.

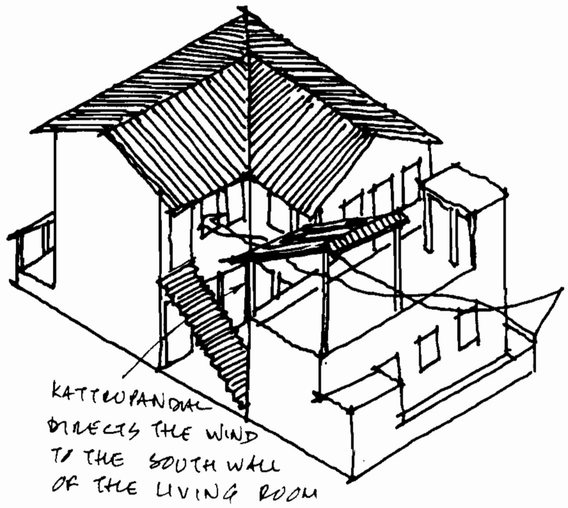


Fig. 5.24
Living room - Other devices

The *kattru pandal* is a thatched roof construction supported on country (inexpensive) timber or bamboo posts. The upward, single slope of the roof is inclined in the direction of the wind (Fig.5.25). This ensures an increased incident area for the wind.

The supports of the wind pavilion could be casuarina posts (used as a scaffolding material in this region) and could be fixed to the parapet walls along the terrace. The thatch could be made of layers of palm fronds, a readily available material. The thatch and posts could be lashed with jute or hemp ropes. This assembly would effect an increased flow of air into the living room of the dwelling.

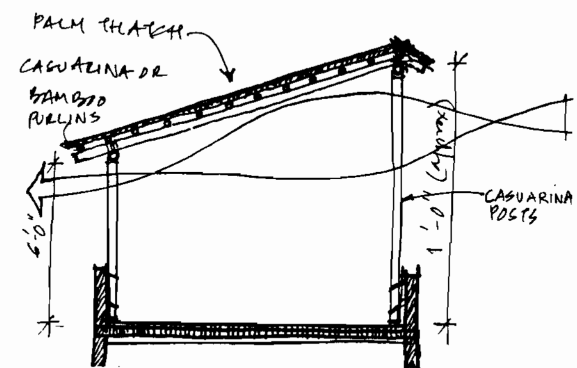


Fig. 5.25
Proposed *kattru pandal*

5.4 Upper floor - Bedroom

Specifications and needs of room regarding indoor ventilation

The bedroom is the only room on the upper floor that does not have a wall exposed to the prevailing wind. This room depends on the breeze that comes from the adjoining two rooms. There is a need therefore to make use of the roof as it is the only surface that is exposed to the prevailing wind (Fig.5.26). The internal walls would have to be perforated to ensure ventilation through the rooms. Since the openings on the common walls cannot be on the lower levels for reasons of privacy, the perforations of these walls would occur at lintel level or higher. Hence it is important for the openings on the north wall to be at a level which aerates the human activity zones. Due to the absence of a double roof or false ceiling, the heat radiated into the room causes increased discomfort. Hence there is a need for a device at the roof level to induce air exchange and stack effect. The device could be either passive or dynamic. It is also important for all openings to have safety grilles and be protected from insects.

The north wall receives maximum insolation during the hottest months of the year - from mid April to the end of August (Fig.5.27). The solar angles are the same as for the living room north wall (refer section 5.3). It is important for the windows on this wall to be well protected from the sun and glare while also facilitating for air movement at all levels of human activity.

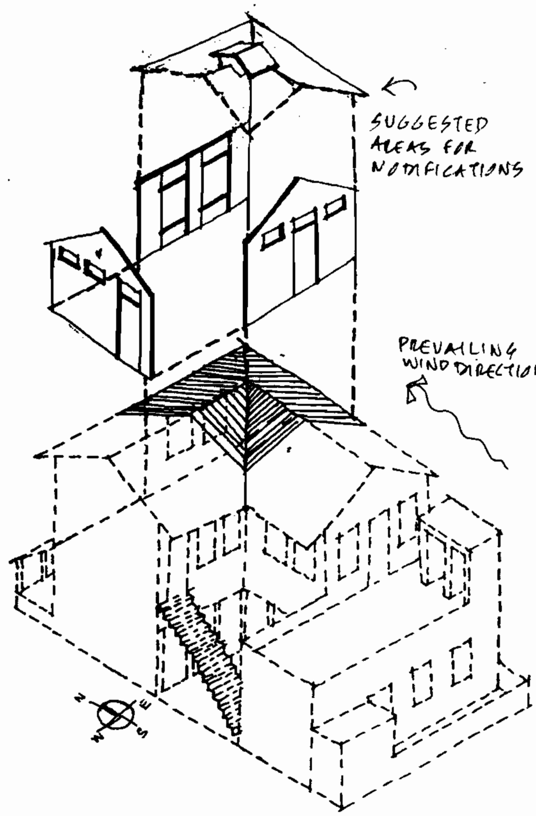


Fig. 5.26
Axonometric view
Suggested modifications to Bedroom

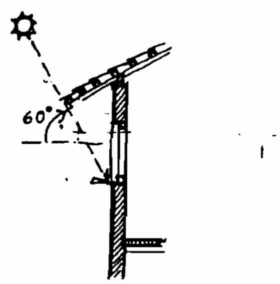


Fig. 5.27
Solar considerations - North wall

5.4.1 Upper floor - Bedroom - North wall

Suggested modifications- building elements

All options are similar to the ones suggested for the north wall of the living room. The section (c) of the opening should be raised because the activity level of the residents is higher than in the previous case.

5.4.2 Upper floor - Bedroom - Internal walls

Suggested modifications- building elements

The suggested openings on the internal walls common to the kitchen and living room occur above lintel height. They are so placed to give as much visual privacy as possible. Although this does not ensure aural and olfactory insulation, it could help in improving air movement in the bedroom.

5.4.3 Upper floor - Bedroom - Roof

Suggested modifications- building elements

The partial ridge could be introduced in the roof of the bedroom. The vent is normally placed over the centre of the room, which means the device would sit in front of the ridge of the roof perpendicular to it. Hence it would be necessary to raise the vent clear of the obstructing ridge (Fig.5.28).

The suggested vent would be raised about a foot above the ridge and would cover an area of two feet (wide) by three feet (long). (The construction of the device and other suggested specifications have been discussed in section 5.3.2).

A smoke tile (or many) could be introduced on the leeward slope of the roof. It would, at best, function as a passive device.

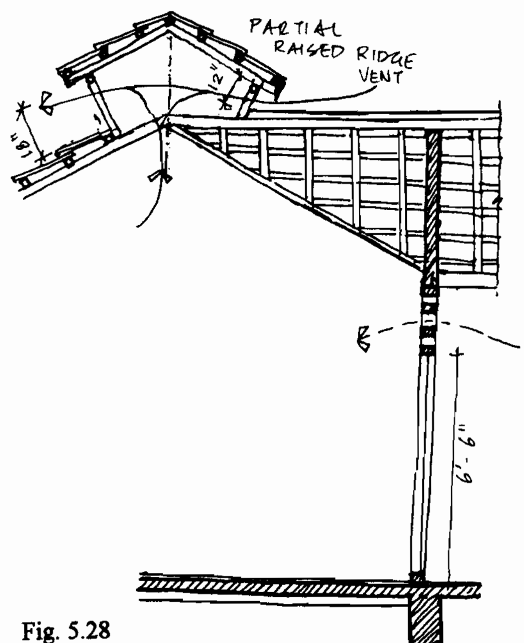


Fig. 5.28
Bedroom - Roof modifications

5.5 Upper floor - Kitchen

Specifications and needs of room regarding indoor ventilation

The kitchen has walls exposed to the south and the west sides. The south facing wall does not have roof overhangs and hence the openings are unprotected from sun and rain (Fig.5.29). Also, the presence of the toilet block in front of the kitchen has led to the disuse of the window in front of the toilet. However, it is important to make the best use of the prevailing south wind. Hence it is necessary to have sun shaded ventilating devices wherever possible on the south wall.

Devices in the roof could help enhance the air movement in the dwelling in a passive or dynamic fashion.

The west wall receives insolation on all days of the year (Fig.5.31). It is also necessary to have openings in this wall to facilitate air exchanges. Hence, the opening devices here will have to provide sun protection in addition to insect protection and security measures. The sun altitude varies from 90° to as low as 20° between noon and about 4:30 p.m. The critical wall azimuth is about 25°. It follows that there is a need for opening devices on the west wall to be suitably shaded from the low sun, at a critical angle of about 20°.

The considerations for the south wall have already been discussed in section 5.3. This wall needs to be shaded as there is no overhanging roof (Fig.5.30).

The other considerations with regard to the protection from rain, insects, security and air movement requirements are the same as in section 5.3.

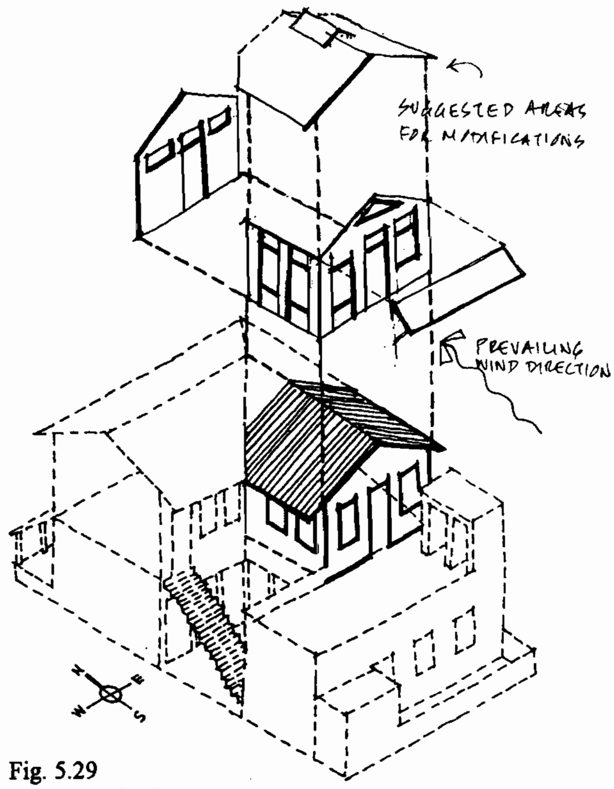


Fig. 5.29
Axonometric view
Suggested modifications to Kitchen

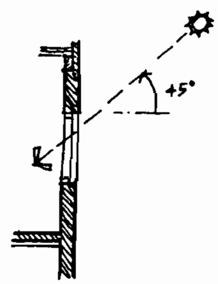


Fig. 5.30
Solar considerations - South wall

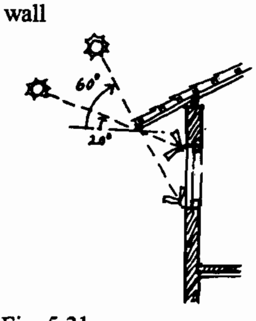


Fig. 5.31
Solar considerations - West wall

5.5.1 Upper floor - Kitchen - South wall

Suggested modifications- building elements

The suggested opening devices on this wall are again in three parts. They are similar to the ones suggested in the earlier sections except that the lower section, (c), of the opening would necessarily have to be raised in order to minimise the reflected radiation and heat from the terrace. The two suggested options for section (c) of the opening are the side hung louvred device and the top hung self-shading louvred device (Fig.5.32).

To shade section (b) of the opening, a sloped sun shade could be introduced which runs the length of the wall. This would also shade the opening devices at (a).

To make use of the gable wall, a gable opening could be introduced. This opening could be closely latticed, the lattices set-in deep in the wall. This in itself could be a self shading device (Fig.5.33).

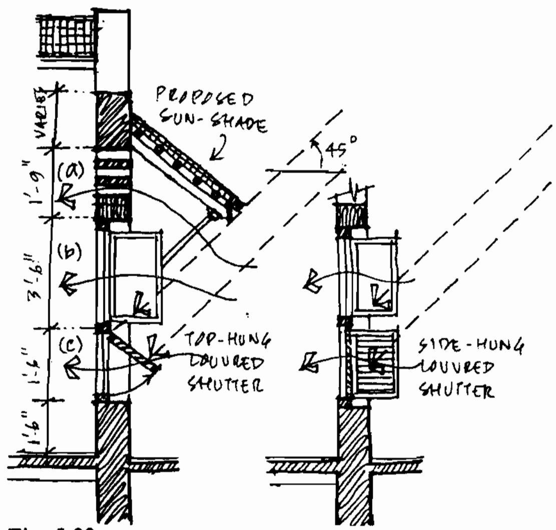


Fig. 5.32
Kitchen - South wall sections - Option 1

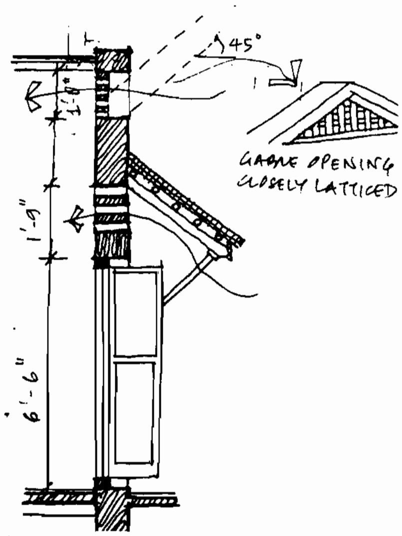


Fig. 5.33
Kitchen - South wall sections - Option 2

5.5.2 Upper floor - Kitchen - West wall

Suggested modifications- building elements

Option 1

This suggestion uses the magic eye for the section (b) of the opening because of its inherent sun shading benefits. It could provide adequate shade for the low angle of the setting sun (Fig.5.34).

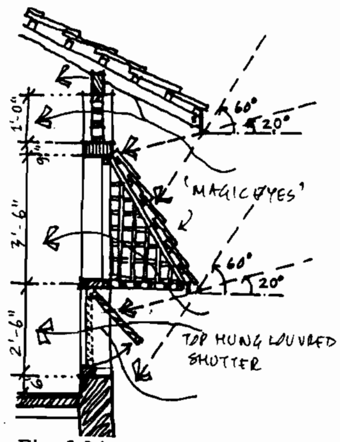


Fig. 5.34
Kitchen - West wall sections - Option 1

The direction of the wind is parallel to the west wall. When air passes through the side latticed panels of the device it would generate air movement in the room. Section (c) of the opening needs to be self shading as even the device at section (b) does not shade the lower opening when the angle of the sun is 20°.

Option 2

The second suggestion uses a *ventanilla* inspired section (c) (Fig.5.35b), retains section (b) of the opening, and leaves a gap at the top of the wall in addition to the latticed panel at the eaves. While these devices have been discussed already in the previous sections, another device has been suggested to shade sections (c) and (b) of the openings. This is a bamboo curtain which is sloped inward.[3] By sloping the curtain inward, a lower angle of sun can be cut off (Fig.5.35, 5.36). For instance, if the same curtain indicated in this figure were purely vertical, it would cut off a sun angle of not less than 32.5°. To overcome the lateral angle of the sun, the curtain could be increased in width by about one foot on either side of the window.

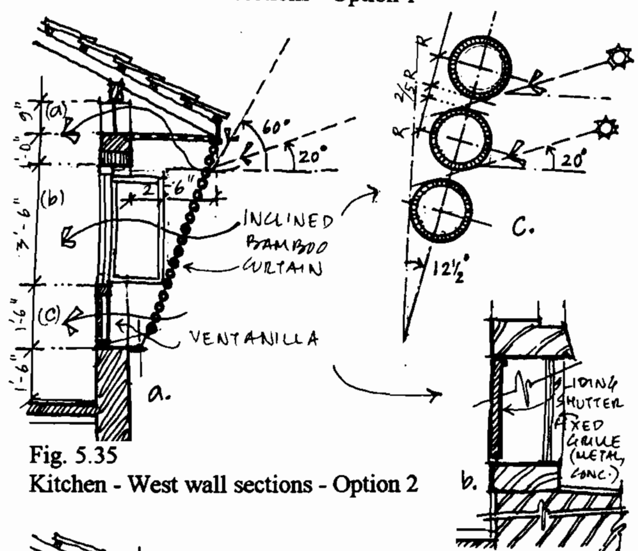


Fig. 5.35
Kitchen - West wall sections - Option 2

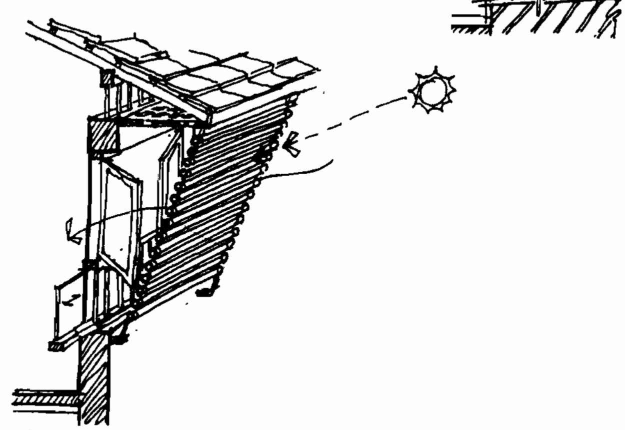


Fig. 5.36
View of Option 2

[3] This is a modification to W1, the lath curtain wall of Papua New Guinea. While the device was rejected as a wall device, it is being used as a sun shading device. The suggested inclination of the device is a context specific modification.

5.5.3 Upper floor - Kitchen - Roof

Suggested modifications- building elements

The suggested device on the roof of the kitchen is a partial ridge vent (Fig.5.37). As opposed to the other two ridge vents previously discussed, this vent would run parallel to the wind direction. So the difference in its fabrication would be that the gable end of this device would be left open with suitable insect protection. The eaves end could also be left open to facilitate more passive air exchanges. The construction of this device would otherwise be similar to the ones suggested over the living room and bedroom.

A smoke tile could be introduced as a passive ventilating device on any side of the roof slope. It could be placed over the cooking area to facilitate exhaust of smoke.

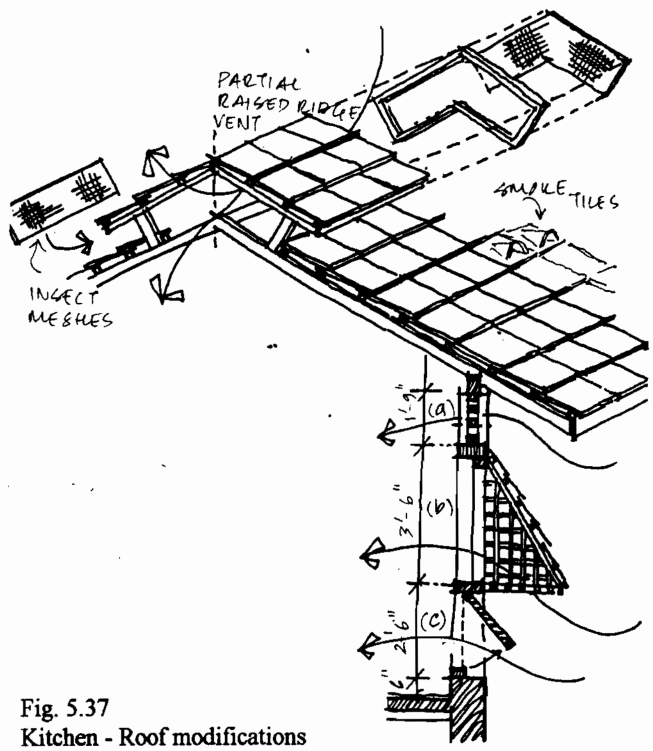


Fig. 5.37
Kitchen - Roof modifications

5.6 Smoke tunnel experiments of the house

A scale model of the house has been tested in the smoke tunnel incorporating most of the suggested modifications (Fig.5.38).[4] Not all the suggested devices have been tested (such as the eaves lattice of the *Bahay na Bato*) because the scale of the model was too small to study their effectiveness. The model was made so as to see the air movement in the whole house, rather than looking at each room in isolation. However, this approach has its flaws. Notable among them is the small size of the final model (approximately 1:50 scale) as determined by the fixed size of the smoke tunnel.

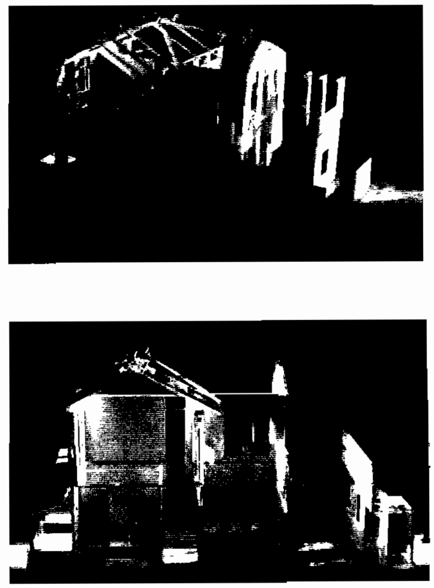


Fig. 5.38
Scale model of Case Study

The devices used for this experiment were the adjustable roof flap, the ridge vent (both parallel and perpendicular to the wind flow), a gable end wall opening, full length wall openings (from close to the finished floor level up to top of wall - with the bottom section having a fixed grille on the west wall and a top hung louvred window on the south wall), the 'magic eye' and the *kattru pandal.*

The streams of white smoke which simulate the laminar flow of air come out of nozzles that are spaced about 10 mm apart. For more accurate experimentation with such a small model, the spacing between the nozzles needs to be smaller so as to allow more smoke streams to strike a larger wall area. The model has been tested in two ways, (1) in a vertical form (Fig.5.39 - model is viewed from the top) where the streams of smoke flow parallel to the planes of the walls, and (2) in a horizontal form (Fig.5.42 - model is viewed from the side) where the streams of smoke flow parallel to the floor of the model. In the first case, the smoke streams strike only a part of a wall, while in the second,. the streams of smoke strike the whole model at a particular level.

[4] Only modifications suggested for the upper floor have been incorporated and not those for the lower floor. This is because of a practical difficulty. Since the floor had to be transparent to let in more light for photography, the top view does not clearly reveal at which level the smoke is passing, which makes it difficult to tell what the air flow pattern is at each level.

The scale model has been tested in two scenarios - with the suggested devices and without. In the latter case, the same model has been used by simply taping up the extra openings to simulate the existing house. The following sections discuss the experiments conducted on the house showing both scenarios.

5 . 6 . 1 - Vertical side view of house - I

The model was placed as shown in Fig.5.39a. The smoke was directed vertically and the model was moved back and forth in order to bring the smoke streams in line with the devices. This experiment was conducted on the (upper floor) living room part of the dwelling.

Observations

With devices incorporated (Fig.5.39b)

The roof flap caught a few streams of smoke which it directed into the living spaces.

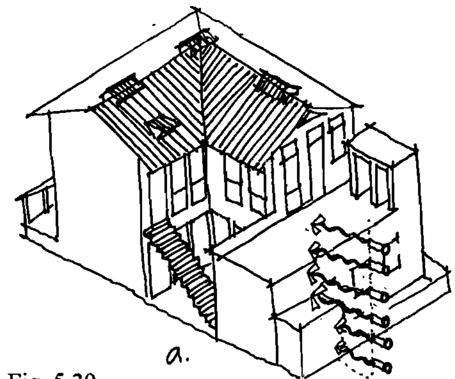
The roof vent (perpendicular to the direction of the smoke) seemed unaffected by the incident smoke.

The air flow ignored the walls of the upper floor and the lower parts of the dwelling.[5] One of the lower streams passed through the corridor at the lower floor of the dwelling.

Without devices (Fig.5.39c)

While the two lower smoke streams were diverted into the dwelling through the roof flap in the previous case, in this case they pass over the roof of the upper floor.

Aside from the small air movement in the corridor, there seems to be little movement anywhere else in the house.



a.

Fig. 5.39
Vertical side view of house I

b.

c.

[5] This can be attributed to one of the shortcomings of the experiment and its apparatus. Since the experiment used a single stream of smoke and the laminar flow of the smoke diverted itself upwards, the smoke did not reach the south wall of the living room. In reality however, slower wind would probably strike the wall and also reach the lower floor.

Analysis

The adjustable roof flap works well, as it directs the incident wind into the room and improves the air movement in the dwelling. From the experiment, the roof vent does not seem to be a dynamic ventilating device. This may be due to the small scale of the model and the lack of details in the vent. Also, in reality, air flow always varies in speed and would probably go through the vent at lesser speeds. The experiment does not show the efficiency of passive devices. A roof vent might function well as a passive device. The lack of air flow to the walls of the upper and lower floor can be considered a shortcoming of this experiment as the laminar flow of air seems to clearly ignore this part of the building. However, the later sections which discuss the plan view of the model show air movement in the dwelling due to air flow through the wall devices.

5.6.2 Vertical side view of the house - II

The model was placed as in the previous case. There was an introduction of the *kattru pandal* over part of the roof over the kitchen and *pooja* of the lower floor (Fig.5.40a). The objective of this exercise was to try and direct the south breeze towards the south wall of the living room.

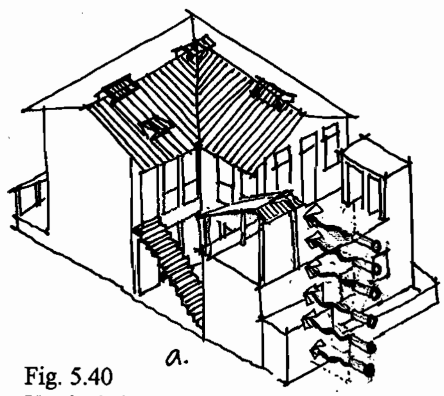
Observations

With devices incorporated (Fig.5.40b)

The device directed at least three streams of smoke towards the south wall of the living room. But it blocked the air going to the roof flap and the roof vent.

Without devices (Fig.5.40c)

In the absence of the *kattru pandal*, the air flow did not strike the wall at all.



a.

Fig. 5.40
Vertical side view of house II

b.

c.

Analysis

The *kattru pandal* definitely improves the incident focus of the prevailing wind towards the dwelling. Moreover, the device cools the rooms below by providing shade from direct insolation and also cools the air flowing beneath it towards the upper floor living room. However, because of this obstruction, the other roof devices are not touched by the air. By varying the height of the device and distance from the roof, this problem could be overcome.

5.6.3 Vertical side view of house - III

The model was turned around and placed as shown in Fig.5.41a. The smoke was directed vertically and the model was moved back and forth in order to line up the smoke streams with the devices. This experiment was conducted on the upper floor kitchen and bedroom of the dwelling.

Observations

With devices incorporated (Fig.5.41b)

The roof vent was ignored by the streams of smoke.

The gable opening provided air movement in the kitchen/dining room.

On the lower floor, a turbulence in the kitchen area was observed, but did not appear to move on to the other rooms due to the lack of openings to facilitate cross ventilation.

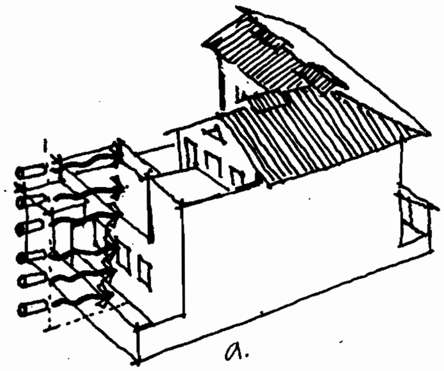
The full length opening on the western end of the south wall was not affected by the smoke streams.

The openings above the lintel height provided some air movement.

Without devices (Fig.5.41c)

There was no indoor air movement on the upper floor.

On the lower floor, there was a turbulence in the kitchen.



a.

Fig. 5.41
Vertical side view of house III

b.

c.

<u>Analysis</u>

The roof vent, which ran parallel to the direction of the wind, did not seem to provide any dynamic ventilation to the room. The gable ventilator provided some air movement in the room, particularly closer to the roof. However, very little air movement (barely discernible in the photograph) was generated in the bedroom except through the openings in the partition wall between the two rooms. The full length opening provided on the west end of the south wall was not affected by the smoke. This could be attributed to the same shortcomings of the experiment as discussed in section 5.6.1. The openings above the lintel level did enhance the air movement in the dwelling. However, these openings need to be suitably protected from the sun to ensure that they are kept open. The 'magic eye' was ignored in all the experiments seen so far. It probably has greater importance as a sun shading device that also produces passive air exchanges.

5.6.4 Horizontal top view of house - I

The model was placed horizontally in order to facilitate a horizontal stream of smoke flowing across it as shown in Fig. 5.42a. The model was located such that the stream of air passed the roof level, to test the efficacy of the roof devices.

<u>Observations</u>

<u>With devices incorporated (Fig.5.42b)</u>

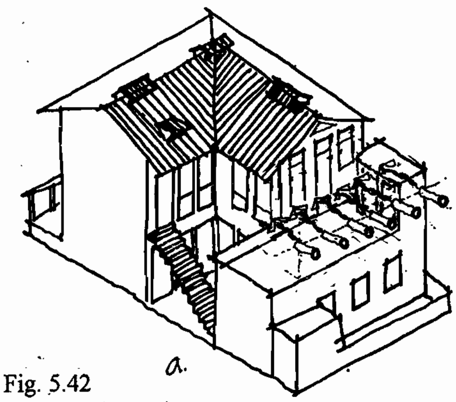
The kitchen/dining areas were clouded with turbulence due to smoke going through the gable opening.

The living room had less turbulence than the kitchen. It shows a clear stream of air due to the roof flap.

The bedroom shows the least turbulence.

<u>Without devices (Fig.5.42c)</u>

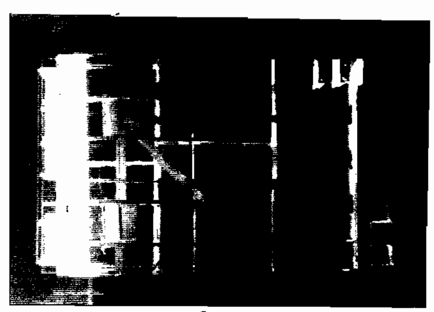
The turbulence observed in the previous case was absent in this case given the same settings. The air flowed over the roof or struck it and continued straight through.



a.

Fig. 5.42
Horizontal top view of house I

b.



c.

Analysis

The roof flap and the gable opening, as already discussed, seemed to provide dynamic air movement at the roof level of the dwelling. The roof vent was not affected by the air movement. The turbulence seen in the bedroom was due to borrowed air movement from the kitchen. The turbulence generated in the living room was less than in the kitchen, primarily because of their respective locations. Since the living room is set back from the kitchen with respect to the smoke streams, it can be seen in Fig.5.43b that while two full streams of smoke struck the kitchen gable wall, only one hit the living room roof. Although the difference in position of the rooms would matter, in reality, there may be less of a 'preferential' treatment by the actual breeze.

5.6.5 Horizontal top view of house - II

The model was located such that the stream of air passed at the level of the walls of the upper floor, to test the efficacy of the wall devices and to observe the patterns of air flow they generated within the dwelling (Fig.5.43a).

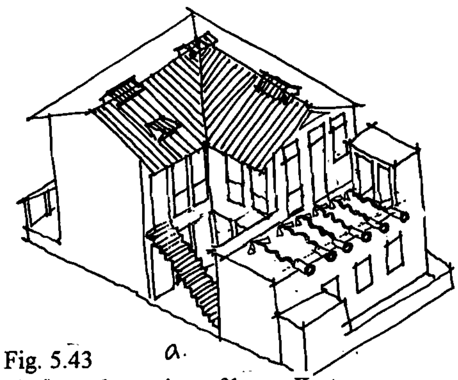


Fig. 5.43 a.
Horizontal top view of house II

Observations

With devices incorporated (Fig.5.43b)

The kitchen/dining areas were clouded due to smoke going through the openings above the lintel and the full length opening at the west end of the wall.

The living room also showed considerable air movement through its openings.

The bedroom showed the least turbulence, although more than in the previous case.

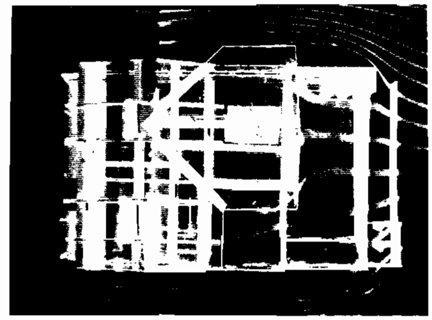
The courtyard showed a swirling movement of air, after it hit the south wall of the living room.

Some eddies were created near the 'magic eye'.

b.

Without devices (Fig.5.43c)

The turbulence observed in this case was minimal, given the same settings. Only the living room showed some amount of air movement.[6]



c.

Analysis

This experiment showed that the introduction of the wall devices did enhance the air flow in the dwelling. The air coming out of the north side was not discernible because of its slow speed. The 'magic eye' did provide some air movement in the kitchen by catching some of the upward draughts from the courtyard. The full length openings on the south wall of the living room were effective in enhancing the air flow in that room. The openings above the lintel in the kitchen/dining room also enhanced the air flow in that room.

5 . 7 Inferences of the suggested implementation stage

While some of the suggested modifications tried to address environmental criteria such as insolation, glare, insect protection and security in addition to ventilation, others cater only to the enhancement of ventilation within the dwelling. Discussed below are inferences drawn from the performances of these modified devices.

The first inference drawn from the suggested implementation exercise was that the introduction of the new devices and strategies did improve the air movement in the dwelling, as shown in the smoke tunnel experiments.

Among the devices in roofs, the adjustable roof flap performed favourably as a ventilating device. Being an adjustable device, it also provides protection from the sun,

[6] In the existing house, the openings on the south wall of the kitchen are kept closed for most of the day. The openings on the south wall of the living room are kept open more often than those in the kitchen. This is the scenario that has been simulated in this experiment.

glare and rain. For protection against mosquitoes and flies there have been no long-standing suggestions. However, the use of plastic screens is by far the most efficient device used in the region. The roof flap also needs to be carefully detailed at the junction with the roof to prevent water penetration.

The ridge vent, according to the results of the smoke tunnel experiment, could not be called a dynamic ventilating device. Neither when placed parallel nor perpendicular to the wind direction was the vent affected by the wind. This could be attributed to the small size of the model. It is probably best described as a passive ventilating device. Hence, further research (with larger models) of this ventilating device is required.

The gable wall opening closer to the ridge also proved effective. The device, available in the region, helped direct the incident wind into the dwelling. The device must, however, be suitably treated for protection against sun and glare (through provision of closely spaced lattices), rain (through provision of shades), and insects (through provision of screens).

Among the wall devices, the strategy of providing full length windows (floor to lintel or top of wall) is sound. Such an opening necessarily has to address the needs of insolation, glare, rain, insect protection, security and privacy. The modifications that have been suggested respond to these needs in varying orders of preference. In Madras, keeping out the heat and glare is of primary importance. Devices like the bamboo curtain and the 'magic eye' meet this requirement while also maintaining air exchange in the dwelling. With the environmental factors taken care of, the full length opening has obvious advantages over the existing sill to lintel window.

The 'magic eye' did not particularly improve air movement in the dwelling, although it did draw in air from the vortexes caused in the courtyard. The device was used in a direction parallel to the wind flow for two reasons, namely, to provide effective protection from the west sun, and to allow the possibility of catching the south breeze by projecting beyond the wall face.[7]

[7] In the smoke tunnel experiments, the 'magic eye' was also fixed on the south wall of the living room perpendicular to the wind direction. It reduced the air flow in the room as compared to a fully openable (middle section) window.

The provision of full length windows on the north wall did not produce conclusive evidence regarding its contribution towards an improved indoor air environment. The basic premise was that outlet openings at all levels of human occupancy would enable the air to pass over bodies and thus cause physiological cooling. In the experiment it was found that the air going out was very slow and the wisps of smoke came in bursts and were not apparent in the photographs.[8] It is a passive ventilation strategy which requires more study.

The eaves lattice device was not tested in the second set of experiments owing to the small size of the model. However, in the first set of experiments (refer 4.6.2), it was found that this device also improved air flow within the dwelling by rendering the incident breeze horizontal (the general tendency is for the wind to move upwards). In addition, this device also prevents birds from nesting in the eaves and rodents from entering the house.

The *kattru pandal*, a device found in a nearby region, performed well in the smoke tunnel tests. Although the primary function of this inexpensive device is to focus the wind into the living areas, it also shades the terrace and cools the air passing through its shade.

Lastly, another factor that affects the indoor environment of the dwelling is vegetation. This comment is not part of the findings of the suggested modifications and experiments, and has been discussed in Chapter I. However, it is relevant in this context. Although the sun protection provided by the suggested devices themselves (or combination of devices) would allow the residents to keep them open in direct sunlight, often the air entering the house may already be heated by the ambient radiation from the surrounding hard surfaces. Hence it is important to provide as much vegetation as possible, on terraces, courtyards, and other open spaces to minimise the radiation from the ground.

[8] The use of white coloured model material further reduced the visibility of the smoke; the verandah formed a white background for the wisps of smoke.

Conclusions

This study makes three main conclusions. The first conclusion concerns the transfer process. *The proposed transfer of strategies and devices, with appropriate modifications, did improve air movement in the dwelling, while also providing the much needed solar protection.* The techniques and devices suggested could have a wider applicability in Madras. A similar process could also effect transfers in order to improve natural ventilation in other existing house types in the vernacular of Madras. While the suggested transfer process addresses the ventilation problems of an existing dwelling in the form of interventions, it could also be used in the design process of new dwellings.

The second conclusion is a reiteration of the argument raised at the beginning of this thesis that *it is relevant to consider cross cultural transfers in vernacular technology in order to enhance and enrich indigenous technology.* The literature review conducted for this study identified many ingenious vernacular devices and strategies that respond favourably to climate. The devices that were collected for this research form a mere fraction of a wealth of devices that exist around the world. [1] This thesis has tried to show that even if the traditional practice of house building of a region is fast vanishing, there are ways of replenishing and revitalising these practices by learning from responses of other cultures with similar environmental conditions.

In the study of the various vernacular ventilation techniques in hot and humid climates, many devices were identified which did not exist in the context of Madras. Likewise, in the field study conducted in and around the Madras region, certain devices were found which the author did not come across in any of the case examples studied in this thesis. This leads one to believe that the very fact that there are some devices that exist only in certain indigenous settlements and are not even thought of in other cultures calls for a cross-cultural dialogue which could enhance the existing palette of any vernacular tradition. Although this thesis does not provide empirical proof of the success of a transfer, it shows that with suitable modifications, one vernacular tradition can

[1] Even as this research was progressing, the author came across other devices [such as the nose-like smoke vents of Kanuri houses, Nigeria (Denyer, 1978, p.124), the gable end flaps of the Donggo house, eastern Sumbawa (Waterson, 1990, p.55), the 'mungh' windcatchers of the delta region of Pakistan (Mumtaz, 1985, p.122)] which could not be included in this thesis.

benefit from other vernacular traditions. However, the transfer process would be complete only if the suggested modifications are tested on site. It can be summed up in Turner's terms; "besides the desk work, we must spend some of our time in the field, and we need to alternate between these two activities of desk work and field work. In the field we must test the ideas that we develop at the desk."[2]

The third conclusion made by this study is that a transfer of devices does not simply imply picking up devices from one culture and implanting them in another cultural context. *There is a need to establish a logical process of selection and modification of devices which would lead to an appropriate implementation in a chosen context.* This thesis has established a process for effecting an appropriate cross cultural transfer of technology which involved identifying, selecting and then suggesting modifications for implementation. There are essentially three stages in the proposed process. The first stage, *identification*, comprises two parts. The first involves identifying devices and strategies that form the data base for the transfer -- Matrix I. For a more complete identification of potential transfer devices, it is important to have an extensive data base. This is a task for a large research body which could document the various vernacular ventilation devices in hot humid climates. The second part identifies the specific context of transfer, and its specific determinants that establish the acceptance or rejection of a device. Next is the stage of *selection,* where the devices that are most relevant to the context of transfer are chosen. The crucial part of this stage is establishing the criteria that determine the acceptance of a device. It is a process of 'sieving,' in which devices not relevant to a context are rejected while the relevant ones are accepted. The third stage deals with the *implementation* of the devices, which is essentially the 'make' or 'break' of the entire transfer process. It involves making appropriate modifications to the chosen devices to suit local conditions. Any new device that comes through the selection process would almost certainly have to be modified in some way or another to suit a local context. The type of modifications may vary from functional changes (like the lath curtain wall device of Papua New Guinea being used as a sun breaker) or changes in the

[2] Jim Kemeny, Community based house and neighbourhood building, an interview with John Turner, Scandinavian Housing and Planning Research, no.6, 1989, p.163

compositional materials (as in the use of locally available thatch for the roof of the 'magic eye' as opposed to the wooden roof used in the indigenous form). The levels of modifications may be minor (as in the proposed partial ridge vent of the case study) or major (as with the proposed adjustable roof flap of the case study). Thus, new technological knowledge is adapted to suit local conditions to effect an appropriate transfer. In Pacey's terms, "transfers of technology nearly always involve modifications to suit new conditions, and often stimulate fresh innovations."[3]

Although this thesis addresses the specific aspect of ventilation, it could help set up the framework for establishing similar appropriate transfers in other aspects of indigenous technology. This process could lead to the enrichment of different aspects of vernacular architecture. For instance, research could be carried out on roofing systems in hot and dry climates with a similar identification-selection-implementation process to effect an appropriate cross cultural transfer of technology. The identification part of the process could well be the formation of a data base of indigenous roofing systems in hot and dry climatic regions of the world. Given this collection of devices, the selection and appropriate implementation could be done by a professional, researcher or user, depending on the context.

Concluding remarks

Although it is an illusion to believe that one can completely renounce modern mechanical means of ventilation, especially during the summer months, it is necessary to create dwellings that efficiently utilise natural means of ventilation. This would minimise the use of mechanical devices and systems and hence reduce energy consumption. This is especially valid in places like Madras, where electricity is constantly in short supply. Vernacular methods of ventilation are invariably simple and encourage contextual innovations, as every case is unique. With the adaptive use of locally available material, devices that are economical and simple to construct can be introduced to a vernacular tradition. This research simply underlines the importance of looking at vernacular

[3] Pacey; 1990, p.51

architectures of the world as a means of evolving more sustainable and energy-conscious architecture.

In the conclusions, there is much mention of the 'need for a data base of vernacular devices.' The author feels strongly that it is important for such a collection of devices to be compiled. There are two reasons for this. The first is that because of the rate at which most of the world is moving towards urbanisation and the adoptation of modern technology, most of the traditional and indigenous technology is being neglected and forgotten. Among other countries, India is one which abounds in traditional wisdom which is unfortunately losing ground to modern technology. During the field study, it was found that information on traditional domestic architecture, and more so on traditional ventilation practices, was very difficult to obtain, primarily because of poor architectural documentation. Moreover, such architectural research is considered a low priority by researchers and professionals in the country, due to the low remunerative returns for the amount of work involved. The result of such an attitude is a loss for humankind; even as we write, much undocumented information on indigenous technology is being lost. There is, however, work being done along similar lines in the documentation and compilation of vernacular architectures of the world: truly a welcome development.[4]

The second reason in the 'need for a data base' is its usefulness as a ready reckoner for developing design strategies to meet particular environmental considerations. While there may be information in the form of papers and journals regarding the efficient performance of particular vernacular devices, for it to become common knowledge or more easily accessible, a data base would be most useful. In addition to looking at indigenous technology as a result of various context-specific parameters, it would also be important to evaluate their functional performance while addressing various environmental factors.

Current trends in housing in the vernacular architecture of Madras suggest that the three to five storeyed apartment buildings are very popular, and hence becoming part of

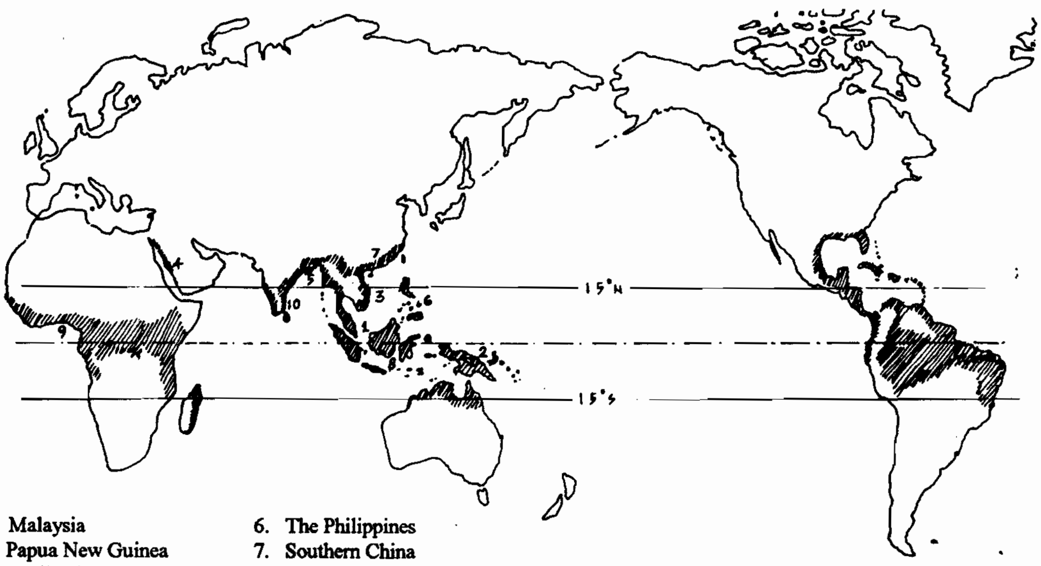
[4] The compilation of the Encyclopedia of Vernacular Architectures of the World (EVAW), edited by Paul Oliver, Oxford Polytechnic, Oxford, UK

the vernacular, though not a traditional house form. It is a dwelling type that is found in many parts of the world and, in a way, is a result of cross-cultural information interaction. Bungalows, or 'garden houses,' are also a result of cross-cultural exchange (with British colonisers). The vernacular of Madras has thus constantly been evolving, by accepting new information and adopting new techniques. Since such information transfers have been happening, it is relevant to promote transfers from other efficient indigenous technologies, which provide energy efficient solutions and do not try to dominate the environment they are a part of.

LIST OF APPENDICES

APPENDIX I

Fig. A Hot and humid regions in the world
(Source: Olgyay, 1963, p.6)



1. Malaysia
2. Papua New Guinea
3. Thailand
4. Saudi Arabia
5. Bangladesh
6. The Philippines
7. Southern China
8. Indonesia
9. Nigeria
10. Madras

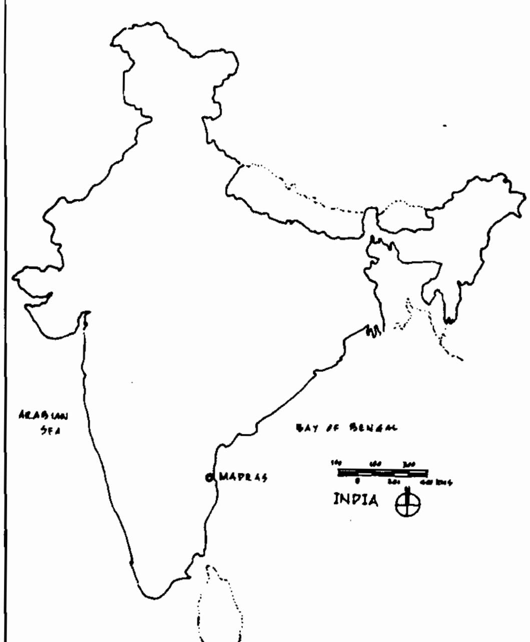


Fig. B Map of India

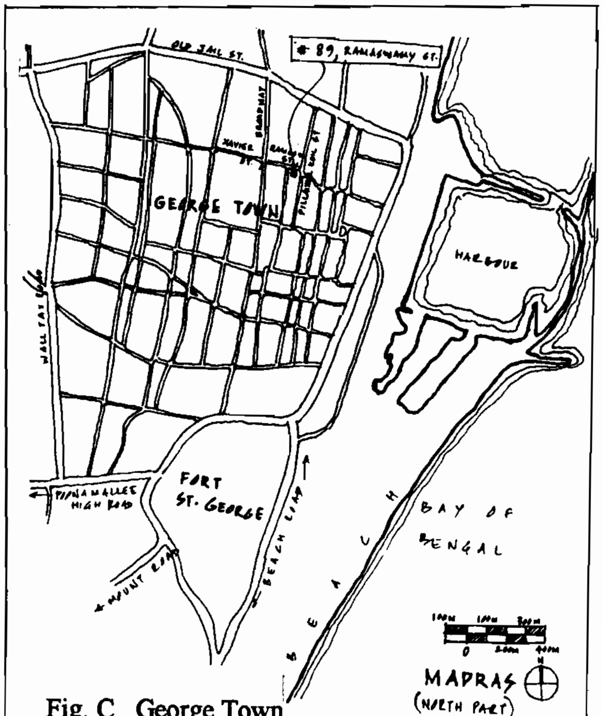


Fig. C George Town

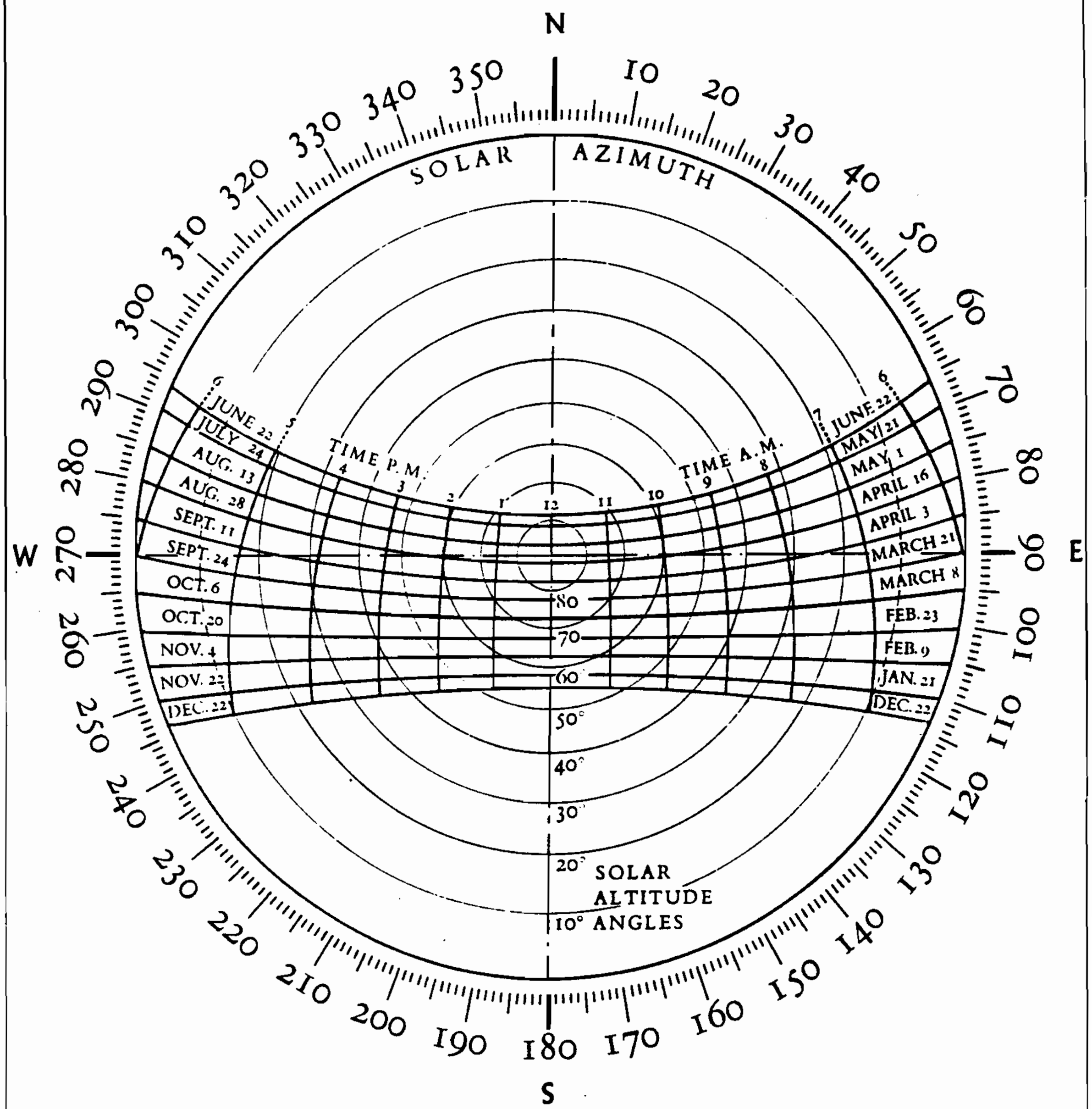


Fig. D Sun path diagram for Madras
(Source: Climate and House design, United Nations, 1971)

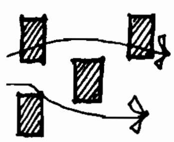
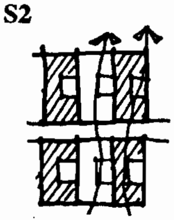
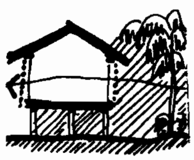
APPENDIX II

Matrix I

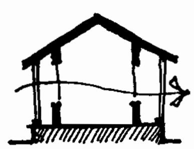
Key -- The following case studies are indicated by numbers in the graphic summary

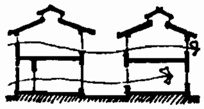
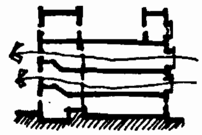
1. Traditional Malay house	5. Hijaz dwellings, S.Arabia	9. Dwellings in S.China
2. Chinese shophouse	6. Najran dwellings, S.Arabia	10. Nias house, Indonesia
3. Sepik house, P. New Guinea	7. Bengal house, Bangladesh	11. Circular houses, Nigeria
4. Thai house	8. *Bahay na Bato*, Philippines	M. Madras vernacular house

A. Strategies due to Siting of built form & Vegetation

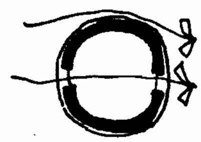
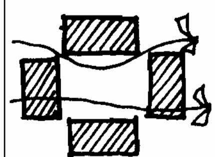
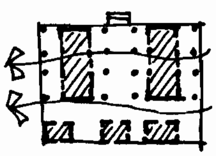
Device/Strategy	Description of device	Device/Strategy	Description of device
S1 	**Scattered layout** The units are placed in a spread out fashion to allow for through air movement. **1 3 4**	**S2** 	**Clustered layout** A loosely clustered layout around a central open courtyard. Often, gaps between units facilitate air flow into the courtyard. **7 11**
V1 	**Vegetation affecting air flow** Shade trees are to cool the incident breeze. Shrubs and bushes can be used to modify air flowing into a dwelling. **1 3 4**		

B. Strategies due to Physical Form

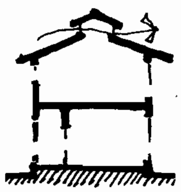
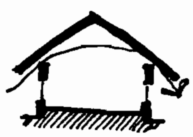
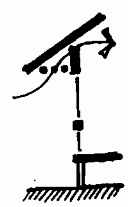
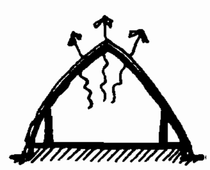
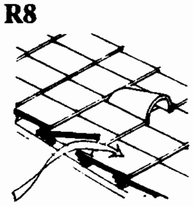
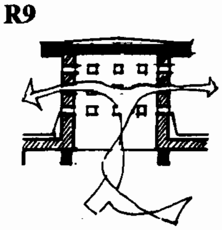
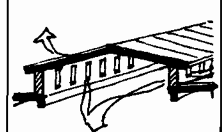
Device/Strategy	Description of strategy	Device/Strategy	Description of strategy
F1 	**Stilted house type** Dwelling is raised on stilts and hence catches winds at a higher level. **1 3 10**	**F2** 	**House on ground with raised plinth and verandah** House has a raised plinth and is open from sides due to verandahs. Verandahs catch winds and shade the house. **7 M**
F3 	**Conical roofed house type** Roof and wall are seemingly amalgamated into one domed enclosure. Passive ventilation is effected through the roof or through gap between roof and wall. **6 11**	**F4** 	**Stilted house with verandahs** Since open from sides verandahs catch winds and shade the house. **4 8**

F5 	**Row house with courtyard** Due to tight urban settlements, long and linear houses are provided with courtyards and air wells in between to facilitate ventilation. **2 9 M**	F6 	**Tall 'airy' structures** Urban setting; taller structures with large openings on wind facing facade. Ventilation is effected through openings in walls between rooms. **5 M**

C. Strategies due to Plan Form

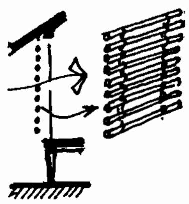
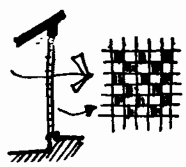
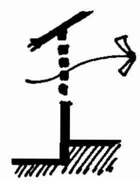
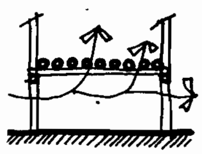
Device/Strategy	Description of strategy	Device/Strategy	Description of strategy
P1 	**Slender elongated plan** Dwelling unit is narrow and elongated which facilitates cross ventilation in every room. **3 7 8 M**	P2 	**Circular plan form** Circular plan does not allow for as much pressure build-up as a flat surface -- draws air into the dwelling through peripheral openings. **6 11**
P3 	**Rowhouse with courtyard** Due to blank side walls, courtyards are introduced in the plan form to facilitate air movement. **2 9 M**	P4 	**Rooms around courtyard** Rooms are arranged around a central courtyard. The open yard facilitates air exchange in the rooms. **7**
P5 	**Units with verandahs and terraces** Rooms are arranged on large open terraces with most rooms opening onto verandahs. **1 4 M**		

D. Devices in Roofs

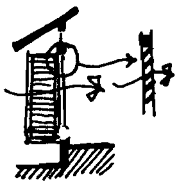
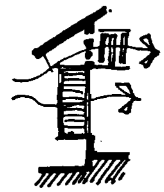
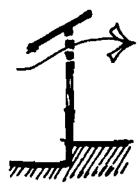
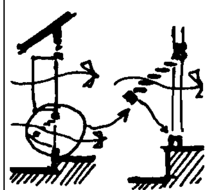
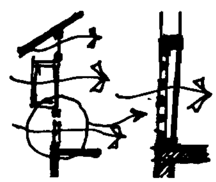
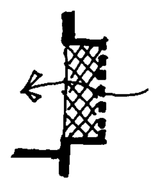
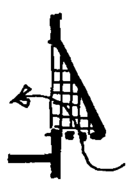
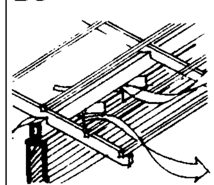
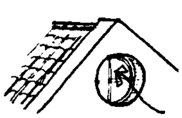
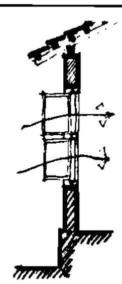
Device/Strategy	Description of device	Device/Strategy	Description of device
R1 	**Split roofs** The split in roofs (because of introduction of a verandah) provides a ventilating gap. **1 4**	**R2** 	**Roof vent** A projected ridge, open at the two ends forms the roof vent. It normally runs parallel to the wind. **8 M**
R3 	**Partial roof vent** A part of the ridge is raised to form a cap-like vent. **2**	**R4** 	**Adjustable roof flap** A roof flap, manually adjustable from within -- placed on the windward roof slope **10**
R5 	**Gap between roof and wall** The construction gap that occurs between roof and walls due to thickness of rafters facilitates a passive exchange of air. **7 8 11**	**R6** 	**Eaves lattice** Soffits of the eaves are boarded with perforated lattices which prevent pests from entering while allowing air exchange at the roof level. **8**
R7 	**Domed roof** The inner skin of the roof provides for air exchange while being protected by the outer roof covering.[1] **6 11**	**R8** 	**Smoke tile** A modified clay tile with a rectangular gap covered by a tapering cylinder cut in half. It is used as a passive smoke remover. **M**
R9 	**Smoke exhaust/hole** A passive device, which essentially works like a chimney. It is used for removal of smoke and cooking fumes. **M**	**R10** 	**Raised roof vent (flat roof)** Essentially a clerestorey where a part of the flat roof is raised with openings on the sides. It is a passive ventilating device. **M**

[1]Kaizer Talib; p.79. (In this research, this device has not been verified by the author. Talib's description of this device does not occur in the other related sources. Nevertheless, the device has been included in Matrix I)

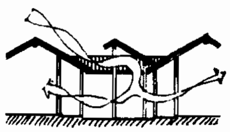
E. Devices in Walls and Floors

Device/Strategy	Description of device	Device/Strategy	Description of device
W1 	**Lath curtain wall** The wall comprises a suspended curtain of horizontal lath allowing air through but blocking the sun. **3**	**W2** 	**Inclined timber board wall** Panels of the wall are made of horizontal inclined boards of timber with gaps between them. **4**
W3 	**Woven bamboo/thatch walls** The fine gaps in the woven bamboo or thatch walls allow for a continuous passive movement of air while blocking off glare and insects. **4 7 8 M**	**W4** 	**Honeycomb brickwork walls** Walls or panels of the wall are built with gaps in them which facilitates ventilation. These panels could also be in the form of 'permanent' grilles and lattices. **M**
F1 	**Gaps between floor boards** The floor is made of boards of timber or bamboo. Gaps are provided between boards which facilitate air movement from underneath (such houses are invariably stilted). **4 8**		

F. Wall opening devices

Device/Strategy	Description of device	Device/Strategy	Description of device
D1 	**Louvred window** Windows with timber louvres allow for air movement while blocking the sun and rain. **1 4 7 8**	**D2** 	**Full length openings** The entire height of the wall below the roof is utilised for ventilation. **1 3 4 8**
D3 	**Opening above lintel level** The part above lintel level is perforated to ventilate the upper levels of the room. This opening is also invariably shaded by roof overhangs. **1 4 8**	**D4** 	**Opening below sill level** Top hung louvred window which is self-shading (from the sun) while allowing for air movement **4**
D5 	**Opening below sill level** This device has two independent panels; the outer one being a perforated device, the inner one being a blank screen which is slid shut to block sun and rain. **8**	**D6** 	***Rowshan*** Latticed timber windows cut off sun, glare and afford privacy while letting air inside the dwelling. **5**
D7 	**'Magic eye'** This device is open from the sides and the bottom and covered from the top. It catches upward draughts of wind. **5**	**D8** 	**Gaps in walls** Just below the roof rafters, gaps are left in the wall to facilitate passive air exchange closer to the roof. **M**
D9 	**Gable ventilator** These are openings on gable walls close to the ridge of the roof. A passive device, it facilitates air movement at the roof level thus enhancing stack effect. **M**	**D10** 	**Double windows** The window is in two panels, one above the other, with each panel operable independently. **M**

G. Other ventilating devices

Device/Strategy	**Description of device**
E1 	***Kattru Pandal*** Generally placed in courtyards, it is a single sloped wind pavilion, sloped upward, facing the wind. It is used to focus the wind into rooms neighbouring the courtyard. **M**

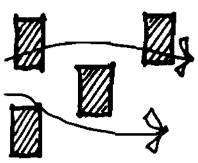
APPENDIX III

Sieve I

The 'sieve' establishes the appropriateness of the vernacular ventilation devices (from Matrix I) in the context of Madras. As discussed in Chapter IV, Solid black circle = 'appropriate', half circle = 'appropriate with modifications', empty circle = 'inappropriate.' The code given to each device is the same as in Matrix I.

Device/Strategy	**I. Cultural Compatibility**				**II. Performance relating to environment**			**III. Material resource viability**		
		Compatibility w/ lifestyle			Protection against					
With respect to **Siting of Built form** and **Vegetation**	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability

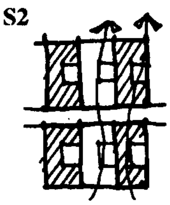
S1



S1	●	-	◑	◑	◑	◑	◑	●	●	●
	TOTAL POINTS - 4/6		PERFORMANCE INDEX: 0.677		TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000	☑

A scattered layout of the built form is prevalent in Madras. The aspects of security and privacy depend on the control and requirements of the users and are hence considered 'appropriate with modifications.' Since the layout has no direct relationship with the internal spatial use, this sub-criterion is not considered. While the layout helps in air movement between and through the units, the other environmental factors determine specific responses of the built form depending on the requirements and modifications of the users. The prevalence of this layout in the region justifies the use of locally available building materials and construction skills.

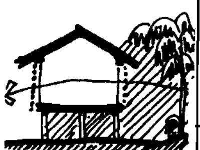
S2



S2	●	●	◑	●	●	◑	◑	●	●	●
	TOTAL POINTS - 7/8		PERFORMANCE INDEX: 0.875		TOTAL POINTS - 4/6	PERFORMANCE INDEX: 0.677		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000	☑

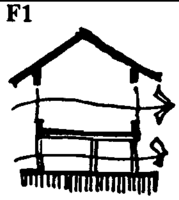
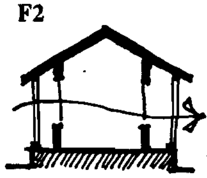
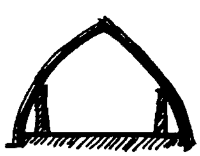
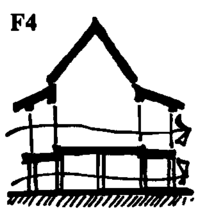
The tightly packed street house layout is also prevalent in Madras. The inherent privacy the layout lends to the introverted houses, their physical form and internal spatial layout make it 'appropriate.' This layout facilitates less solar exposure of the walls. Rain and insect protection again depend on user control. The prevalence of this layout in the region justifies the use of locally available building materials.

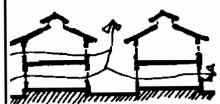
V1



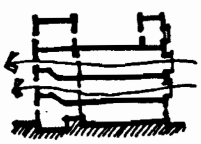
V1	●	◑	-	◑	●	◑	-	-	-	-
	TOTAL POINTS : 4/6		PERFORMANCE INDEX: 0.677		TOTAL POINTS - 3/4	PERFORMANCE INDEX: 0.750		-		☑

The use of vegetation to influence indoor ventilation requires no justification, as highlighted in section 1.5.1 (p.19). This strategy requires suitable modifications with respect to size, location and type of vegetation to suit internal spatial use and privacy of the residents. In addition, it also would provide protection from sun and rain (depending on the type and size of vegetation).

Device/Strategy	I. Cultural Compatibility				II. Performance relating to environment			III. Material resource viability		
		Compatibility w/ lifestyle			Protection against					
With respect to **Physical form**	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability
F1 	○	○	◑	◑	●	●	◑	○	◑	○
	TOTAL POINTS - 2/8	PERFORMANCE INDEX: 0.250			TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833		TOTAL POINTS - 1/6	PERFORMANCE INDEX: 0.166	☒
The dwelling type on stilts is not found in Madras. As discussed in section 4.2.1 (p.68), it is not 'appropriate' in terms of the first two sub-criteria. The aspects of security, privacy, and insect protection require user specific modifications. The sloped roof and deep overhangs afford sun and rain protection. This dwelling type requires an elaborate structure (invariably of timber) and skill for the stilts. In terms of material availability and cost, it is not viable.										
F2 	●	●	◑	◑	●	●	◑	●	●	●
	TOTAL POINTS - 6/8	PERFORMANCE INDEX: 0.750			TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000	☑
The house with a raised plinth and outer verandahs, is prevalent in Madras. As discussed in section 4.2.1 (p.68), it is 'appropriate' in terms of the first two sub-criteria. The aspects of security, privacy, and insect protection require user specific modifications. The outer verandahs protect the house from direct insolation and rain. The prevalence of this house type justifies the use of locally available material.										
F3 	○	○	◑	◑	●	●	●	◑	○	○
	TOTAL POINTS - 2/8	PERFORMANCE INDEX: 0.250			TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000		TOTAL POINTS - 1/6	PERFORMANCE INDEX: 0.166	☒
As discussed in section 4.2.1 (p.69), this form of dwelling is not appropriate in Madras. While factors of security and privacy require user specific modifications, this dwelling provides suitable protection against sun, rain and insects. Although locally available thatch and earth could be used for construction, the skill required to build such a structure is specialised and would not be available in Madras, which makes it non-viable.										
F4 	○	○	◑	◑	●	●	◑	○	◑	○
	TOTAL POINTS - 2/8	PERFORMANCE INDEX: 0.250			TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833		TOTAL POINTS - 1/6	PERFORMANCE INDEX: 0.166	☒
This house form has a similar performance with respect to the three determinants of F1. Although the verandahs provide more protection from sun and rain, the dwelling form is not viable with respect to the first and third determinants.										

Device/Strategy	I. Cultural Compatibility				II. Performance relating to environment			III. Material resource viability		
		Compatibility w/ lifestyle			Protection against					
With respect to **Physical form**	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability
F5 	●	●	●	●	●	◑	◑	●	●	●
	TOTAL POINTS - 8/8	PERFORMANCE INDEX: 1.000			TOTAL POINTS - 4/6	PERFORMANCE INDEX: 0.667		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000	☑

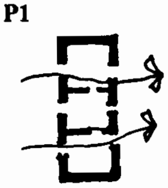
The street house type, with rooms grouped around an internal courtyard is prevalent in Madras. In terms of the physical form, the internal spatial use and privacy, this house form is 'appropriate.' The aspect of security depends on user specific requirements. Common walls with adjacent units minimise the solar exposure of walls. Protection from rain and insects can be provided with suitable modifications. Being a prevalent house type, locally available material resources can be used.

F6 	●	◑	◑	◑	◑	◑	◑	●	●	●
	TOTAL POINTS - 5/8	PERFORMANCE INDEX: 0.625			TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000	☑

Tall residential structures are prevalent in Madras. The three to five storeyed apartment blocks of Madras, invariably professionally designed, are an example of these structures. For all other sub-criteria of the first two determinants, this house form would need to be modified to suit particular requirements of the users. The prevalence of such structures indicates their viability in terms of available material resources.

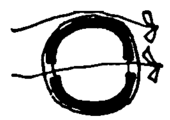
Device/Strategy	I. Cultural Compatibility				II. Performance relating to environment			III. Material resource viability		
		Compatibility w/ lifestyle			Protection against					
With respect to **Plan form**	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability

(None of the strategies discussed here in plan form provide any special protection against the sun, rain or insects. Protection against these environmental factors needs to be provided and hence these strategies are considered 'appropriate with modifications.')

P1 	●	●	◑	◑	◑	◑	◑	●	●	●
	TOTAL POINTS - 6/8	PERFORMANCE INDEX: 0.750			TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000	☑

The slender and elongated plan is prevalent in Madras. This plan facilitates cross ventilation to every room. Privacy and security have to be provided by suitable modifications. To generate such a plan does not require elaborate 'skills' or any special material resource and is hence viable in Madras.

P2

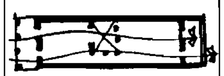


○	○	◑	◑	◑	◑	◑	◑	◑	◑
TOTAL POINTS - 2/8		PERFORMANCE INDEX: 0.250		TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500	

☒

The circular plan form is not common in Madras. While architecture practised today does experiment with such forms, circular dwellings are not traditional. The inner spatial use of residences in Madras is traditionally governed by the cardinal directions,[1] which would be difficult to ascertain in a circular dwelling. Factors regarding security and privacy could be modified as required. The construction of curved structures would require greater skill and careful detailing.

P3

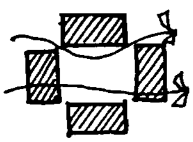


●	●	◑	●	●	◑	◑	◑	●	●
TOTAL POINTS - 7/8		PERFORMANCE INDEX: 0.875		TOTAL POINTS - 4/6	PERFORMANCE INDEX: 0.667		TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833	

☑

This plan form is found in Madras. The inner courtyard provides a private open space which suits the local lifestyle. Suitable modifications would have to be integrated into the built form to address security, and protection from rain and insects. The tightly arranged plan form provides solar protection. The materials and skill for such construction is easily available.

P4

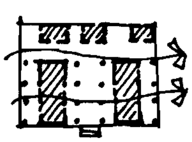


●	●	◑	●	●	◑	◑	◑	●	◑
TOTAL POINTS - 7/8		PERFORMANCE INDEX: 0.875		TOTAL POINTS - 4/6	PERFORMANCE INDEX: 0.667		TOTAL POINTS 4/6	PERFORMANCE INDEX: 0.667	

☑

The house with rooms around a courtyard is not very common in Madras. However, it is an accepted house type as it suits the local lifestyle, with day to day activities spilling into courtyards. The open courtyard, which facilitates cross ventilation in the dwelling, is shaded (to an extent) by the rooms grouped around it. Special modifications would be required for the aspects of security and insect protection. While the skills of construction are available, suitable materials would have to be used. The cost of construction will be more than that of a rowhouse because of the increased number of walls.

P5



●	●	◑	◑	◑	◑	◑	●	●	●
TOTAL POINTS - 6/8		PERFORMANCE INDEX: 0.750		TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000	

☑

Rooms with verandahs and large terraces are prevalent in Madras (especially in bungalows), provided there is sufficient space. Verandahs and terraces are important spaces in the local lifestyle. While the rooms would be shaded from the sun and glare, the other criteria of rain and insect protection, security and privacy would require context specific modifications. The prevalence of this plan form justifies its material resource viability.

[1] Even today, Madras inhabitants prefer not to sleep with their heads facing south, and prefer to have the cooking area in the north-east corner of the house, for example. (Swami Vijayananda; <u>Selvam kozhikkum veetin amaippu</u>, (Madras: *Velli Putthaka Nilayam*, 1994), p.76

Device/Strategy	I. Cultural Compatibility				II. Performance relating to environment			III. Material resource viability			
		Compatibility w/ lifestyle			Protection against						
In Roofs	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability	
R1 	◑	◑	◑	◑	●	●	◑	●	●	●	
	TOTAL POINTS - 4/8	PERFORMANCE INDEX: 0.500			TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000		☑

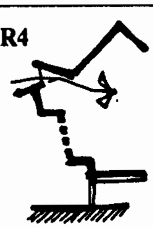
This is not commonly found in Madras. However, residents are used to having ventilators in roofs. The device involves splitting and raising the roof. This would entail a change in plan form (as in introducing supports at the point of split) and hence would affect the internal spatial use. While the device gives suitable solar and rain protection, modifications will have to be incorporated to provide privacy and security and insect protection. The vertical wall between the two roofs could be of brick masonry or slats of ferro-concrete or bamboo. Since sufficient skills pertaining to sloped roof construction exist in the region, this device is viable.

Device/Strategy	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability	
R2 	●	●	◑	●	●	◑	◑	◑	●	●	
	TOTAL POINTS - 7/8	PERFORMANCE INDEX: 0.875			TOTAL POINTS - 4/6	PERFORMANCE INDEX: 0.667		TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833		☑

This device is prevalent in the high rainfall regions around Madras. Familiarity of local residents with the roof vent would ensure acceptance in terms of internal spatial use. While the device gives solar protection, modifications would have to be made to provide rain and insect protection, and security. Country timber, bamboo, ferro-concrete or compressed timber-concrete could be used for construction.

Device/Strategy	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability	
R3 	◑	●	◑	●	●	◑	◑	◑	◑	◑	
	TOTAL POINTS - 6/8	PERFORMANCE INDEX: 0.750			TOTAL POINTS - 4/6	PERFORMANCE INDEX: 0.667		TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		☑

This device is prevalent in the high rainfall regions of a neighbouring state (Kerala). The introduction of this device would not alter the plan form and hence would not affect internal spatial use. While the device affords solar protection, modifications to provide rain and insect protection, and security, would have to be made. In its construction, country timber, bamboo, ferro-concrete or compressed timber-concrete could be used. Skills pertaining to sloped roof construction exist in the region.

Device/Strategy	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability	
R4 	◑	●	◑	●	●	◑	◑	◑	◑	◑	
	TOTAL POINTS - 6/8	PERFORMANCE INDEX: 0.750			TOTAL POINTS - 4/6	PERFORMANCE INDEX: 0.667		TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		☑

This device is discussed as an example of the working of Sieve I (section 4.2.4, p.75)

Device/Strategy	I. Cultural Compatibility				II. Performance relating to environment			III. Material resource viability		
		Compatibility w/ lifestyle			Protection against					
In Roofs	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability
R5 	●	●	◐	●	●	●	◐	●	●	●
	TOTAL POINTS - 7/8	PERFORMANCE INDEX: 0.875			TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000	☑

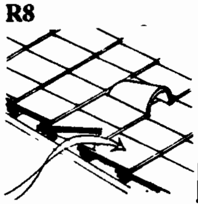
This device is prevalent in much of the sloped roof, timber and tile construction of Madras. Because of its location, it would not affect the visual privacy of residents. While the device gives suitable solar and rain protection by the overhanging roof, modifications would have to be incorporated to provide insect protection and security.

Device/Strategy	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability
R6 	◐	●	●	●	●	●	●	◐	◐	◐
	TOTAL POINTS - 7/8	PERFORMANCE INDEX: 0.875			TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000		TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500	☑

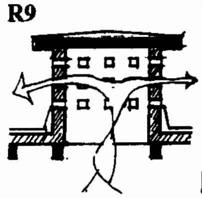
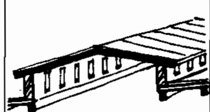
Although this device is not prevalent in the region, it is part of the roof construction and does not alter the appearance of a house. As the device is located outside the habitable spaces, it does not affect the internal spatial use. The latticed device blocks some of the reflected glare, and splashes of rain water. It provides insect protection. In its construction, country timber, bamboo, ferro-concrete or compressed timber-concrete could be used. Since sufficient skills pertaining to sloped roof construction exist in the region, this device could be made viable.

Device/Strategy	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability
R7 	○	○	◐	●	●	●	●	●	○	○
	TOTAL POINTS - 3/8	PERFORMANCE INDEX: 0.375			TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000		TOTAL POINTS - 2/6	PERFORMANCE INDEX: 0.333	☒

The domed roof form is not found in Madras. As discussed in section 4.2.1, (p.69), culturally this roof form is not compatible. It provides solar, rain and insect protection by virtue of its few openings. Factors of security and privacy require user specific modifications. Although locally available reeds, thatch and earth could be used for construction, the skill required to build such a structure is specialised and is not available in Madras, which makes this form non-viable.

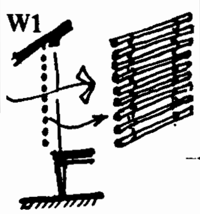
Device/Strategy	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability
R8 	●	●	●	●	●	●	◐	●	●	●
	TOTAL POINTS - 8/8	PERFORMANCE INDEX: 1.000			TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000	☑

The smoke tile is a locally found device. Its wide prevalence in the region automatically justifies its selection for implementation.

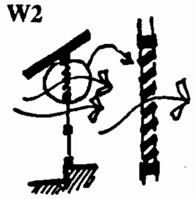
Device/Strategy	I. Cultural Compatibility	Compatibility w/ lifestyle			II. Performance relating to environment — Protection against			III. Material resource viability			
In Roofs	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability	
R9 	●	●	◑	●	●	◑	◑	●	●	●	
	TOTAL POINTS - 7/8	PERFORMANCE INDEX: 0.875			TOTAL POINTS - 4/6	PERFORMANCE INDEX: 0.667		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000		☑
R10 	●	●	◑	●	●	◑	◑	●	●	●	
	TOTAL POINTS - 7/8	PERFORMANCE INDEX: 0.875			TOTAL POINTS - 4/6	PERFORMANCE INDEX: 0.667		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000		☒

R9: This device is not used as widely as before (reasons discussed in section 3.6.3, p.62). This device occurs on terraces of flat roofs and hence needs to be suitably modified to maintain security, prevent rain water from entering, and to provide insect protection.

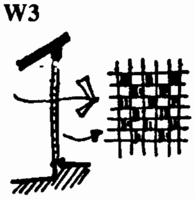
R10: The disuse of this device is due to reasons similar to R9. Similar modifications are required for this device too.

Device/Strategy	I. Cultural Compatibility	Compatibility w/ lifestyle			II. Performance relating to environment — Protection against			III. Material resource viability			
In Walls and Floors	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability	
W1 	○	◑	◑	○	●	○	◑	◑	◑	◑	
	TOTAL POINTS - 2/8	PERFORMANCE INDEX: 0.250			TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.5000		☒

W1: The lath curtain wall is not found in Madras. As a wall, this device is not culturally compatible. Although security can be provided with modifications, it does not afford the required privacy. While allowing air to pass through, the lath members also block the sun. Modifications are required for protection from rain and insects. Bamboo can be used in place of lath. The skill required for tying the members of the curtain is available in Madras (as there are cane and hemp weavers of mats and furniture in the region).

Device/Strategy	I. Cultural Compatibility				II. Performance relating to environment			III. Material resource viability			
		Compatibility w/ lifestyle			Protection against						
In Walls and Floors	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability	
W2 	●	◑	◑	◑	●	●	◑	◑	◑	◑	
	TOTAL POINTS - 5/8	PERFORMANCE INDEX: 0.625			TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833		TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		☑

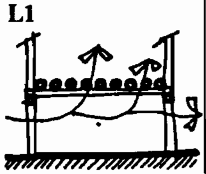
Inclined timber louvres are found in windows but not as wall panels, in Madras. Familiarity of the residents with this device in windows could make it acceptable. The device does not affect internal spatial use. While the device gives suitable solar and rain protection and affords visual privacy, modifications to provide insect protection and security would have to be made. Ferro-concrete panels or compressed timber-cement panels could be used instead of timber. Since sufficient skills pertaining to timber construction exist in the region, with suitable adjustments, this device could be made viable.

Device/Strategy	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability	
W3 	●	●	◑	●	●	●	●	●	●	●	
	TOTAL POINTS - 7/8	PERFORMANCE INDEX: 0.875			TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000		☑

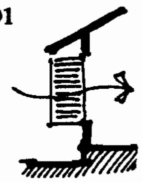
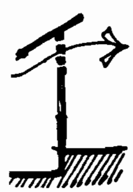
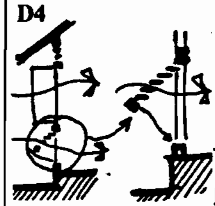
This wall type exists in the region. Suitable measures are required to provide security as the woven bamboo wall panel is easy to break. The woven bamboo wall provides protection from sun, glare, rain and insects. As a prevalent wall construction technique, its material resource viability is justified.

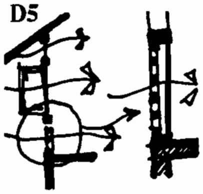
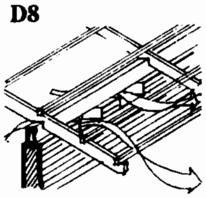
Device/Strategy	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability	
W4 	●	●	●	◑	◑	◑	◑	●	●	●	
	TOTAL POINTS - 7/8	PERFORMANCE INDEX: 0.875			TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000		☑

This wall type also exists in the region. Suitable measures are required to provide visual privacy, and rain and insect protection. The honeycomb brick wall provides protection from sun and glare. As a prevalent wall construction technique, its material resource viability is justified.

Device/Strategy	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability	
L1 	○	○	◑	◑	●	●	◑	○	○	○	
	TOTAL POINTS - 2/8	PERFORMANCE INDEX: 0.250			TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833		TOTAL POINTS - 0/6	PERFORMANCE INDEX: 0.000		☒

This device is not found in the region. Culturally, such a device is not compatible with the local lifestyle. Traditionally, the floor has always been flat and continuous, without gaps. While the device addresses the environmental factors suitably, the construction of such a flooring system is not viable. In terms of material of construction, concrete panels can be used in place of timber but that too would be too expensive and uneconomical.

Device/Strategy	I. Cultural Compatibility				II. Performance relating to environment			III. Material resource viability			
		Compatibility w/ lifestyle			Protection against						
Openings in Walls	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability	
D1 	●	●	◑	●	●	●	◑	◑	●	◑	
	TOTAL POINTS - 7/8 PERFORMANCE INDEX: 0.875				TOTAL POINTS - 5/6 PERFORMANCE INDEX: 0.833			TOTAL POINTS - 4/6 PERFORMANCE INDEX: 0.667			☑
Timber louvred windows are prevalent in Madras. While the device gives suitable solar and rain protection, and provides visual privacy due to the inclined louvres, modifications would have to be incorporated to provide insect protection and security. Due to the decreased availability of timber, bamboo, ferro-concrete panels or compressed timber-cement panels could be used for louvres. Since sufficient skills pertaining to timber construction exist in the region, with adjustments, this device could be made viable.											
D2 	◑	●	◑	◑	◑	◑	◑	◑	●	◑	
	TOTAL POINTS - 5/8 PERFORMANCE INDEX: 0.625				TOTAL POINTS - 3/6 PERFORMANCE INDEX: 0.500			TOTAL POINTS - 4/6 PERFORMANCE INDEX: 0.667			☑
Full length openings are not found in Madras. To be made appropriate, suitable measures, with respect to security and privacy of the dwelling, would have to be provided. Protection from sun, rain, and insects would also have to be provided. This device requires high level of modifications.											
D3 	●	●	◑	●	●	●	●	◑	◑	◑	
	TOTAL POINTS - 7/8 PERFORMANCE INDEX: 0.875				TOTAL POINTS - 6/6 PERFORMANCE INDEX: 1.000			TOTAL POINTS - 3/6 PERFORMANCE INDEX: 0.500			☑
Openings above lintel level are seldom found in Madras. This device occurs above the activity levels in the house and would not directly affect the day to day activities. While the device is protected from direct insolation and rain because of the overhanging roof, modifications would have to be provided for insect protection and security. The openings could be in the form of fixed grilles or lattices of bamboo, steel, ferro-concrete or compressed timber-cement panels.											
D4 	◑	◑	◑	◑	●	●	◑	◑	◑	◑	
	TOTAL POINTS - 4/8 PERFORMANCE INDEX: 0.500				TOTAL POINTS - 5/8 PERFORMANCE INDEX: 0.833			TOTAL POINTS - 3/6 PERFORMANCE INDEX: 0.500			☑
Openings below sill level are also seldom found in Madras. This device provides ventilation at the activity levels of the house. The louvred device provides protection from direct insolation, rain and also provides visual privacy when closed. Adequate modifications would have to be provided for security and insect protection. The louvres could be made of bamboo, ferro-concrete or compressed timber-cement.											

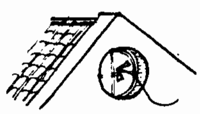
Device/Strategy	I. Cultural Compatibility				II. Performance relating to environment			III. Material resource viability			
		Compatibility w/ lifestyle			Protection against						
Openings in Walls (*contd.*)	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability	
D5 	◑	◑	◑	◑	●	●	◑	◑	◑	◑	
	TOTAL POINTS - 4/8	PERFORMANCE INDEX: 0.500			TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833		TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		☑
D6 	○	○	◑	●	●	◑	◑	○	○	○	
	TOTAL POINTS 3/8	PERFORMANCE INDEX: 0.375			TOTAL POINTS - 4/6	PERFORMANCE INDEX: 0.667		TOTAL POINTS - 0/6	PERFORMANCE INDEX: 0.000		☒
D7 	◑	◑	◑	●	●	◑	◑	◑	◑	◑	
	TOTAL POINTS - 5/8	PERFORMANCE INDEX: 0.625			TOTAL POINTS - 4/6	PERFORMANCE INDEX: 0.667		TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		☑
D8 	●	●	●	●	●	●	◑	●	●	●	
	TOTAL POINTS - 8/8	PERFORMANCE INDEX: 1.000			TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000		☑

D5: This device, similar in principle to D4, is also seldom found in Madras. As in the previous case, modifications would have to be provided for insect protection and security. The lattices could be made of bamboo, ferro-concrete or compressed timber-cement.

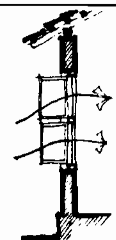
D6: *Rowshans* are not found in Madras. This device requires elaborate lattice work to block off glare and sun, and afford privacy. The level of privacy the device provides is not required in Madras. In terms of local culture and lifestyle, such elaborate latticework is not required and is hence not appropriate to the context. Moreover, to achieve such a high level of intricacy in detail, a suitable material (apart from timber) and a highly specialised skill are required, neither of which are available in Madras.

D7: 'Magic eyes' are also not found in Madras. However, this device does not have as elaborate a lattice work as that in a *rowshan*. To block off glare and sun, and afford privacy, the device uses a blank front sloped panel. In appearance, the device almost looks like a window with a deeply sloped sun shade, which is commonly found in Madras. To make it appear like that, suitable modifications could be made in the treatment of the roof of the device (it could be made of a bamboo structure, with tiles or thatch as roof covering). The device requires protection from rain (on the sides of the device) and insects.

D8: This device is used widely in Madras. The main modification required for this device is insect protection.

Device/Strategy	I. Cultural Compatibility				II. Performance relating to environment			III. Material resource viability		
		Compatibility w/ lifestyle			Protection against					
Openings in Walls (*contd.*)	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability
D9 	●	●	●	●	◑	◑	◑	●	●	●
	TOTAL POINTS - 8/8	PERFORMANCE INDEX: 1.000			TOTAL POINTS - 3/6	PERFORMANCE INDEX: 0.500		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000	☑

Gable ventilators are also prevalent in Madras. The modifications required for this device are protection from sun, glare, rain and insects.

Device/Strategy	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability
D10 	●	●	●	●	●	●	◑	◑	●	◑
	TOTAL POINTS - 8/8	PERFORMANCE INDEX: 1.000			TOTAL POINTS - 5/6	PERFORMANCE INDEX: 0.833		TOTAL POINTS - 4/6	PERFORMANCE INDEX: 0.667	☑

Double windows are losing popularity in Madras because of the non-availability of timber. These devices can be modified by the use of ferro-cement, compressed timber-cement or treated bamboo panels in place of timber.

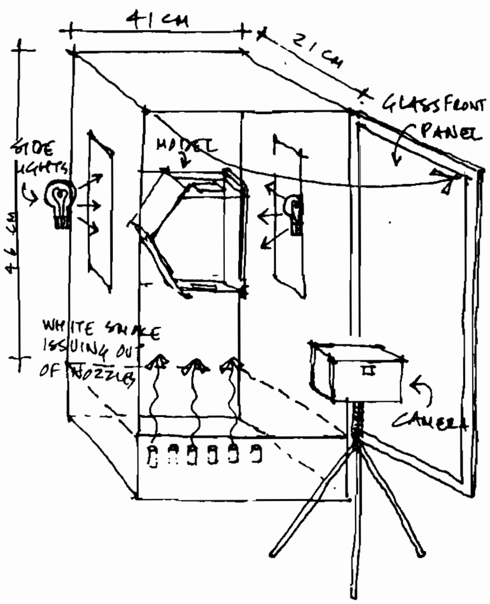
Device/Strategy	I. Cultural Compatibility				II. Performance relating to environment			III. Material resource viability		
		Compatibility w/ lifestyle			Protection against					
Other devices	Physical appearance	Internal spatial use	Security	Privacy	Sun & Glare	Rain	Insects	Material availability	Skills	Economic viability
E1 	●	●	–	–	●	●	–	●	●	●
	TOTAL POINTS - 4/4	PERFORMANCE INDEX: 1.000			TOTAL POINTS - 4/4	PERFORMANCE INDEX: 1.000		TOTAL POINTS - 6/6	PERFORMANCE INDEX: 1.000	☑

The *kattru pandal* is found in certain coastal regions near Madras. Since the device is used in open spaces in and around the house, it has no relation to factors such as privacy, security and insect protection. It can be constructed using locally available thatch and bamboo or country timber. Being a temporary structure, the cost of construction is also minimal.

APPENDIX IV

Smoke tunnel experiments

The smoke tunnel apparatus consists of an enclosure with an openable glazed front panel, a blank rear panel, and side walls with glass panels. Side lights illuminate the enclosure through these glass panels, to facilitate photography (as in figure). The white smoke used is kerosene based and emerges from nozzles at the bottom of the apparatus. The speed of the smoke was approximately eight to ten metres per second (this calculation is based on a rough calculation of the time taken by the smoke to traverse a particular distance, since the smoke regulator is not calibrated in terms of wind speeds).



The model is placed as shown. A dark background, preferably black, is required to accentuate the white smoke. The roof and floor of the models should be transparent (made of plexi-glass) to let in light. The model making strategy, in this thesis, had a major flaw. The colour of the board used was white. This reduced the visibility of the white smoke. A darker colour board (like grey) would have provided an ideal contrast for the smoke. Another drawback in the model of the case study was the use of a 'translucent' floor between the two floors. In the photographs of the top view of the house, it is difficult to tell at which level the smoke draughts occur.

The apparatus has some constraints. The smoke emerging from a single row of nozzles often misses parts of the model altogether. Moving the model back and forth does not always produce favourable results. A few more rows of nozzles, and at closer spacing, would cover a larger area. Another constraint was the need to place the model at an angle of ninety degrees because the smoke flow was vertical. An apparatus with smoke flowing horizontally would show better results as it would provide more flexibility in model making and photography.

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