DEPARTMENT OF ARCHITECTURE AND BUILDING SCIENCE
UNIVERSITY OF STRATHCLYDE, GLASGOW, UK

Design solutions for naturally ventilated houses in a hot humid region with reference to particulate matter and noise reduction

CHRISTINA E. MEDIASTIKA

A thesis submitted for the degree of Doctor of Philosophy
November 1999

ABSTRACT

Pollution in developing countries is generally much worse than in developed countries, and is caused by the widespread use of poor quality machines both industrial and in motor vehicles. Obviously, motorised vehicles are a major source of today's pollution. Motor vehicle emissions, whether gases, particulate matter or noise, can all be dangerous. Particulate matter, especially very fine particulates, is the major concern of this thesis, which considers their capacity for penetrating deep into the lungs and developing slowly to cause noticeable illnesses.

Low-income people who live within the city centre are the most exposed to traffic pollution whether on the move or indoors. Low cost housing, whether self built or provided by government or private sectors, often exposes occupants to both lack of thermal comfort and pollutant intrusion from adjacent street traffic.

Houses in warm-humid regions depend on large openings and through ventilation for thermal comfort. Openings allow air pollution and noise to penetrate these houses easily, thereby affecting the health, comfort and well-being of residents. Closing all openings and changing from natural ventilation to air conditioning is not however a practical solution for low cost housing.

This study explores the effect of boundary fences, vegetation, and detailed opening design in reducing the penetration of airborne particulates and noise into the living spaces of typical low-cost urban houses. The experiments carried out for this study include computational simulation, manual calculation and field experiments.

The research indicated that there are feasible and practical solutions to the reduction of fine particulate matter and street noise in such housing by using solid and massive barriers combined with vegetation and a specific window type. Solid and massive barriers were constructed to slow the progress of the pollutants by reduction of wind speeds on approaching obstructions. If the wind slows down enough, this effectively 'holds' the pollutant in place. In this case, the deposition surface was provided by vegetation with dense foliage. The surface of the vegetation was predicted to deposit particulate matter effectively, which would then be washed away naturally by rains. Some types of leaves were studied to find the relationship between the physical characteristics of leaf surfaces and their ability to deposit particulate matter. Before entering the living spaces, the particulate matter then encounters further obstruction by jalousie windows thus reducing its concentration.

The solid and massive fence also created an acoustic shadow and noise was then further reduced by the jalousie windows. The resulting indoor noise level was found to be closer to the proposed Indonesian standards of 45 dBA.

ACKNOWLEDGEMENTS

This study would never have been completed without the help, guidance, and assistance of many people to whom I am in great debt.

I am deeply in debt to my first supervisor Professor Michael Corcoran for his patient guidance and encouragement. My sincere gratitude goes to my second supervisor Dr. Paul Yaneske for his guidance and advice particularly dealing with acoustic sections. I would also like to thank Dr. Tom Scanlon from the Department of Mechanical Engineering for his assistance with the CFD simulations and Mr. Paul Mathew and Mr. Purnomo MS for our discussion on vegetation.

All the research steps would also never have been finished without financial support from the "Slamet Rijadi" Foundation and encouragement from all my colleagues in Atma Jaya Yogyakarta University, Indonesia, in particular those in the Engineering Faculty.

Finally, I would like to express my deepest gratitude and thanks to my mother and father, grandmother, sister and brother, aunt and uncle and especially for my "*abang*" for his love and support.

Christina E. Mediastika

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PART I

INTRODUCTION

CHAPTER 1

INTRODUCTION

The environment, especially the condition of the air, is one of the key determinants in the health of population [WHO/UNEP, 1985]. People know that low air quality will impair their health. However, it is difficult for people to control air quality. For people living in urban areas, air pollution has been a continuing problem, particularly since the industrial revolution. Increasing numbers of motor vehicles has brought even worse conditions. More recently, vehicles in particular have brought not only air pollution but also sound pollution.

Initially, air pollution usually affects human respiratory systems, but later it can cause other illnesses which are indirectly connected to respiratory systems. The types of air pollution are various, from gases and liquid drops, to invisible solid particles which can penetrate and be deposited deep down in the respiratory tracts of the body and cause chronic illnesses.

Traffic, especially motorised vehicles, also creates sound pollution. However, people tend to ignore this unseen pollution. They are aware of noise as an occasional annoyance or disturbance. The effect of noise on human emotions ranges from negligible, through annoyance and anger, to psychological disruption [Nilsson, 1993]. Physiologically, noise can vary from harmless to painful and physically damaging (the most common are decreasing hearing ability at earlier ages and tinitus).

There are several ways to minimise noise and air pollution, such as minimising the use of motorised vehicles and of manufacturing/industrial machines, or the use of zoning, whereby residential and road or industrial zones are physically separated. Sometimes, in developed countries as well as in developing countries, it is very difficult to apply such strategies. This is because most cities have grown chaotically. It might be possible to persuade people to use breathing masks and hearing protection to protect them when directly exposed to traffic, but it is not reasonable to expect people to protect themselves in this way within buildings. Therefore, unless pattern of traffic use can be changed, the best solution seems to be to protect buildings from both air and sound pollution.

One design problem in building in tropical countries is the conflicting need for natural ventilation and for noise and pollution prevention. In addition, even though the openings provide a satisfactory level of air changes per hour for natural ventilation, the quality of the air is well below requirements. Houses, especially low cost houses, in tropical climates mostly depend on the use of natural ventilation in maintaining indoor health and comfort. The outdoor air supplied into the house will remove the concentration of CO_2 accumulated indoors resulting from breathing and burning activities such as cooking for maintaining health. The air supplied should also be adequate to remove smells resulting from indoor activities such as sleeping and cooking and to cool occupants skin for comfort.

It is more difficult for people with low incomes who live in low cost housing to reduce pollution, especially noise, when the building materials are of poor quality and in bad repair. No known method of window treatment that allows adequate natural comfort ventilation will serve to quieten high levels of street noise to the extent desirable for bedrooms, wards in hospital, nursing homes, or rooms used for reading or studying [Fitzmaurice, 1939]. For better sound insulation, it may be necessary to have the ventilator separate from the window, or, where a high standard is required, mechanical ventilation may be necessary [BRE/CIRIA Report, 1993]. A solution by using specific louvre (jalousie) windows with absorbent lining over the surfaces may reduce outdoor noise levels [Thomas, 1996]. However, the cost of the absorbent linings is likely to be far too high for low cost housing, and the insulation values given by this material are still insufficient to provide the desired attenuation.

1.1 Pollution in hot humid developing countries

Most urban buildings in tropical counties experience a conflict between natural ventilation requirements and pollution prevention. Uncomfortable indoor conditions are experienced in low cost urban housing in tropical developing countries, since cost does not permit the installation of artificial ventilation system in order to improve the indoor environment. Therefore, a study that seeks the possibility of how low cost housing could improve their poor conditions by natural means is important.

This study explores the possibility of using vertical building elements to do their task as pollutant barriers. The exploration is based on earlier studies into air and sound pollution.

One growing city in Indonesia, Yogyakarta, was chosen as a case study. Yogyakarta's environmental and physical conditions are similar to other growing Indonesian cities and are considered to be similar to other growing cities in other hot humid developing countries.

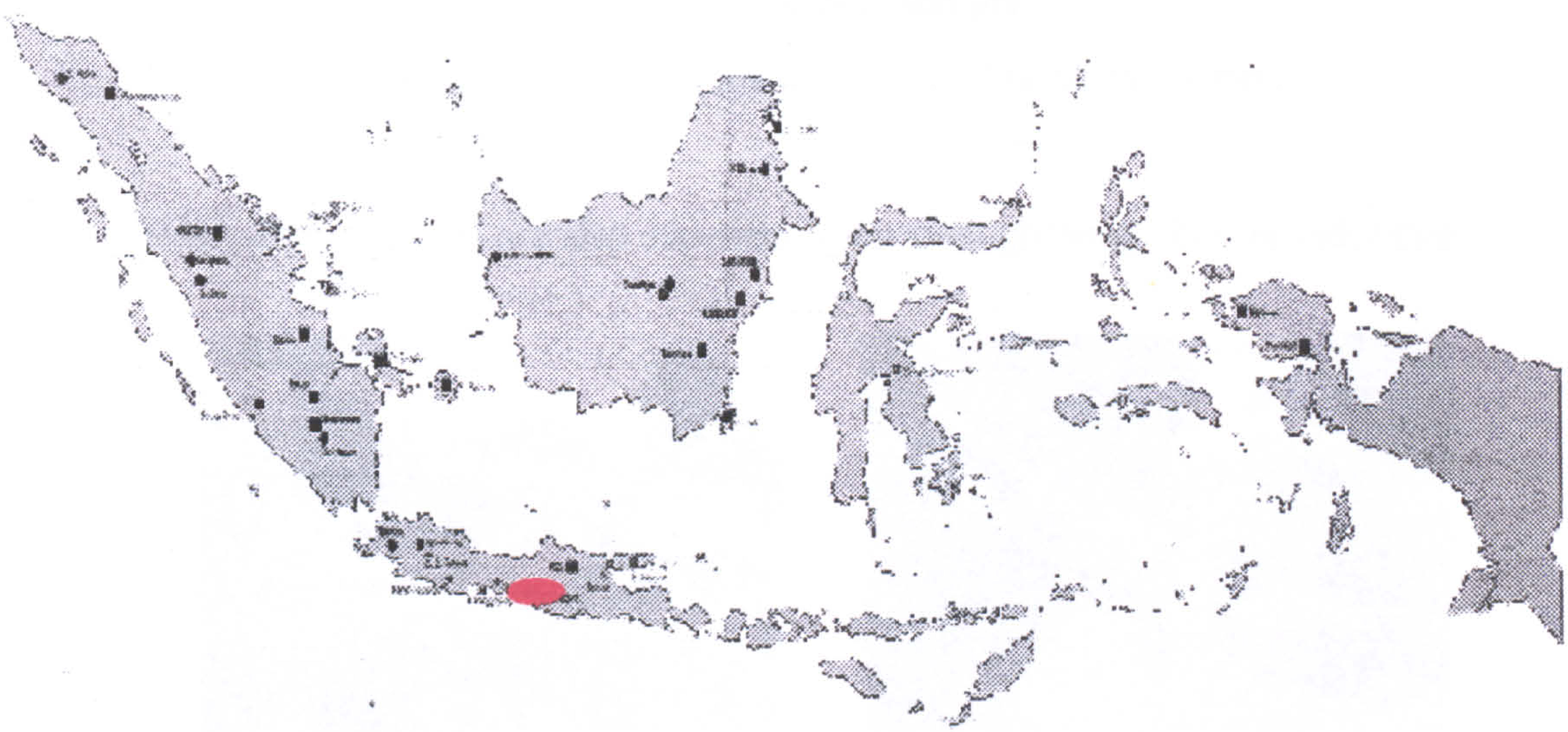


Figure 1.1. Indonesia

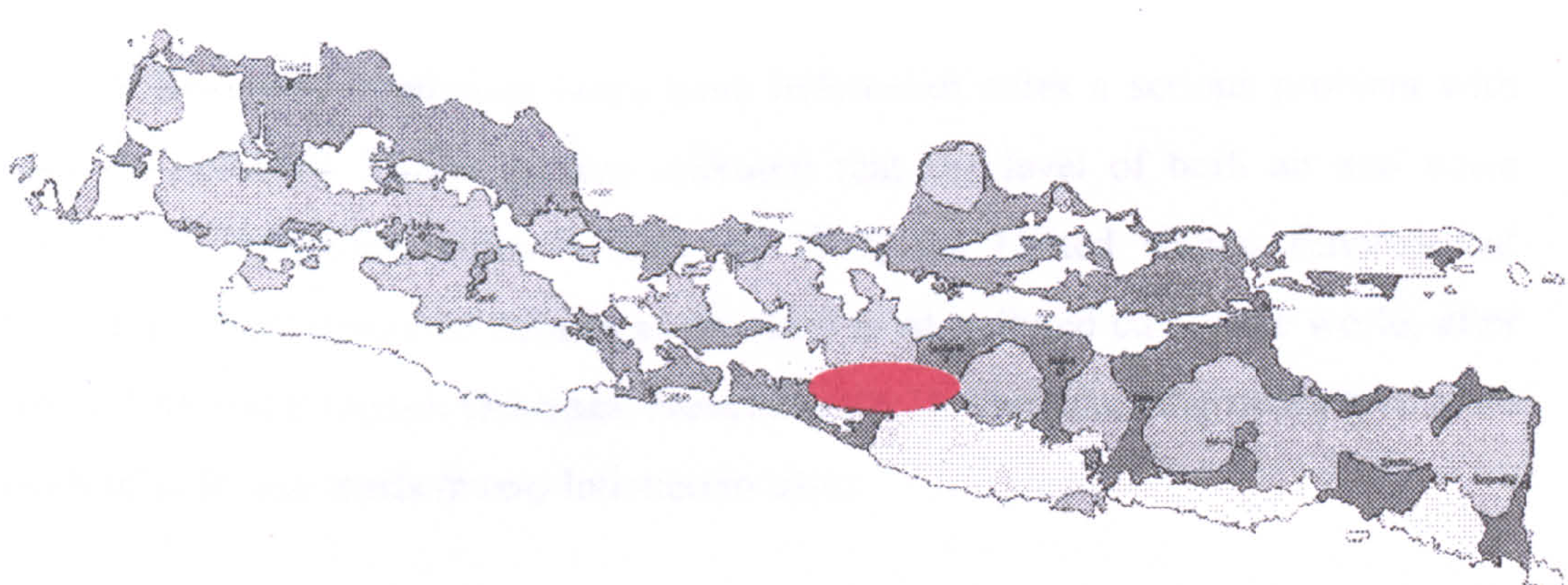


Figure 1.2. Jawa Island; Yogyakarta is shown in red.

Aspects of Yogyakarta which are fairly representative of cities of this type are as follows:

1. The city is growing chaotically therefore it is difficult to keep polluted areas and residential areas, in which occupants need to be protected from pollution, separate.
2. There are many housing areas adjacent to busy street traffic within the city centre.
3. Low cost housing is one of the urban problems, and in most cases provides insufficient facilities and uncomfortable indoor environments.
4. Pollution is mostly generated by street traffic, which consists of a wide range of vehicles, from traditional bicycles to diesel passenger cars.
5. The weather conditions of the city are typical of a hot humid climate.

All the above aspects are also experienced by most growing cities in Indonesia.

Figure 1.3 and 1.4. Left: traditional vehicles, and right: two stroke motorcycles are common private transport in Yogyakarta and other growing cities in Indonesia.

All the above conditions bring most Indonesian cities a serious problem with regard to pollution. Earlier studies indicated that the level of both air and noise pollution in Indonesian cities is high. In 1997, the United Nation Environment Program (UNEP) described Jakarta as the third most polluted city in the world, after Mexico City and Bangkok [Kompas, November1997]. The following tables give more details of pollution levels in two Indonesian cities.

1. Jakarta [Kusmaningrum, 1997/1998]:

Pollutants	Locations of measurements	Facts	Indonesian Standard
NO_x	Adjacent to traffic within the city centre	40% was ≥ 0.15 ppm 37% was 0.15 ppm> n ≥0.10 ppm 23% was < 0.10 ppm	0.05 ppm
NO_x	In residential areas within the city centre	10 % was > 0.05 ppm 90% was < 0.05 ppm	0.05 ppm
Total Suspended Particulate	In residential areas within the city centre	Vary: from 2.5% to 45.5% of the measurements were above 260 μg/m³	260 μg/m³

Table 1.1. Concentrations of some pollutant types in Jakarta, Indonesia
(Source: Kusmaningrum, 1997/1998)

2. Bandung [Kompas, 14 May1997]:

Pollutants	Indonesian Standards	Concentration measured adjacent to traffic within the city centre of Bandung
NO_x	0.05 ppm	0.10 ppm
Hydrocarbon	0.24 ppm	1.0 to 4.0 ppm
Particulate matter	260μg/m³	400 μg/m³

Table 1.2. Concentrations of some pollutant types in Bandung, Indonesia
(Source: Kompas, 14 May 1997)

Types of pollution vary, so the first important step before conducting the research is to determine the type of pollutants concerned. These pollutants are the key issues of this study. Hence, the building design most likely to reduce pollutants while also allowing natural ventilation must take account of the specific pollutants found in Yogyakarta.

1.2 Issues

Some issues that create problems in housing, especially low cost housing in a hot-humid developing country are as follows:

1. Population increases, which has a detrimental effect on the standard of housing. This can be explained as follows. When population rises rapidly, the obvious result is more unemployment and thus more poverty, which in most cases will encourage people to live in slum areas. Alternatively even if they live in a house, the house will be insufficient to provide the desired indoor thermal comfort.
2. The increase in air pollution as a result of using motorised vehicles, in particular motorcycles and diesel engines.
3. The increase in environmental noise as a result of using motorised vehicles.

4. Low-income families who cannot afford artificial ventilation (air conditioning/AC) to provide more comfortable indoor environment, as the use of air conditioning will help to cool air and to control temperature and humidity as required.

1.3 Problems

Indonesian low-income families have not yet addressed any formal complaints in regard to air and sound pollution to the government. However, this does not indicate that there are no problems. It may be that the low-income groups do not understand the risks, and even if they do, they do not know how to avoid them or they cannot afford the solutions.

Creating openings for buildings in hot-humid developing countries presents several architectural problems. This research focuses on one of these problems: how to create a perceptible environmental improvement for single-story low cost houses by reducing particulate matter from the outer environment whilst also considering thermal comfort and noise issues.

Particulate matter pollution has been chosen for the following reasons:

1. Most research carried out in Indonesia has dealt with gaseous pollutants [Department of Public Works, Indonesia, 1997/1998];
2. Diesel-engine vehicles are common in Indonesia and thus produce more particulates compared to other countries [EPA, 1982];
3. In many Indonesian cities, asphalt streets in poor condition are common. These create more particle pollution [EPA, 1982].
4. Particulates have been shown to be seriously damaging to human health [Source & Inhalable Particulate Potential Health Impacts, 1998]

This study also focuses on noise because:

1. In developing cities of this region, in contrast to large established cities, the ratio of motorcycles to cars is significantly higher. Motorcycles create high levels of noise [White, 1982], therefore they create more nuisance;
2. Diesel vehicles, which are common in Indonesia, are also sources of specific noise [White, 1982];
3. It appears likely that the noise problem can be solved together with the particulate problem.

1.3.1 Research Aims

This research is based on some assumptions which underpin the research objectives of the thesis. These assumptions are:

1. Building design (i.e. house) affects the indoor concentration of pollutants from adjacent street traffic.
2. It is possible to explore the ability of vertical building elements (e.g. walls, windows, fences, etc.) to provide prevention from pollutants whilst also providing natural ventilation.
3. The exploration of how building elements can reduce particulate matter and noise is more effective when physical behaviour of the pollutants are considered.

The aims of this research are to provide guidance for designing low cost housing in hot humid and polluted developing countries (referring specifically to Yogyakarta, Indonesia) that will create a perceptible indoor environmental improvement. This is to be achieved by:

- Providing sufficient air supply for comfort cooling by using natural ventilation;
- Reducing particulate matter as much as possible; (both fine and coarse particles are concerned, but the major concern is fine particulate matter with a diameter less than 10 μm that has the greatest health effects);
- Reducing indoor noise levels (which in Chapter 13 are typically identified to be 60 dBA) by at least 10 dBA better than existing reduction (i.e. 10 dBA, refer to Chapter 13). In most cases this might still put the indoor noise above the Indonesian proposal of 45 dBA.

This guidance is to be developed at little extra cost.

1.4 Importance of the research

Because most of the research into reducing particulate matter has been done from a science or engineering perspective, the results are, most of the time, either in the form of mathematical models or in the form of technical devices. Hence, they are not particularly relevant to the question of how building design can be improved as regards the intrusion of particulate matter. Therefore, the results of research developed by scientists or engineers are required to be in a form that architects and developers can more easily implement their concepts in the design.

Most of the studies into reducing noise have also been carried out for non-domestic buildings, which in most cases are only intermittently occupied compared to domestic buildings. Therefore, the advice related to noise insulation for those non-domestic buildings needs to be extended to the conditions found in low cost domestic buildings.

1.5 Limitation of the research

As a research subject, pollution covers an enormously wide area and comprises a huge range of factors. The pollutant itself includes gaseous, particulate, liquid and sound components. Pollution research covering all these types and all their effects on human beings requires an extremely long research time and a vast research team. Therefore, given the constraints on this investigation, it is mostly focussed on two types of pollutant, i.e. particulate matter and noise. As the present author is an architect, the particulate matter and noise reduction concepts will be directly related to the building design, which in this case is for low cost housing.

1.6 Research Methodology

Based on several related studies, the investigation has followed the following major working steps:

1. Identifying the general condition of low cost housing in a chaotically growing city (i.e. Yogyakarta) and its relation to traffic pollution.
2. Identifying the general weather conditions in a hot humid climate and the demand for air ventilation rates to be supplied within buildings to achieve thermal comfort.
3. Identifying the concentration of particulate matter and noise levels within the city centre, which are necessary to determine the pollution levels. The data on pollutant levels are provided by both secondary data and primary data, which are important when published data for the chosen city is not available.
4. Identifying the nature and behaviour of particulate matter and noise in hot humid weather conditions and seeking possible design solutions for vertical building elements given these conditions.

5. Determining the most appropriate detailed design of vertical building elements in order to minimise the intrusion on particulate matter and noise into living spaces, and thus leading to design propositions.
6. Carrying out a computational simulation to provide data for indoor thermal comfort (ventilation flow rates) and data of particulate matter dispersion within the suggested design.
7. Carrying out a manual calculation to predict noise reduction values provided by the suggested vertical building elements.
8. Carrying out field experiments, to give indications as to how the suggested designs will reduce particulate matter and noise in real conditions, particularly since a computational simulation cannot represent the real condition of the proposed vertical building elements (vegetation and specific window types). There were two major field experiments taken within two different periods of time. The first experiment was mostly to explore the effects of porous and solid fences and some types of windows to be compared with louvre windows. The second experiment explored different types of vegetation and examined and compared fully opened windows and louvre windows in relation to their ability to deposit particulate matter.
9. Analysing the field experiments and computational simulations to provide a summary of all the research steps, which then leads to the final design guidance for low cost housing in hot humid climates with natural ventilation and particulate matter and noise reduction.

1.7 Writing Methodology

This thesis consists of five parts. In part I, the major issue, the assumptions on which this thesis are based, the aims, and methodology of the research are identified. Part II which contains four chapters describes the present condition of low cost housing in Yogyakarta and its relation to pollutant sources and provides general information on the uncomfortable weather, the concentration of particulate matter, the level of noise and the standards to be met. Part III contains three chapters which discuss the possibilities of particulate matter and noise attenuation by using vertical building elements. The fourth part of this thesis describes the design propositions for vertical building elements and how the suggested vertical building elements are predicted do their task in real conditions. The five chapters of Part IV discuss the design propositions, the calculations of how the suggested design provides indoor ventilation flow rates, and how the design propositions of vertical building elements (fence, vegetation and openings) compared to the current design may reduce particulate matter and noise. The last part, Part V, defines the final guidance for building low cost housing and identifies the indoor thermal comfort, particulate matter concentration and noise levels within the suggested housing design. Issues requiring further research are also discussed within this part.

PART II

RECENT CONDITIONS TO BE MET WITH THE STANDARD OF THERMAL COMFORTS AND POLLUTANT STANDARDS

CHAPTER 2

TRAFFIC POLLUTION AND LOW COST HOUSING IN INDONESIA

One of the most complicated problems experienced by developing countries is urban housing. In hot-humid developing countries, where high levels of ventilation are required for indoor comfort, this problem is compounded by environmental problems such as the increase of air and sound pollution resulting from development. Closing or minimising the number of windows, which might reduce pollution intrusion, is not a practical solution for buildings with natural ventilation located in this region. Some hot/warm-humid developing countries face similar problems to Indonesia. It is thus useful to compare their conditions.

2.1 Low cost housing in general with comparison to other countries

2.1.1 Singapore

Singapore, a small country very close to Indonesia, is also one of the hot-humid countries. However, with a higher gross national income than many South East Asia countries, Singapore is probably no longer a developing country. With quite a high population and high density in the city centre, the problem of urban housing can be solved more readily. At least, based on their modern life styles, it is not difficult to move people into multi-storey houses where they can also install air conditioning for their comfort [Singapore, 1995/1996].

2.1.2 Malaysia

Malaysia, a nearby developing country, which has a similar climate, faces a similar urban housing problem to Singapore or Indonesia, in particular for the low and middle classes. Many of the poor live in shacks in squatter settlements. About a quarter of the population of most Malaysian cities consists of squatters and about a third -including the squatters-have inadequate housing. The Malaysian government and their university experts have proposed solving the problem by providing low-cost housing either single storey or multi-storey houses [Osman, 1991]. However, some experts have suggested that low-cost housing in Malaysia still has several negative factors [Osman, 1991]. These negative factors are exacerbated by traffic-generated air pollution and noise. The analysis is:

type of development :	high density
type of buildings :	low rise flat
floor area :	minimal
comfort level :	poor
material :	cheapest range
services piping :	poor quality
services appliances :	low quality
design and lay-out :	can be improved (minimum)

Table 2.1 Malaysian low cost housing conditions
(After O. Osman, 1991)

Figure 2.1. An example of Malaysian low cost housing
(After M.Ramli and NMD. Noordin, 1993)

2.1.3 Cuba and Venezuela

Another warm-humid developing country with temperature and humidity ranges to Indonesia is Cuba. The Cuban government provides single storey low-cost housing for low and middle-income families in the city of Havana. One example is Quinta Palatino. All the single storey houses are designed to permit cross-ventilation by using patios, supported by a three-metre ceiling height for climatic reason [Fry, 1956].

Venezuela is also a warm-humid developing country with similar housing problem faced by other developing countries. The Venezuelan government provided multi-storey low-cost housing for low and middle-income families. An example is low-cost housing in Pamona which consists of six types of houses including duplex and simplex apartments. Material used for these houses is light-weight brick conforming to the traditional building style of Venezuela [Fry, 1956].

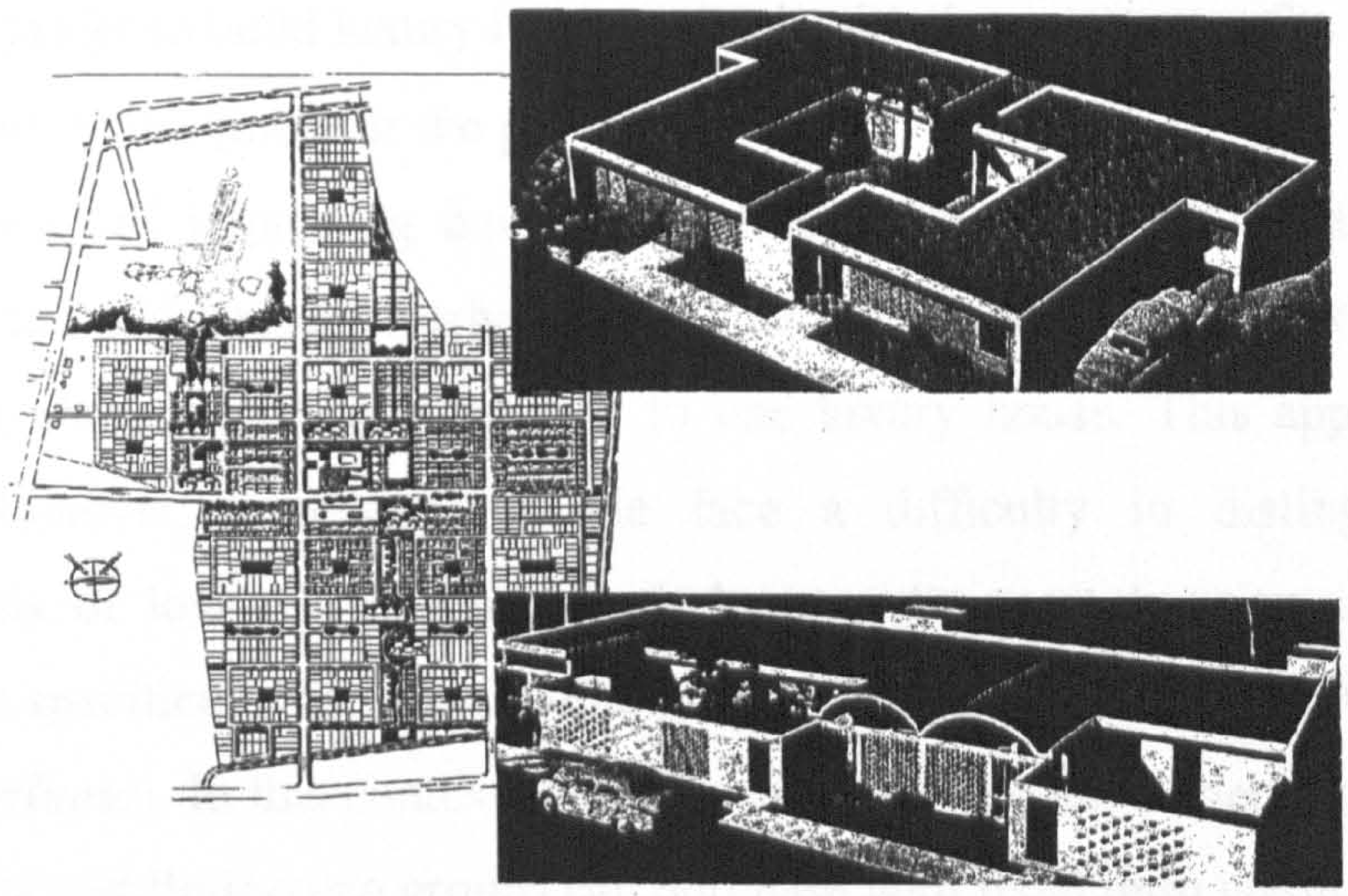


Figure 2.2. Low cost housing in Havana, Cuba
(After M. Fry, 1956)

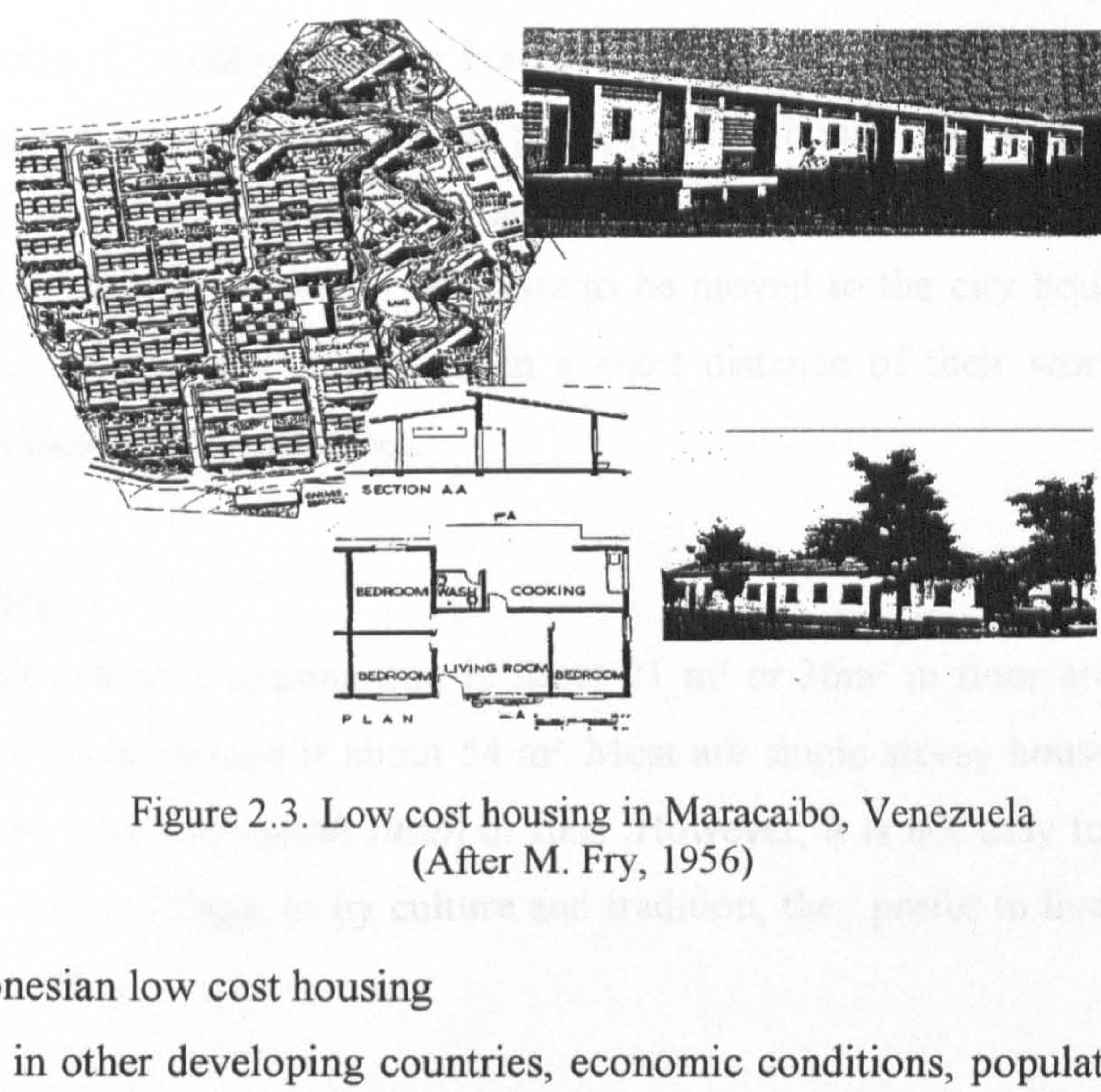


Figure 2.3. Low cost housing in Maracaibo, Venezuela
(After M. Fry, 1956)

2.2 Indonesian low cost housing

As in other developing countries, economic conditions, population and space are the basic housing problems in Indonesia. Although several programmes have been successful in solving demographic problems such as transmigration and family planning, most Indonesian cities have slum areas where many city dwellers live. Many condominiums, apartments and luxury houses are built, but these are for high-income groups who can afford to purchase them either as homes or as an investment.

Developers prefer to build luxury houses, which will give greater profits than will the low cost housing designed for the poor.

By way of improving housing conditions, the government has laid down regulations to build houses in urban areas. The ratio must be 6:3:1. Six simple low-cost houses, three middle-cost houses, to one luxury house. This approach seems sensible. However, sometimes people face a difficulty in distinguishing the specifications of low-cost housing. In Indonesia, low-cost housing is defined as houses built specifically for low-income groups (called *rumah sederhana* and *rumah sangat sederhana*). In this context, government or private developers provide houses which low or middle-income groups can purchase with fixed term credit.

2.2.1 Location

There are two possible locations for low cost housing: the city boundary or the city centre. Currently, the city boundary is the preferred area for building this type of housing, because for a similar price, it offers house with a larger area which can be utilised for garden. However, sometimes the people who have been living in slum areas in the city centre do not want to be moved to the city boundaries. They prefer to live in the city centre within a short distance of their work place, even though this means smaller houses.

2.2.2 Design

Each low cost housing unit is about 21 m^2 or 36m^2 in floor area, whilst that for middle income groups is about 54 m^2. Most are single storey houses and several are multi-storey called *rumah susun* or flats. However, it is not easy to move people to multi-storey buildings, as by culture and tradition, they prefer to live and socialise at ground level.

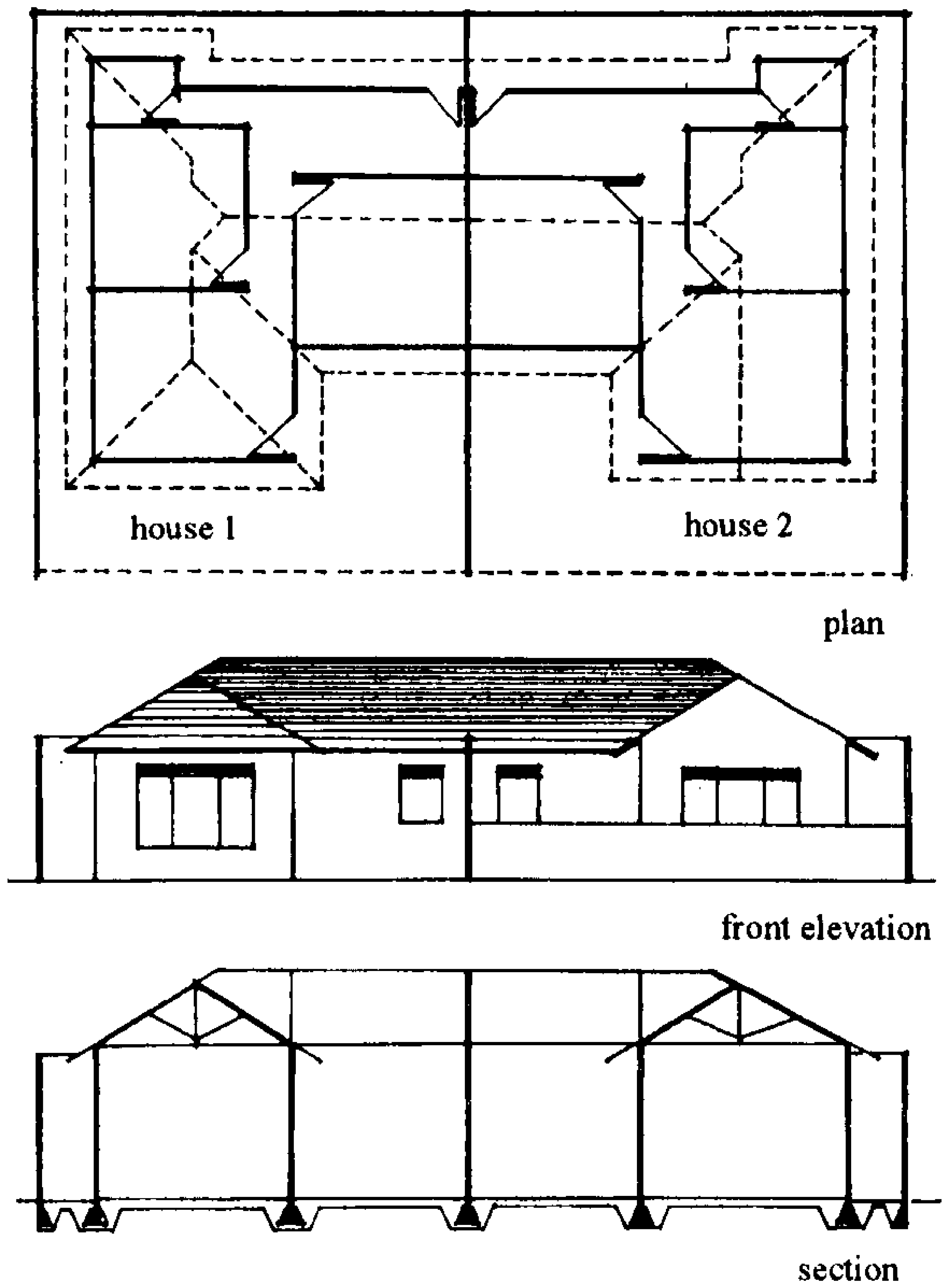


Figure 2.4. Common Indonesian low cost housing: plan, elevation, and section

A problem which sometimes occurs in low cost housing design is the design itself which maybe either too simple or too complicated for poor people to live in. For example, developers/designers do not provide enough space for clothes to dry in the sunshine or put the toilet and washing area within the house while the householders prefer to have it outside. These disadvantages can then encourage people to recreate slum conditions within their new houses.

2.2.3 Building materials

Low-cost housing materials are usually local materials which are readily found in Indonesia, such as light red brick or heavier grey brick, timber, cement, stone, sand, etc. These types of material are sufficient for building materials. However, in the process of building, the quality is sometimes reduced by unscrupulous developers.

Brick is the most common walling material in Indonesia. Many developers, because of the cheaper total cost, choose the heavier grey brick. Another material is timber or multiplex that can be used for internal partitions. Sometimes brick and timber or bamboo is mixed, for example half of the walls use brick and the rest use timber/bamboo. This then reduces the total cost of a house. However, this type of house is less resistant to environmental conditions such as rain, air and sound pollution (due to leakage of the woven bamboo). Nowadays, this type of building is less common.

Timber frames are used to create the shape of the traditional roof, which is then finished with clay tiles. The shape is usually triangular with lower angle of 30° or 35°. The use of the triangular shape and clay tiles is sufficient for natural ventilation and sound/noise reduction. Some low cost housing uses asbestos or zinc as the roof covering, with an angle of 20°or 25°. Compared to the clay tile roof, asbestos or zinc material provides less natural ventilation and lower sound insulation, particularly in the rainy season when the sound of rainfall is noisier as it beats on the surface of the roof.

Windows and doors usually have timber frames and timber panels or timber frames and glass panels. Common window styles to be used in Indonesian low cost housing are presented in Figure 2.6.

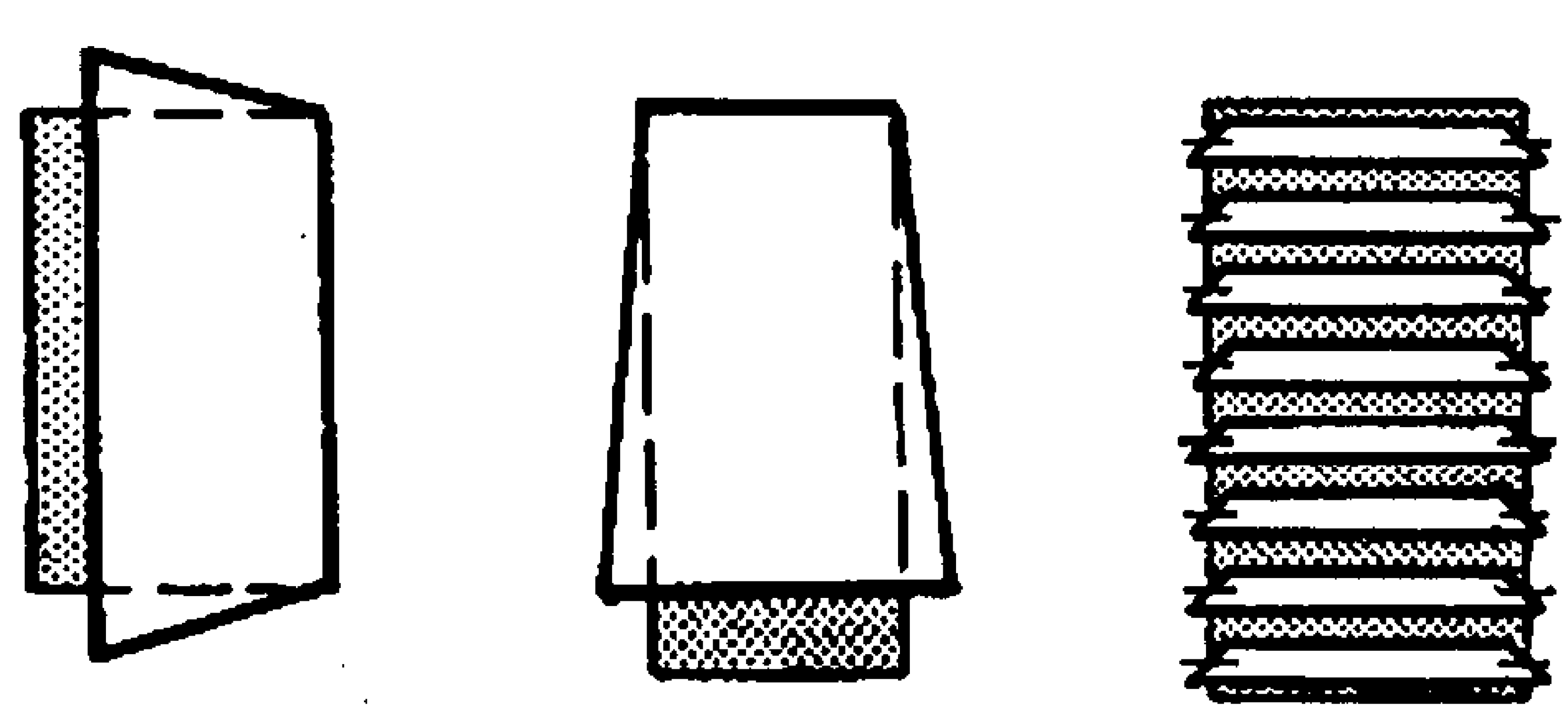


Figure 2.5. Common window styles in low cost housing

2.2.4 Infrastructure and utilities

The infrastructure and utilities provided for low-cost housing are simpler than for other types of housing. They comprise local sewage links to city sewers and above ground structure for electricity. Plumbing is provided for clean and dirty water, either from wells or main pipes.

2.3 Low cost housing in Yogyakarta

Yogyakarta area is approximately 3,185.81 km², with a population of approximately 3,185,384. The city centre area is about 420 km², with a population of about 1,115,500 [*Kantor Statistik* Yogyakarta, 1996]. Some self-built low-cost houses are located in the heart of the city. This type of housing has encountered many problems as the city has grown.

Old or new houses located in the city centre are unable to escape from the excesses of city development, such as air and noise pollution. With light low-cost material and limited space between house and street, occupants of low cost housing in the city centre encounter lack of ventilation rates and pollution intrusion from the adjacent street traffic. As was observed during field trials the indoor noise level is approximately 60 dBA (refer to Chapter 13), which is 15 dBA higher than the indoor noise standard proposed by the Indonesian government. Realising this and the limitations on space, starting in the 1980's the government determined to build new housing on the city boundaries. However, this merely solves part of a huge problem.

Since housing has begun to be located on the city boundaries, it has brought other city facilities such as schools, offices and shops with it. In other words, only moving the residential area to the city boundaries cannot prevent air and noise pollution. Over the last ten years, both air and noise pollution have risen rapidly and seem unlikely to slow down in future. For this reason, detailed planning and detailed design are very important for simple buildings like houses, especially when people spend most of their work and leisure time at home.

Indonesians very rarely consider designing and building their houses in advance to reduce pollutants, especially related to particulate reduction and acoustic design. It is commonly believed that advanced design in acoustics is important only for buildings like auditoriums, broadcasting studios, etc., but not for houses. Low wages and limited education place them in the position of passive recipients of houses designed by government or private developers from whom they are asked to purchase. Whereas one might expect houses built by government/private developers to perform better than self-built houses, there is no evidence suggested that this is the case.

Indonesian houses, especially in Yogyakarta still respect traditional values, i.e. room arrangement, roof style, etc. People prefer to live in single storey houses; hence, there are no multi-storey houses in Yogyakarta. Most houses still use natural ventilation and, if it is found that they use air conditioning, it is merely for one or two rooms, such as the bedroom or the living room, not for the whole house and it is also only found in luxury houses.

From the above description, it is clear that windows and other openings are very important for low-cost houses, both for ventilation and for access. In fact, the windows/openings, which have been designed for conventional houses, need to be improved by seeking possibilities for reducing pollutants and still permitting airflow for natural ventilation.

Figure 2.6. and 2.7. Low cost housing in Yogyakarta

Figure 2.7 and 2.8 shows typical low cost housing in Yogyakarta that usually have floor areas of approximately 21 m² or 36 m². These are the two types of house which are the main concern of this study. Later in this thesis, these types of house are simplified to house types A (21 m²) and B (36 m²).

2.4 Road traffic and buildings

2.4.1 Road traffic

Transportation has existed since the earliest human society, from the simplest means (feet) to the most sophisticated (motorised vehicles). As populations have grown, as well as their needs, transportation has become an important factor in everyday life. This can easily be seen in busy Indonesian metropolitan cities, where most of the people live in suburbs and work within the city centre. Every morning and afternoon the streets swarm with humanity: people are moving either in private vehicles or by public transport. Road traffic then becomes the essence and heart of city living. The high densities of traffic combined with indisciplined driving usually causes traffic jams.

An understanding of traffic flow characteristics and factors affecting their variation is useful to evaluate the performance of the traffic for planning, evaluation and other purposes. Traffic flow characteristics comprise volume, composition of traffic (type of vehicles), time, classification of the street, type of service (commuter travel, recreational and other seasonal travel, etc.), and type of geometric design (control of access, separation of opposing traffic, number of lane, intersecting areas, etc.)[Baerwald, 1965].

2.4.2 Road traffic and buildings

Since streets give access to buildings, it is difficult to separate the two. Even when located in a very remote area, a street is always an access to a building. Streets will not create environmental problems for the inhabitants as long as they comply with governmental standards. But this seems practicable only in rural areas. In a crowded city, buildings will always be close to streets with all their attendant problems. Urban traffic pollution is the major concern of those who live and work in this environment.

2.4.3 Indonesian road traffic

Traffic jams occur in the centres of Indonesia's major cities, particularly during working hours. Sooner or later, this problem will be experienced by other growing cities, as most cities have grown chaotically with poor street conditions, such as:

1. Street length and width being insufficient for the rapidly increasing number of vehicles (high density);
2. Poor street surface conditions, hence slow-moving vehicles;
3. Poor vehicle conditions, hence slow-moving vehicles and obstruction of other vehicles from moving;
4. Indisciplined driving;

These poor conditions bring many disadvantages for buildings adjacent to the street, especially if the buildings are used for offices or houses. In Indonesian cities, there are still many houses located close to busy street traffic. This can be understood when the space is very limited and there is not enough space to build more streets to accommodate the increasing number of vehicles and not even enough to create any distance between street and housing.

Type of vehicles	Traffic Characteristics in Main Streets	Traffic Characteristics in Residential Streets for short-cut
Buses/Trucks	13% middle speed (30-40 km/h) diesel emissions	0%
Private Cars	32% high speed (40-50 km/h) both gasoline and diesel emissions	40% high speed (30-40 km/h) both gasoline and diesel emissions
Motorcycles	41% high speed (50-70 km/h) gasoline emissions	44%, high speed (50-60 km/h) gasoline emissions
Bikes and other traditional vehicles	14% very low speed no emissions	16% very low speed no emissions

Table 2.2. Examples of type of vehicles and traffic characteristics in Yogyakarta representing other Indonesian middle cities
(Source: *DLLAJ*, Yogyakarta, 1993)

2.5 Air pollution

2.5.1 Air pollution

The most obvious pollution resulting from the use of mechanical vehicles is air pollution. Sometimes it is difficult to determine whether or not air is contaminated. The addition of any substance will alter to some degree the physical and chemical properties of clean air. Such a substance could thus be considered an air pollutant. It means that if there is addition of any substances to the pure composition of clean dry air (Table 2.3), air pollution will occur to some degree [Stoker, 1972]. However, pollutants are usually classified as only those substances which are added in amounts sufficient to cause a measurable effect on humans, animals, vegetation, or even materials. Such substances may occur as gases, liquid droplets, solid particles, or as mixtures of these forms [Stoker, 1972].

Components	Concentration (volume %)
Major: Nitrogen (N_2) Oxygen (O_2) Argon (Ar) Carbon dioxide (CO_2)	 78.09 % 20.95 % 0.93 % 0.032 %
Minor : Neon, Helium, Methane, Krypton, Hydrogen, Nitrous oxide, Carbon monoxide, Xenon, Ozone, Ammonia, Nitrogen dioxide, Nitric oxide, Sulphur dioxide, Hydrogen sulphate	± 0.002 %

Table 2.3. Composition of clean dry air (After HS. Stoker, 1972)

There are five major substances that can cause air pollution:

- carbon monoxide (CO)
- nitrogen oxides(NO_x)
- hydrocarbons (HC)
- sulphur oxides (SO_x)
- particulates

To see how these major pollutant types cause air pollution, it is useful to find which source sends the largest amount of pollutants into the air. Data compiled from the USA Environmental Protection Agency, the USA commission for air quality issues, gives the major sources of air pollution in Table 2.4.

Pollutant Source	Percentage as the total weight of pollutant produced per year					
	CO	NO_x	HC	SO_x	Particulate	Total
Transportation	42.00%	4.40%	8.00%	0.37%	0.26%	55.00%
Fuel combustion (stationary sources)	0.30%	3.80%	0.23%	10.00%	2.50%	16.80%
Industrial processes	4.30%	0.07%	2.00%	2.20%	4.90%	13.50%
Solid waste disposal	2.70%	0.15%	0.07%	0.11%	1.30%	4.30%
Miscellaneous	6.20%	0.15%	2.60%	0.10%	1.30%	10.40%
Total weight of each pollutant	55.50%	8.60%	12.90%	12.80%	10.20%	**100.00%**

Table 2.4. Pollutant source in USA (Source: EPA, 1973, 1982, 1986)

From Table 2.4, it can be seen that transportation generates approximately 50% source of pollution in the USA. The highest percentage of pollutant type from the entire pollution source is CO, followed by Hydrocarbon (HC), SO_x and particulate matter. In other countries, where the degree of industrialisation and fuel combustion differs from the USA, transportation is still likely to be the major source of pollution, since transportation has become so essential in most advanced and developing countries.

2.5.2 Particulate Matter

It is obvious from Table 2.4 that pollutants mostly come in gaseous form. However, it should not be assumed that gas pollutants are the only pollutants to be considered. Small, solid particles and liquid droplets, collectively called particulates, are also present in the air in great numbers, and at times they constitute serious pollution problems. Pollution effects caused by particulate matter range from nuisance when deposited on surfaces to respiratory illnesses. Deposited ambient particles are usually generated by coarse particles commonly called dust. More fine particulate matter, particularly with a diameter of less than 10 μm can penetrate down into respiratory system to cause chronic illnesses. Currently, people are more concerned with fine particulate matter due to its severe health effects. However, this does not mean that coarse particles should be disregarded. Dust and odour are two main causes of complaint about air pollution [Vallack and De Shillito, 1998]. Unfortunately, there are no international standards or guidelines for deposited dust, whilst there are standards of total suspended particulate matter or more specifically standards for fine particles which allow analysis of their ambient conditions more readily whether or not they satisfy the standards [Vallack and De Shillito, 1998].

Based on the composition, particulate matter is divided into:

- mist: composed of suspended liquid droplets
- smoke: composed of fine soot particles produced by combustion
- fumes: condensed vapours of both metallic and organic substances
- dusts: resulting from the mechanical break-up of solid matter

2.5.3 Indonesian particulate matter and the standards

As described in Chapter 1, in 1997, the United Nation Environment Program (UNEP) determined Jakarta as the third most polluted city in the world after Mexico City and Bangkok [Kompas, November1997]. This indicated that pollution in Indonesian cities has already become a serious problem among other serious problems experienced by Indonesia in the last few years. The level of pollution in two Indonesian cities as presented in Chapter 1, which are copied in the following tables, give more detail descriptions regarding particulate matter concentrations in those cities.

1. Jakarta [Kusmaningrum, 1997/1998]:

Pollutants	Locations of measurements	Facts	Indonesian Standards
NOx	Adjacent to traffic within the city centre	40% was ≥ 0.15 ppm 37% was 0.15 ppm> n ≥0.10 ppm 23% was < 0.10 ppm	0.05 ppm
NOx	In residential areas within the city centre	10 % was > 0.05 ppm 90% was < 0.05 ppm	0.05 ppm
Total Suspended Particulate	In residential areas within the city centre	Vary: 2.5% to 45.5% of the measurements were above 260 μg/m³	260 μg/m³

Table 2.5. Concentrations of particulate pollutants in Jakarta, Indonesia (Source: Kusmaningrum, 1997/1998)

2. Bandung [Kompas, 14 May1997]:

Pollutants	Indonesian Standards	Concentration measured adjacent to traffic within the city centre of Bandung
NOx	0.05 ppm	0.10 ppm
Hydrocarbon	0.24 ppm	1.0 to 4.0 ppm
Particulate matter	260μg/m³	400 μg/m³

Table 2.6. Concentrations of particulate pollutants in Bandung, Indonesia (Source: Kompas, 14 May 1997)

The above tables show that the level of particulate matter pollution in two major Indonesian cities is high and exceeds the Indonesian standard of particulate matter concentrations. These are probably higher compared to particulate matter concentration in growing cities. Unfortunately, data of particulate matter concentrations in other cities is not available. However, it is postulated that without serious attempts to reduce it, soon the concentration of particulate matter in other large or growing cities will increase to levels experienced in Jakarta and Bandung, particularly if poorly maintained vehicles and diesel vehicles remain in common use.

2.6 Sound pollution

2.6.4 Sound pollution

Another effect of using motorised vehicles is sound pollution. As mentioned above, most people do not perceive sound pollution as dangerous, especially people in developing countries with limited knowledge. Most people regard this sound pollution as at most a source of annoyance during their working/studying and leisure time. However, this pollution should be regarded as highly detrimental to human health in the long term.

There are of course standards for noise pollution, especially for those who live close to noisy areas, such as industrial areas, train stations, airports, highways, etc. The standards may vary from one country to another, as can be seen in Table 2.7 (measured within the buildings).

FUNCTIONS	France (L_{50})	Japan (L_{50})	USA (L_{10})	USA ($L_{eq,24}$)
laboratories, hospitals	-	-	55 dB(A)	-
residences, schools	40-45 dB(A)	40-55 dB(A)	55 dB(A)	45 dB(A)
offices, commercial buildings	45-50 dB(A)	60 dB(A)	55 dB(A)	-

Table 2.7. Noise standard in selected countries (Source: Chunnif, 1977 and Watkins, 1981)

2.6.5 Indonesian noise conditions and the Indonesian standards

The main source of noise in cities is road traffic. No other single noise is of comparable importance [White, 1982]. Such a finding is not surprising, as the number of automotive vehicles in comparison with other machines is huge. The vehicles used in Indonesia are extremely varied, from the simplest and most traditional such as bicycles to diesel trucks and buses. In most Indonesian cities (excluding Jakarta) the use of two-stroke motorcycles is much common than cars. So, although the noise from heavy vehicles is less, high noise levels come from motorcycles. Some motorcycle companies design mufflers which create a very high noise level, and unfortunately, these are very much in use, especially amongst Indonesian teenagers. Thus, it is not surprising that the noise level is much higher compared to that in many developed countries. In 1987 the Indonesian government attempted to improve this situation by determining guidelines as follows:

1. Statements of Chairman of Diminishing Disease and Healthy Housing Environmental Programs no 70 I/PP.03.04.LP, which describes the affect of noise on human comfort and feasible attempts to eliminate noise.
3. Regulation of Minister of Health of Indonesia no 718/Menkes/Per/XI/ 1987, which also describes the affect of noise on human comfort and feasible attempts to eliminate noise
4. Proposal of Minister of Environment of Indonesia describing noise standards (as can be seen in Table 2.8), vibration standards, radiation standards, and odour standards. Maximum noise (dBA) suggested for specific areas are :

ZONE	FUNCTION	Suggested indoor noise levels	Maximum to be permitted
A	laboratories, hospitals	35	45
B	residences, schools	45	55
C	offices, dept. stores	50	60
D	industries, railways/bus stations	60	70

Table 2.8. Noise zoning in Indonesia (Source: Indonesian Noise Regulation, 1987)

In reality, the above standards are difficult to achieve. Indonesians regard noise only as nuisance and accept the noise conditions as parts of their everyday life. Most of them have not yet aware of noise as factors that could impair their health. Therefore, the increase of noise and air pollution is difficult to prevent, as many Indonesians seem not to care about noise problems or are not inclined to comply with the standard. To give a general idea of the Indonesian noise levels, whilst the detail noise levels in the reference city (Yogyakarta) will be presented later in Chapter 5, data on noise levels taken in some Indonesian cities in 1994 is presented below (Table 2.9). The measurements were carried out by The Physic Engineering Team of the Bandung Institute of Technology, Indonesia. From this data, it can be seen that the average noise levels in these cities were high. In these noise conditions, to comply with the standard, the building envelopes should at least provide noise attenuation of approximately 15 dBA to 25 dBA, which is difficult to achieve with lightweight materials and the many openings commonly found in Indonesian housing.

Zone	Functions	Suggested indoor noise levels	Maximum to be permitted	Average of field measurements in some cities (adjacent outside the buildings)
A	laboratories, hospitals	35 dB (A)	45 dB (A)	60-70 dBA
B	residences, schools	45 dB (A)	55 dB (A)	60-70 dBA
C	offices, dept. stores	50 dB (A)	60 dB (A)	65-75 dBA
D	industries, railways/bus stations	60 dB (A)	70 dB (A)	80 dBA - more

Table 2.9. Noise zoning in Indonesia and the real field conditions
(Source: Physic Engineering Team of Bandung Institute of Technology, Indonesia, 1994)

From the above facts, it can be seen that the task of designers is made greater as long as actions for reducing noise at source are not taken. If the source of noise is not reduced, the only practicable alternative is to protect the occupants of building. In the Indonesian low cost housing case, it is then important for designers to find design solutions for building envelopes which offer noise attenuation of approximately 15 dBA to 25 dBA by using local and low cost materials.

2.7 Conclusion

The data presented in this Chapter shows that the pollution levels of particulate matter and noise in major Indonesian cities exceed the standards, and sooner or later, will impair human health. The data of these types of pollutant within growing cities is not currently available, but are presumably lower than those in the major cities. However, attempts to reduce these types of pollutant within growing cities are important, since pollution levels here will increase to levels experienced in major cities, especially when the newest EPA (Environment Protection Agency, USA) standard for particulate matter of 150 $\mu g/m^3/24$ hours (earlier standard was 260 $\mu g/m^3/24$ hours) is used.

CHAPTER 3

THE UNCOMFORTABLE CLIMATE

We must begin by taking note of countries and climates in which homes are to be built if our design for them is to be correct. One type of house seems appropriate for Egypt, another for Spain... One still different for Rome.... it is obvious that design for homes ought to conform to diversities of climate. (Vitruvius [cited in Lechner, 1991])

Climate is one of the most significant factors to be considered in designing buildings, besides activities and cultures. Thus, buildings always have their own styles, which depend - in part- on the place where they are built. For example buildings in tropical countries have a different style from buildings in moderate climates, especially if they use natural conditions to maintain comfort [Lechner, 1991].

3.1 The climate of Indonesia

Indonesia is a tropical country which lies between latitudes 6°N and 11°S. This position creates a hot climate throughout the year. As an archipelago, rainfall is quite high, so that humidity levels are also higher compared to surrounding continental countries. Hence, Indonesia has a hot-humid climate. Below are the details of Indonesia's climate.

3.1.1 Monsoon

Indonesia has two seasons during the year. They are the dry season that usually occurs between June and September, and the rainy season of December to March. In the dry season, the wind blows from Australia, containing little water, and thus creates the dry season. In the rainy season, the wind blows from Asia and the Pacific Ocean and contains a considerable amount of water. These two seasons change every half-year after passing through transitional seasons in April-May and October-November.

3.1.2 Temperature and humidity

In general, the annual temperature lies between 18°C-31°C. Some places have more extreme temperatures, like Semarang which in June can be as low as 16°C and Palu which reaches 35°C in November. At low altitudes (seashore) temperatures are around 28°C and at high altitudes (plateau) temperatures are around 23°C. The daily temperature range is greater than the annual temperature range. Relative humidity is high, varying from 60% to 90%. In the hottest monsoon, the weather is hot and humid (almost wet) and in the coolest monsoon the weather is still hot and humid. High humidity means little evaporation. When high temperature and high humidity occur at the same time, the process of natural cooling by perspiration is decreased [McMullan, 1992], hence the skin becomes sticky and uncomfortable.

3.1.3 Rainfall and wind

The winds from Asia bring the rainy season in Indonesia but, as a country of islands, rain can happen at any time outside the rainy season (although it is quite rare), so that Indonesia has quite a high annual rainfall of over 2500 mm. The daily average (with regional variation) is about 25mm to 30mm in the rainy season and 0.35mm to 11mm in the dry season. Wind velocity during the rainy season is usually slightly higher.

3.1.4 The weather of Yogyakarta

Although, in general, the weather in Yogyakarta (altitude 114m/342 feet) is typical of the region, it is important to explore the weather of Yogyakarta to provide data for considering the design requirements. Table 3.1 shows weather data from the most recent year available, 1994/1995. This data represents the general conditions because there have been no significant variation in recent years, as can be seen from the data collected by the Bureau of Meteorological and Geophysics in the last 20 years [*Dinas Navigasi Udara*, Adicucipto, Yogyakarta, 1995]. Data presented in Table 3.1 is the average of daily conditions during each month measured at altitude of 350ft (116.7m) in a built environmental condition. Average maximum and minimum daily temperatures are given.

MONTHS / SPECIFICATIONS	OCT 94	NOV 94	DEC 94	JAN 95	FEB 95	MAR 95	APR 95	MAY 95	JUN 95	JUL 95	AUG 95	SEP 95	Ave-rage
Temperature °C (Daily average) max	33.0	33.9	30.7	30.7	30.7	30.8	31.9	32.3	31.6	31.0	30.3	32.5	31.6
min	23.6	24.7	24.1	23.7	23.4	24.1	24.2	24.4	23.9	22.9	22.0	23.1	23.7
Humidity %	77	79	85	88	88	87	84	83	86	83	80	78	83.2
Wind m/s Average	2	1.5	1.5	1	1.5	1.5	1.5	1	1.5	1.5	1.5	1.5	1.5
Most of angle	210	120	210	210	210	210	210	120	120	120	180	180	-
Rainfall mm	1.1	3.2	9.0	19.7	21.8	10.6	7.7	0.9	5.2	0.7	0	0.005	-

Table 3.1. The weather of Yogyakarta in 1994/1995
(Source: *Dinas Navigasi Udara*, Adicucipto, Yogyakarta, 1995)

3.2 Climate, health and human comfort

The thermal comfort of human beings is affected by many physiological mechanism of the body and may vary from person to person. Factors affecting thermal comfort are differentiated in two aspects [McMullan, 1992]:

- Personal variables which consist of activity, clothing, age and sex.
- Physical variables which consist of air temperature, surface temperatures, air movement and humidity.

The human body maintains an energy balance with its environment to maintain the normal body temperature of 37°C. This process needs a relatively narrow range of climatic conditions. (i.e. temperature, humidity, wind speed, etc.) which is called the comfort zone. The comfort zone may differ from one region to another, as this is determined by climatic factors, activities, and clothing. Different activities need different environmental conditions to maintain comfortable levels. Therefore, detailed studies of climatic factors are important in order to create the preferred conditions for a particular activity, whether by natural or artificial means.

3.2.1 General factors

Several factors which relate air quality to health and human comfort are temperature, materials/particles content (toxic gases, dust, etc.), velocity, and direction. All of these factors have their own limits for maintaining health and providing human comfort.

3.2.1.1 Air temperature

When people discuss temperature, they usually mean the air temperature which surrounds them (ambient temperature). Life can exist only within a relatively small range of temperatures. Each species has definitive limits and thrives only within this narrow range. Many species have ways of extending their range in association with deep body temperature. Most mammals and especially humans, maintain constant deep body temperature- a process known as homeostasis. To do this, it is necessary to exactly balance the total heat exchange of the body so that the amount lost to the ambient environment equals the amount gained. Man has a normal deep body temperature of about 37°C [Egan, 1975]. Figure 3.1 shows examples of a deep body temperature caused by extended periods of overheating or overcooling from a wide range of environmental conditions.

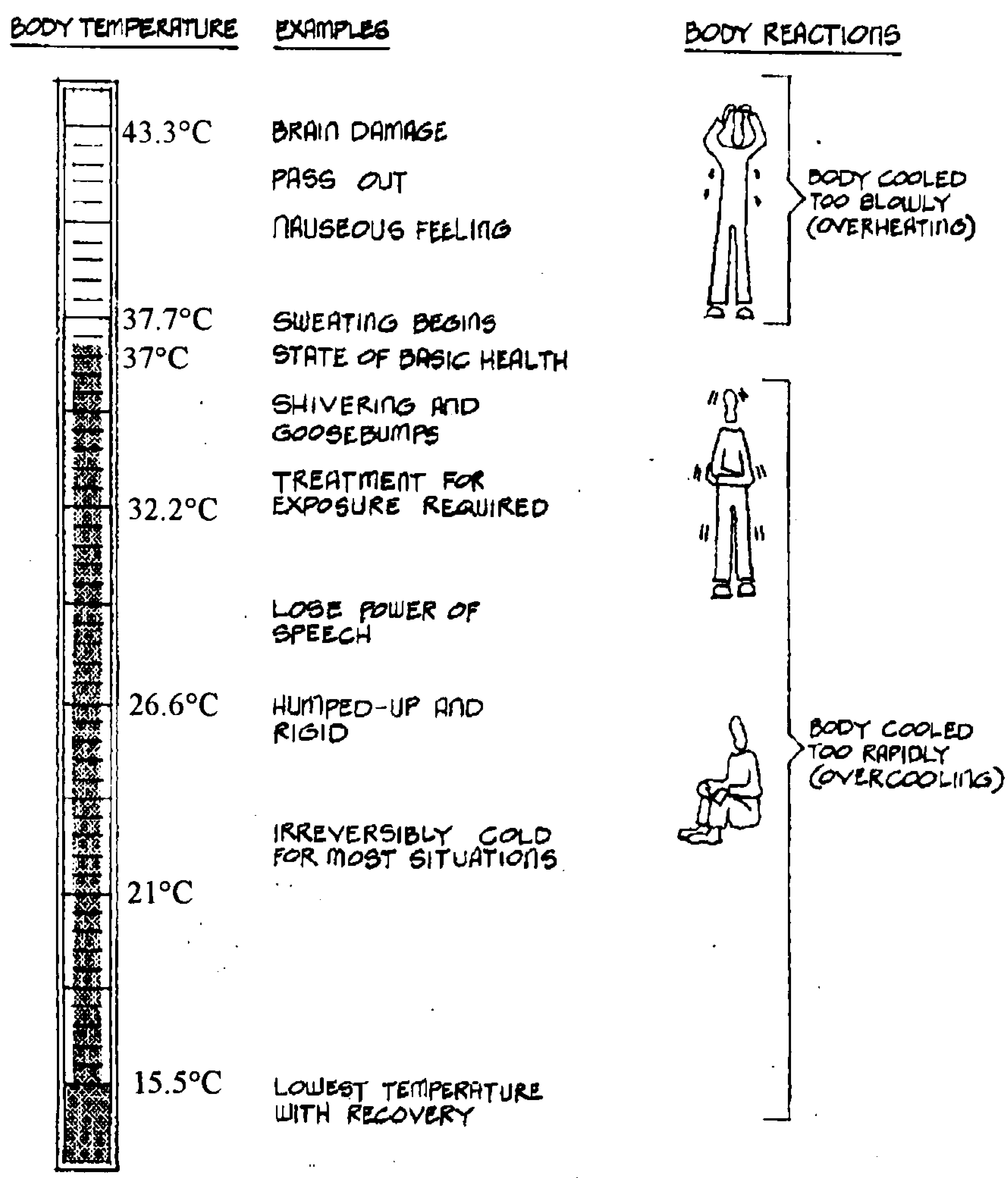


Figure 3.1. Human body temperature
(After Egan, 1975)

3.2.1.2 Materials and particles content

The material content of the air, usually termed air quality, is the composition of the air itself. The natural content of air is a mixture of O_2, N_2, H_2O, with the addition of pollutants such as CO, NO_x, and particles (dust, ash, etc.). As a standard, humans need O_2 for respiration. Fresh air contains about 21% O_2 and 0.04% CO_2 while expired air contains about 16% O_2 and 4% CO_2. The added pollutants affect health if their levels are higher than those specified by the standard, and reduce human comfort when they produce odour. Another component of air, which affects human comfort, is H_2O (i.e. the moisture content in the air). People commonly associate relative humidity with human comfort. Relative humidity is the amount of moisture in the air compared to the maximum amount that can exist at a given temperature without condensation. There is no particular relative humidity that will induce human comfort not also associated with air temperature. This means that for a particular temperature, there is also a particular level of humidity needed to maintain human comfort. However, in association with temperature, humidity only affects bodily heat loss by evaporation. This will be most important at higher air and surface temperatures where radiation and convection heat loss are less effective.

3.2.1.3 Air/wind velocity and air/wind direction

The movement of air contributes to thermal comfort by removing the moisture and heat surrounding the body. Air movement affects heat loss by convection and evaporation. Convection heat loss increases with air movement because the warmer air adjacent to the skin is more rapidly displaced by cooler air than would normally occur in still air conditions. Then, evaporation rate (and thus skin cooling) increases with air motion as saturated air near the skin is displaced by dryer ambient air [F. Moore, 1993].

Because heat loss by convection and evaporation are the most important factors associated with environmental comfort, so air movement is an important factor in inducing heat loss. However the efficacy of air in cooling is effected by air velocity and air temperature and direction. The right direction of wind in relation to available openings in a building can supply sufficient air changes. However, although speed is sufficient for the theoretical cooling for a person in a building, if the wind blows against the walls where there are no openings provided, indoor comfort is unlikely to be achieved.

3.2.2 Human reactions to the (surrounding) environment

Because deep body temperature must be maintained at a constant level, the heat generated by metabolism and activities must be released to the surrounding environment through the skin surface and by respiration. As mentioned above, this is done by a combination of convection, radiation, conduction and evaporation.

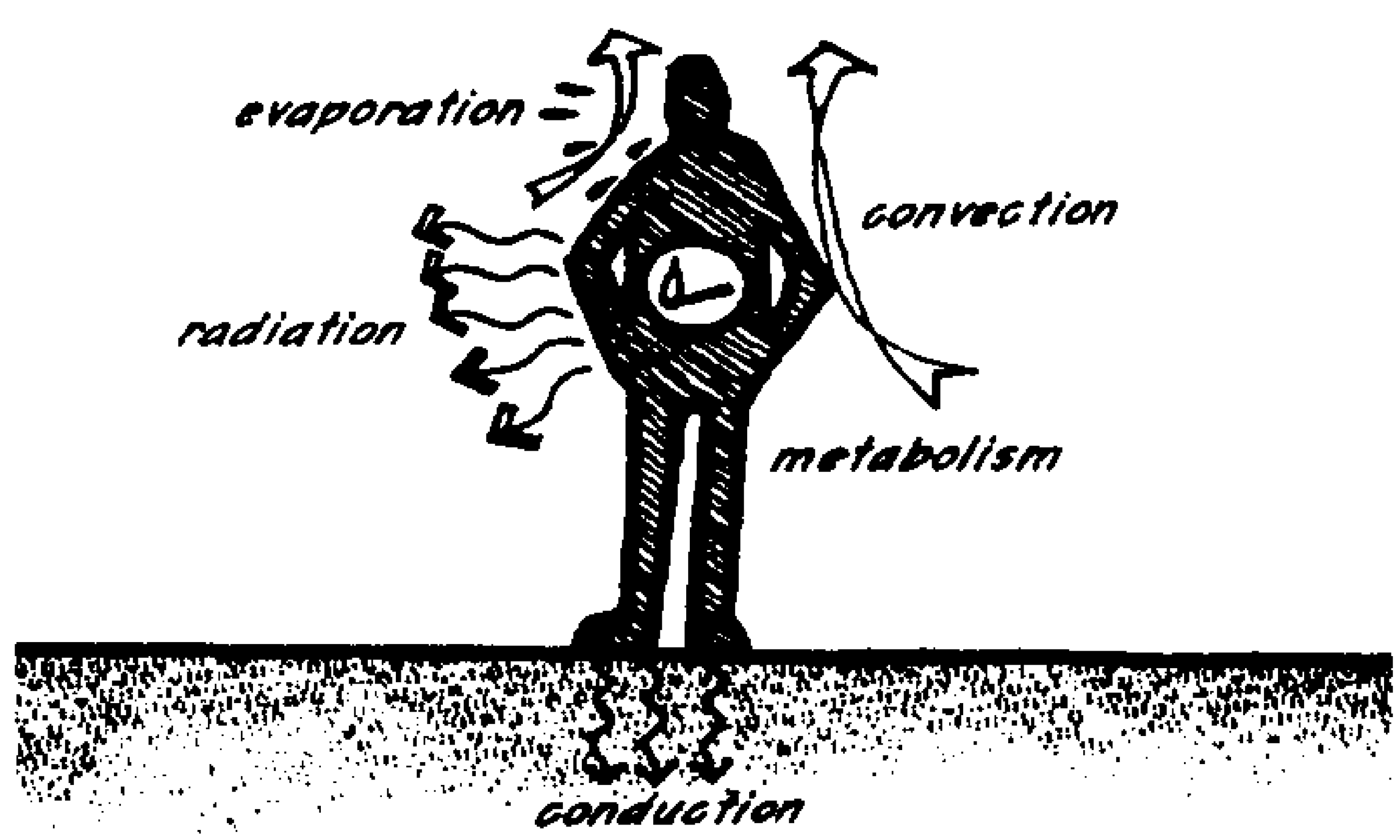


Figure 3.2. Four ways of heat loss
(After F.Moore, 1993)

The heat exchange process is affected by four environmental conditions: air temperature, humidity, airflow/air velocity and the temperature of surrounding surfaces. The interaction of these conditions is complex and is beyond the scope of this study. In high temperature (above skin temperature) and high surface temperature conditions, heat loss by convection and radiation are minimised. In such circumstances, heat loss is by evaporation becomes more important. In a condition where the humidity is also high, evaporative heat loss will be minimised, resulting in an increase of body temperature [Sanders and McCormick, 1987]. The various processes of heat loss were studied in an experiment carried out by Winslow as shown by Figure 3.3.

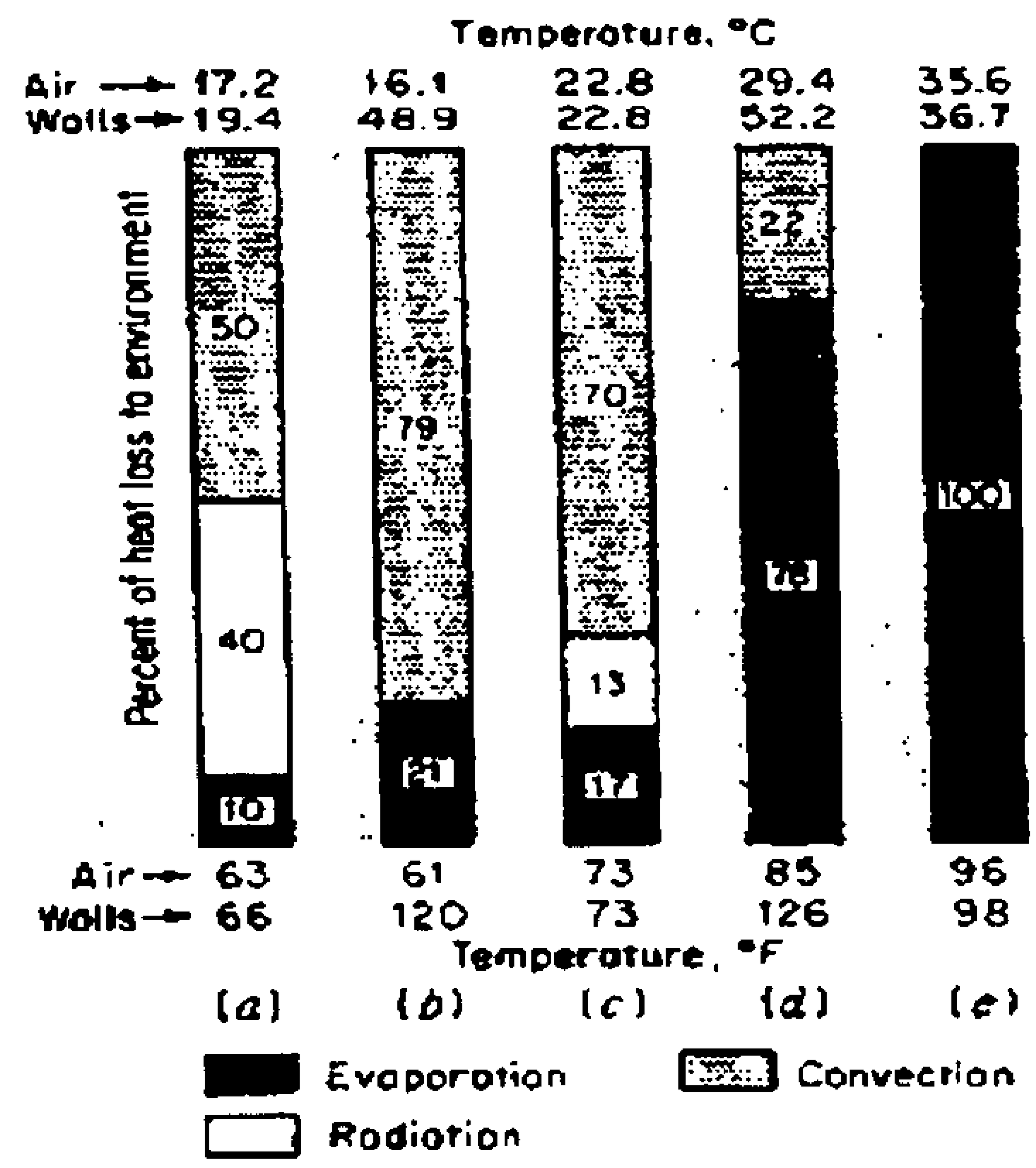


Figure 3.3. Heat body loss by three factors
(After C.E.A. Winslow, 1949, cited in Sanders and McCormick, 1987)

The last two bars of Figure 3.3 represent heat body loss in Indonesia due to high temperature and humidity.

Each air condition supports bodily heat transfer differently. Temperature differences and air movements induce convection heat transfer. Mean radiant temperatures (MRT) of surrounding surfaces induce radiation heat transfer, while temperature, humidity and air movement induce evaporation heat transfer. Conduction heat transfer is induced by surface contact and, because in architectural environments, where people typically sit on chairs or thick carpets, the area of contact with hot or cold surfaces is limited, it will be ignored.

3.2.3 Air related to indoor comfort and factors inducing indoor comfort

People living in buildings need a supply of air for respiration. Adequate ventilation is therefore essential for well-being and health. This means that ventilation is one of the most important factors for buildings. Ventilation fulfils a number of different functions [CIBSE Guide, 1986]:

- Health: respiration, odour avoidance and pollutant removal;
- Cooling: removal of heat produced by internal and solar gains, during both day and night;
- Comfort: provision of air movement to increase actual body cooling.

For the cooling requirement the ventilation rates to be supplied depends on the level of heat gains and is typically between 5 to 30 air changes per hour. For warm humid countries, it is recommended that 30 air changes per hour is the minimum [F. Moore, 1993].

Generally, ventilation is the replacement of internal air with outside air and air movement is the movement of air as sensed by the occupants. In what follows, the feelings of the occupants of buildings will be considered in terms of designing comfort ventilation. Personal feelings of warmth depend on air temperature, radiant temperature, air movement, humidity and personal factors (clothing, activities) [Fanger, 1973 and McMullan, 1992]. To provide comfort ventilation, there are two methods: natural and artificial. Basic considerations in choosing between natural and artificial (mechanical ventilation, air conditioning, etc.) are [CIBSE Guide, 1986]:

- the quantity of air required;
- the quality of air required;
- consistency of control required;
- isolation required from external environment;
- cost.

Mechanical ventilation will be chosen in the following circumstances:

- when the quantity and velocity for natural ventilation are below the requirements;
- when the quality of air for natural ventilation is below the requirements;
- when the consistency of the quantity, quality and velocity cannot be controlled;
- when the external environment encourages the use of a sealed system (noise, dust, etc.).

Sometimes it happens that mechanical ventilation is required but that the occupants are unable to afford it, as is in low cost Indonesian housing. This means that the cost factor also needs to be taken into consideration. In such circumstances when the quality (i.e. temperature, humidity, windspeed) and the quantity (adequate ventilation rates as specified for specific function, e.g. offices, housing, hospitals, etc.) of air are as desired, the use of mechanical ventilation can be avoided as this will lower the operational cost.

As mentioned earlier, to provide human comfort, there are several factors which are always dependent on one another. Comfort within buildings depends on factors which cannot be separated from each other. The most important factors are air temperature, mean radiant temperature (MRT), humidity, and air velocity [Egan 1975]. The relationship among these factors was graphed in Figure 3.4 showing the comfort zone which is acclimatised for warm climates (men at sedentary work wearing light clothing)

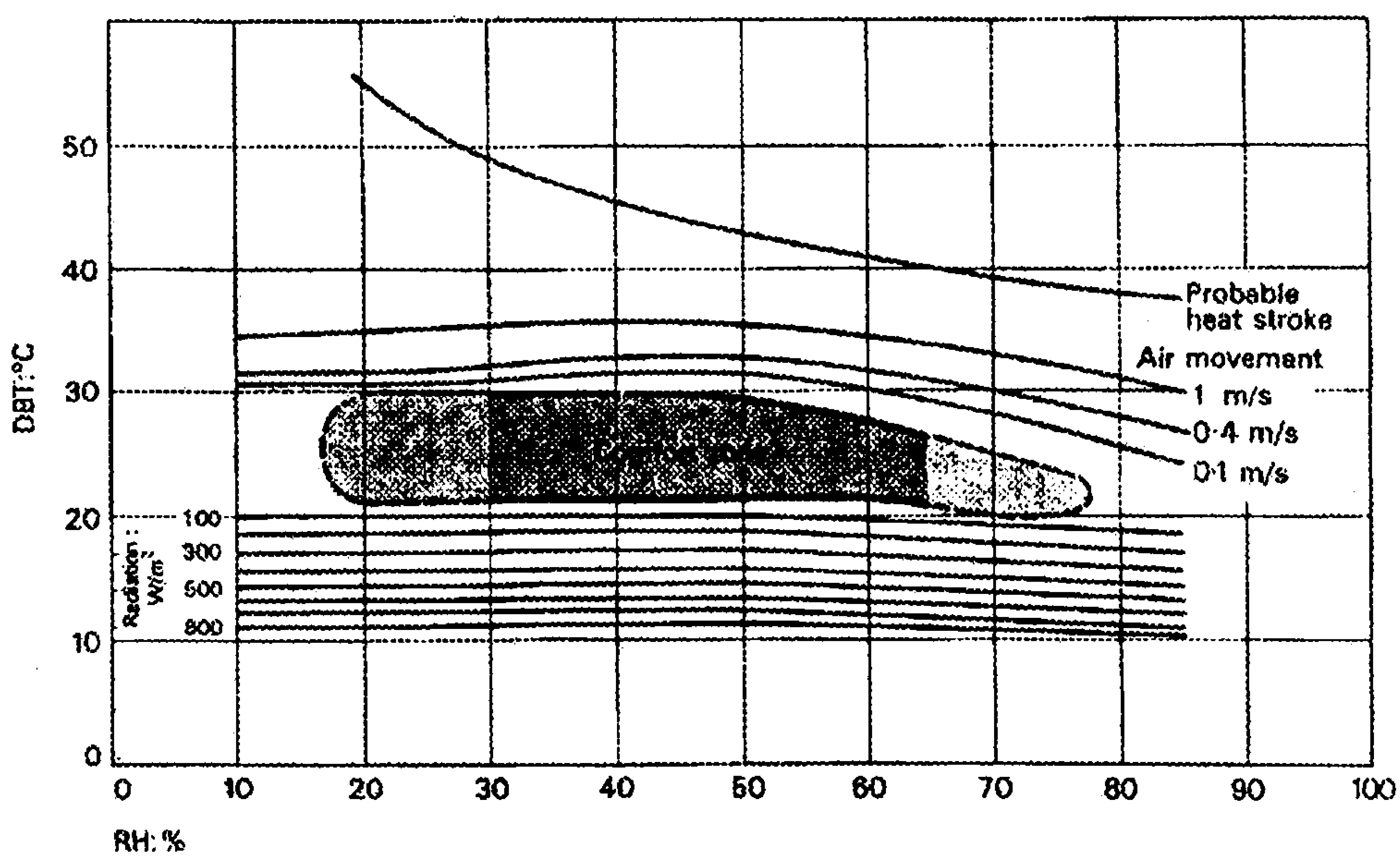


Figure 3.4. Comfort zone for warm climates
(After Olgyay, cited in O.H. Koenigsberger, et al, 1973)

Figure 3.4 shows that the comfort zone acclimatised for warm climates is as follows:

- With 30% relative humidity, the comfort temperatures lie between 20°C to 30°C
- With 65% relative humidity, the comfort temperatures lie between 20°C to 25°C

More interesting is that, according to this Figure, the comfort range can be extended by increasing air movement when dry bulb temperature (DBT) increases and by increasing radiation when DBT decreases.

The assumption that outdoor air is clean is not always true. For this reason, many modern buildings use air conditioning as a comfort supplier. Unfortunately, the assumption that using air conditioning means providing cleaner air is also not always true. Research carried out by the Ventilation Group of Building Research Establishment (BRE), UK showed that air quality with air conditioning is no better than natural ventilation in heavily polluted areas [Kukadia, 1997]. This study was carried out by comparing a building which uses natural ventilation to one with air conditioning. The study showed that by installing inlet windows away from the polluted areas, the concentration of NO_2 could be reduced. On the other hand, it was found that there was an increased concentration of NO_2 within the buildings in polluted areas where air conditioning was used. It was suggested that the increase could be caused by the air conditioning 's inlet positions.

Thus, with environmental issues in mind, designers are increasingly considering natural ventilation as the primary design option. Minimising or avoiding the use of air conditioning reduces primary energy consumption and consequent CO_2 emissions whilst avoiding refrigerant emissions from refrigeration plant. Natural ventilation also offers the potential bonus of avoiding the perceived health risks associated with air-conditioned buildings.

3.2.4 Natural ventilation for human comfort

Natural ventilation is the airflow resulting from specific building apertures such as openable windows, ventilators, shafts, etc., and is usually controlled by the occupants. Infiltration on the other hand is unintentional and cannot be controlled. The rate of airflow through a building depends upon the areas and resistance of various apertures, the pressure difference across the building, and the internal/external temperature differences. In principle, air flow through buildings and the ventilation rate of individual spaces within buildings can be determined for a given set of weather conditions (i.e. wind speeds, wind directions, and external temperatures) if the following are known:

- the positions and characteristics of all openings through which flow can occur;
- the detailed distribution of mean pressure coefficients for the wind direction under consideration;

- the internal and external air temperatures.

The standard for using natural ventilation in tropical countries to achieve comfort levels, as a more detailed guideline than shown before by Figure 3.4, is shown by Table 3.3.

Region	Season	Category	Resultant Temperature (C°)	RH (%)
tropics	summer	transient (humid climate)	25 26	70 50

Table 3.3. Standards for using natural ventilation in tropical climates (Source: CIBSE Guide, 1986)

Key:

Resultant temperature is a combination of air temperature, radiant temperature (i.e. the average effect of radiation from surrounding surfaces) and air movement.

Apart from what have been mentioned that there are standard of thermal comfort related to climatic factors (i.e. temperature, humidity and windspeed), there is an adaptive approach to thermal comfort introduced by Humphreys [Humphreys, 1995]. Humphreys showed that people use numerous strategies to achieve thermal comfort. When there are adequate possibilities for selection and adjustment, people will make themselves comfortable. In this case, discomfort then is caused by excessive constraints on the process of choice and adjustment, rather than by temperature or humidity themselves, except in such extreme conditions. This is the case of low-income families in Indonesia who have limited selection to improve their conditions as they wish caused by their low affordability.

From the above study, it can be seen that thermal comfort is not primarily as a matter of the physiology of heat regulation and the science of clothing, but rather as wide-ranging and intelligent behavioural response to climate. This means that thermal comfort can also be flexible rather than fixed as is determined in the thermal standard, and may be more conveniently specified by climate and culture [Humphreys, 1995].

3.3 The Indonesian guidelines related to air quality

The Indonesian government has determined several guidelines regarding air quality. The guidelines are as follows:

1. Quality of air to supply human needs should be 100% pure (no toxic/poison contained, no odour, no colour)
2. For single houses, the minimum pure air volume to be supplied to each room is as shown in Table 3.4:

Room types	Pure air standards	Air changes per hour	l/s
living room	0.3 m^3/min/room(30m^3)	0.6	5
bedroom	0.3 m^3/min/room(30m^3)	0.6	5
kitchen	3.0 m^3/min/room(15m^3)	12.0	50
toilet	1.5 m^3/min/room(10m^3)	9.0	25
garage	3.0 m^3/min/car(19m^3)	9.5	50

Table 3.4. Indonesian standard of ventilation rates to be supplied into houses (Source: The Standard of Designing Building with Energy Conservation, (*Standar: Tata Cara Perancangan Konservasi Energi pada Bangunan Gedung*), Indonesia, 1993)

If we compare the Indonesian standards in Table 3.4 to the Chartered Institution of Building Services Engineers (CIBSE) recommendation for outdoor air supply rates for residential building of 8l/s/person to 12l/s/ person [CIBSE Guide Vol. A, 1986], it can be seen that the Indonesian standards for the rates of air to be supplied in residential buildings are far too low.

3. Houses should have windows which can be opened for natural ventilation
4. To avoid direct solar radiation, windows may be completed by sun screens, which should be designed not to greatly obstruct the air circulation.

3.4 Conclusion

The following table helps to summarise the conclusions of this chapter.

Specifications	The average of Yogyakarta Conditions	Consequences	Indonesian Guidelines	Standards and Guidelines (A, B and C)
Temperature	28.5°C	Hot and humid. Difficult to sweat. Moisture on the skin is difficult to evaporate, so the skin is sticky and uncomfortable. This condition gets worse for people within buildings with inadequate openings.	-	Maximum is 30°C (A)
Humidity	80%		-	Maximum is 65% (A)
Wind speed	1.5 m/s		-	various
Ventilation rates	Data is not available		Approximately 5l/s	8 to 12l/s/person (B)
Building features	Windows, doors, and other ventilation apertures are usually poorly designed (thus the air supplied in to the house is inadequate to provide comfort levels)		Houses should have windows which can be opened for natural ventilation	Openings design shall induce greater wind speed e.g. positions, dimensions, and styles. These are to help body heat loss by convection and evaporation (C)

Table 3.5. Indonesian (referring to Yogyakarta) conditions and the standards
Keys:
Standard A: Acclimatised for tropical climates
[After Olgyay, cited in O.H. Koenigsberger, et al, 1973]
Standard B: CIBSE recommendation for outdoor air to be supplied
[CIBSE Guide Vol. A, 1986]
Guideline C: Egan, 1975 and F. Moore, 1993

By comparing the weather data of Indonesia (including Yogyakarta), Indonesian air quality standards and standards of human comfort, it can be seen that most weather factors in Indonesia are outside comfort requirements. On the other hand, Indonesian air quality standards are difficult to implement, especially in the urban areas with high pollution level concentrations and very slow wind speeds, which are insufficient to induce adequate natural ventilation. In today's conditions, these uncomfortable factors are likely to be improved by using artificial means such as air conditioning. However, it is known that mechanical ventilation or air conditioning is not the best solution. Its bad effect on the environment and high operating cost makes air conditioning systems the last solution. Thus, it is important to explore building design, as it can provide a better environment by natural means, even when the natural factors seem too limited to permit these types of solutions.

CHAPTER 4

PARTICULATE MATTER CONCENTRATIONS

Airborne particulate matter originates from a wide variety of sources, including vehicle exhaust, tyre wear, and combustion sources such as wood stoves, dusty industrial/commercial processes and wind-blown soils. Hence, it is important to define which type of particulate matter (PM) as the major concern in this study.

4.1 Particulate matter

4.1.1 Definition and classification

Particulate matter is solid or liquid particles, which are in the air and are usually composed of chemicals or materials which originate from the origin sources such as soil or motor vehicle exhaust. These particles range over several orders of magnitude in size, from over 100μm down to 0.1μm.

The most common classification of particulate matter is based upon a particle's diameter, as both its physical and chemical properties usually affect the diameter, for example particulate matter from vehicle exhausts composed of lead is categorised as fine particle and particulate from road surface composed of mineral is categorised as coarse particle. Classification, which is based on the diameter, divides particulate matter into [Particulate Matter-PM10, Utah, USA]:

- Deposited particulate is particulate matter that can easily be deposited caused by gravity, larger than 20μm in size and usually create dust on surfaces;
- Suspended particulate is particles mostly smaller than 20μm, which remain suspended in the atmosphere. In this range, there are particles called PM10. These are particulates with diameter smaller than 10μm which are among the most harmful of all air pollutants because of their capability to evade the respiratory system's natural defences and lodge deep in the lungs;
- Visibility-reducing particulate is fine particle in the size range of 0.1μm to 2.0 μm. These particles will scatter and absorb light, thereby impairing visibility.

The above descriptions show that PM10 are of most concern to the public because of the level of danger.

PM10 is formed as a mixture of materials including smoke, soot, dust, salt, acids, and metals. In some cases, PM10 is also formed when gas is emitted from motor vehicles and industrial processes followed by chemical reactions in the atmosphere.

The most common classification of PM10 is based on the distribution, which divides PM10 into four forms as follows [Particulate Matter-PM10, Utah, USA]:

- Coarse particulates are particulate matter with diameters above about 3 μm. These particles are usually mechanically generated.
- Fine particulates are particulate matters with diameters between 1μm and 3μm. These particles are usually formed from gases which coagulate in the atmosphere.
- Accumulation particulates are particulate matter with diameters between 0.1 μm and 1μm. Secondary particulate matters, which are formed from chemical reactions in the atmosphere, often accumulate in this size range.
- Nuclei particulates are particulate matter with diameters below about 0.1 μm. These particles rapidly grow into the accumulation mode.

Whitby and Sverdrup (1980) and Whitby (1975) determined another classification of PM10 as follows [Whitby and Sverdrup, 1980 and Whitby, 1975 (cited in EPA, 1982)]:

- Nuclei particulates are particulates with diameters below 0.1μm
- Accumulation particulates are particulates with diameters between 0.1μm and 2μm
- Coarse particulates are particulates with diameters above about 2μm

Both the nuclei and accumulation particles are also called fine particles. Thus, generally there are two modes of PM10: fine and coarse.

Nuclei rapidly grow to accumulation, but accumulation particles normally do not grow into coarse.

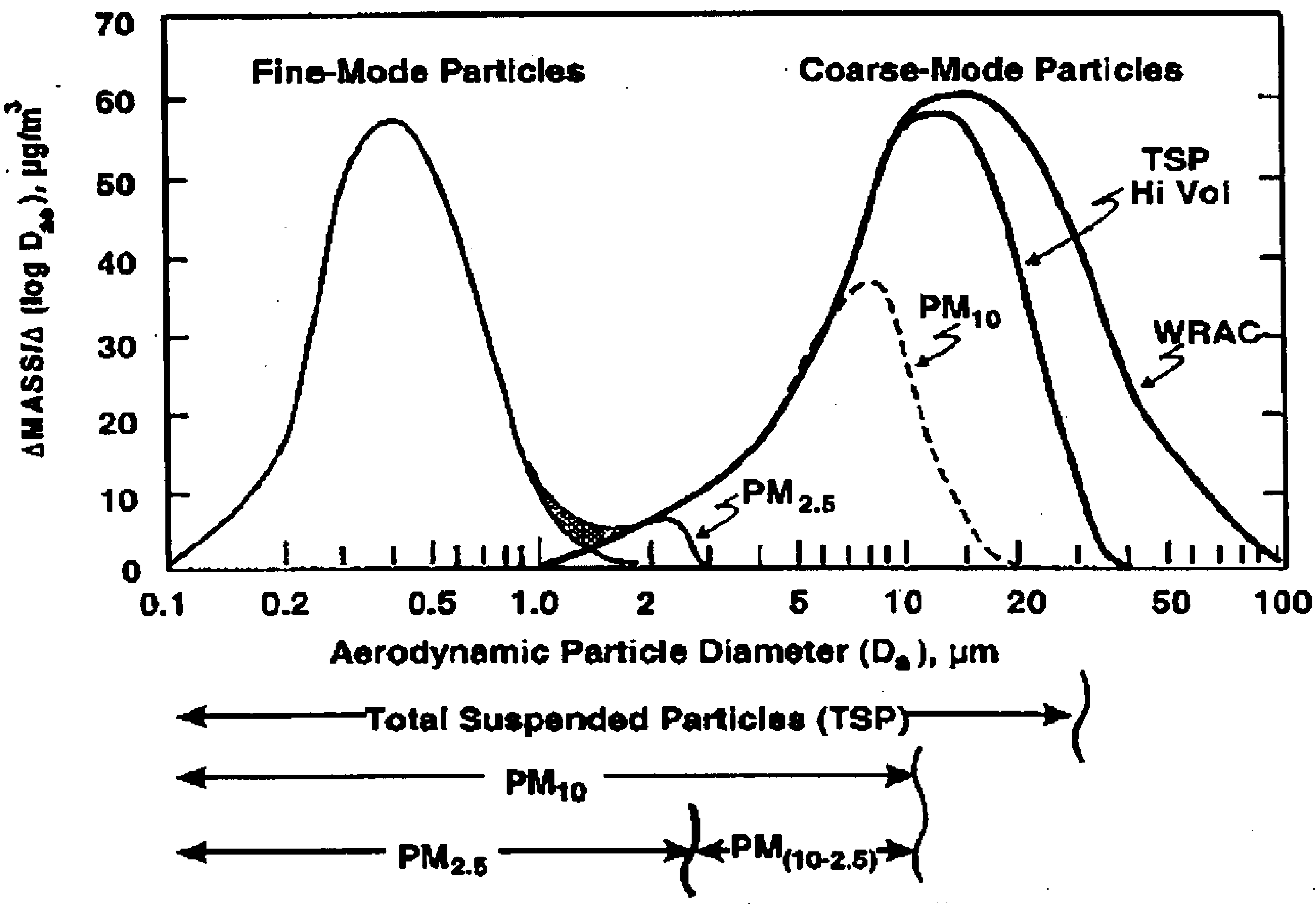


Figure 4.1. An idealised distribution of ambient particulate matter showing fine-mode particles and coarse-mode particles.
(Source: EPA, 1982)

Aqueous-phase reactions may occur within cloud droplets, fog droplets or particles at very high relative humidity. The partial drying out of these particles may lead to a mode which is larger than the accumulation mode formed under drier conditions.

4.1.2 Origins or sources

PM10 comes from a number of sources, such as any activities which involve burning of materials and any dust-generating activities. Major sources come from incomplete combustion such as wood-burning stoves and automobiles. The PM10 from these sources contains a large percentage of elemental and organic carbon, which play a major role in haze phenomena and health effects. Elemental carbon (also called black carbon) is associated with soot emissions from combustion. The remaining, more volatile portion, is termed organic.

Road dust is also a source of inhalable particulates which usually result from natural sources including wind-blown dust.

PM10 from road traffic is mostly a result of:

- motor vehicle exhaust
- vehicle tyres in contact with road surfaces
- wind-blown dust on road surfaces

4.1.3 Chemical properties

Fine particles are generally composed of [EPA, 1982]:

sulphates,
hydrogen ions,
ammonium,
organic compounds,
nitrates,
elemental carbon (soot),
as well as a portion of trace metals.

Coarse particles are generally composed of elements of the earth's crust, such as [EPA, 1982]:

silicon,
aluminium,
Fe,
and other elements commonly found in soil.

Particulates from roads are also composed of lead and some other chemical components as can be seen in the Tables 4.1 and 4.2.

Sources				
	Primary		Secondary	
Aerosol species	Natural	Anthropogenic	Natural	Anthropogenic
$SO_4^=$	Sea spray	Fossil fuel combustion	Oxidation of sulphur gases emitted by the oceans and wetlands; and SO_2 and H_2S emitted by volcanism and forest fires	Oxidation of SO_2 emitted from fossil fuel combustion
NO_3^-	—	**Motor vehicle exhaust**	Oxidation of NO_x produced by soils, forest fires, and lighting	Oxidation of NO_x emitted from fossil fuel combustion; and in **motor vehicle exhaust**
Minerals	Erosion, re-entertainment	**Fugitive dust; paved, unpaved roads;** agriculture and forestry	—	—
NH_4^+	—	**Motor vehicle exhaust**	Emissions of NH_3 from wild animals, undisturbed soil	Emissions of NH_3 from animal husbandry, sewage, fertilised land
Organic carbon OC	Wild fires	Open burning, wood burning, cooking, **motor vehicle exhaust**, **tire wear**	Oxidation of hydrocarbons emitted by vegetation, (terpenes, waxes); wild fires	Oxidation of hydrocarbons emitted **by motor vehicles,** open burning, wood burning
Elemental carbon	Wild fires	**Motor vehicle exhaust**, wood burning, cooking	—	—
Metals	Volcanic activity	Fossil fuel combustion, smelting, brake wear	—	—
Bioaerosols	Viruses, bacteria	—	—	—

Table 4.1. Constituents of atmospheric fine particles (<2.5 μm) and their major sources (Source: EPA, 1982)

Keys:
Fine particulates from motor vehicle exhaust are in red letters.
Coarse particulates from road surfaces are in blue letters.
Sources of both types of particulates are in purple letters.

From the above table, it can be seen that particles from motor vehicle exhaust generally contain NO_3^-, NH_4^+, organic carbon and elemental carbon, which mostly come from primary sources, whilst particles from road dust mostly contain minerals and organic carbon.

	Fine	Coarse
Formed from:	Gases	Large solids/droplets
Formed by:	Chemical reaction Nucleation Condensation Coagulation Evaporation of fog and cloud droplets in which gases have dissolved and reacted	Mechanical disruption (crushing, grinding, abrasion of surfaces, etc.) Evaporation of sprays Suspension of dusts
Composed of:	Sulphate, $SO_4^=$ Nitrate, NO_3^- Ammonium, NH_4^+ Hydrogen ion, H^+ Elemental carbon, Organic compounds (e.g., PAHs, PNAs) Metals, (e.g., Pb, Cd, V, Ni, Cu, Zn, Mn, Fe) Particle-bound water	Resuspended dust (Soil dust, street dust) Coal and oil fly ash Oxides of crustal elements, (Si, Al, Ti, Fe) $CaCO_3$, NaCl, sea salt Pollen, mold, fungal spores Plant/animal fragments Tire wear debris
Solubility:	Largely soluble, hygroscopic and deliquescent	Largely insoluble and non-hygroscopic
Sources:	**Combustion of coal, oil, gasoline, diesel fuel**, wood Atmospheric transformation products of NO_x, SO_2, and organic compounds including biogenic organic species, e.g., terpenes High temperature processes, smelters, steel mills, etc.	**Resuspension of industrial dust and soil tracked onto roads and streets** **Suspension from disturbed soil**, e.g., farming, mining, **unpaved roads** Biological sources Construction and demolition, coal and oil combustion, ocean spray
Atmospheric life:	Days to weeks	Minutes to hours
Travel distance:	100s to 1000s of km	<1 to 10s of km

Table 4.2. Comparison of ambient fine and coarse mode particles
(Source: Wilson and Suh, 1996 (cited from EPA, 1982))

Keys:
Sources of fine particulates are in red letters.
Sources of coarse particulates are in blue letters.

Table 4.2 shows that particulate matters resulting from combustion are fine particles, whilst particulate matters from road surfaces/ dust are coarse particles.

	Vehicles with gasoline engine + engine oil	Vehicles with diesel engine
proportion of emission types :	organic carbon > elemental carbon	elemental carbon > organic carbon
particle diameter :	0.01- 0.1 μm with peak around 0.02 μm	0.1- 1.0μm with peak around 0.15μm
content characteristics :	solid carbon core with a coating of sulphate and trace elements	roughly 10-40% are extractable into organic solvents
range of emission factor	from 0.011 g/km for light duty vehicles to 0.12 g/km for heavy duty vehicles	from 0.23 g/km for diesel passenger vehicles to 1.2 g/km for heavy duty vehicles

Table 4.3. Characteristics of particulate matter from motor vehicle exhaust (Source: EPA, 1982)

The distribution of elemental carbon emitted by automobiles is unimodal, with over 85% of the mass in particles smaller than 0.12μm.

4.2 Particulate matter and health risks

In 1993, John Millar, a Provincial Health Officer in Canada, revealed that particulate matter health impacts appeared to be greater than for any other outdoor air pollutant. This study was then followed by epidemiological evidence which strongly suggests that ambient air particulate matter can adversely effect the health of exposed individuals, even when the exposure is in the range of or below the current ambient air standard [Source & Inhalable Particulate Potential Health Impacts, 1998].

Particles inhaled by humans are segregated by size during deposition within the respiratory system. The major regions of the respiratory system differ widely in structure, size, function, sensitivity, or reactivity to deposited particles and to the mechanisms of particle elimination from the system. Larger particles deposit in the upper respiratory tract, while smaller inhalable particulates travel deeper into the lungs and are retained for longer periods of time. PM10 is of primary concern to people today: not only does it penetrate deeper and remain longer in the lungs than larger particles, but it also contains larger quantities of organic materials that may have significant long-term health effects. The route of toxicity due to particulate exposure also may not be directly through the respiratory system, but may allow for the collection of materials and subsequent entrance to the stomach in swallowed mucous.

Such a mechanism is the primary route for lead exposure from atmospheric lead [Source & Inhalable Particulate Potential Health Impacts, 1998].

Toxicity of particles retained in the lungs varies with chemical composition. Some chemicals such as sulphuric acid may react directly with the system, while others may act to retard clearance of other particles from the lungs. Particulates may also act as carriers for gaseous pollutants and can cause synergistic effects, such as when sulphur dioxide and particulate exposure occurs simultaneously. Carbon particles are the most common carriers for gaseous and semi gaseous pollutants. These pollutants are carried by the fine particulates deep in the lung where sensitive lung tissues may be exposed to their chemical actions. Benzo-a-pyrene, a known carcinogen, is an example of a gaseous or semi-gaseous pollutant, which can cause lung cancer [Dockery, 1993].

Although particulate matter may cause health problems for everyone, certain people are especially vulnerable to PM10. These sensitive populations include children, the elderly, exercising adults, and those suffering from asthma or bronchitis.

EFFECT	Concentration of PM for 24 hour-exposure	
	Effect possible	Effect likely
Reduced lung function in children	140 $\mu g/m^3$	350 $\mu g/m^3$
Aggravation of bronchitis increased mortality	350 $\mu g/m^3$	600 $\mu g/m^3$

Table 4.4. PM10 effect on health on 24- hour exposure
(Source: Source & inhalable particulate potential health impacts)

In general, the inhaled fine particulate matter which is then deposited down the human respiratory system can affect pulmonary lung function (as this is where oxygen enters the bloodstream), which may be impaired temporarily or permanently [Schenker, 1993 and Potential Health Impacts of Inhalable Particulate, 1998]. The decrease of pulmonary lung function can lead to other known diseases, such as chronic bronchitis and bronchial asthma (i.e. the late stages of chronic bronchitis). A long exposure to particulate matter can also have effect on mucociliary (a host defence system) clearance and other host defence mechanisms and can promote morphological alteration of lung tissue [Potential Health Impacts of Inhalable Particulate, 1998].

4.3 Particulate matter standards

Before July 1987, the USA commission for air quality issues (EPA (Environment Protection Agency)), to which the Indonesian government mostly refers its national standards, set a standard for particulate matter called "total suspended particulate " (TSP) of 260 μg /m³ over a 24 hour running average period. In July 1987, EPA revised this standard to 150 μg/m³ and the annual average standard set at 50 μg/m³ over a 24 hour running average period [Particulate Matter-PM10 & PM2.5, Criteria Pollutants, 1996]. Currently, however, the Indonesian government still uses the old standard of TSP, i.e. 260 μg/m³ for a 24 hour running average period [Bapedal, Indonesia, 1992].

Specific for PM10 measurements, there is a World Health Organisation (WHO 1992) guideline of 70 μg/m³ (24 hour average) [Radojevic and Hasan, 1999]. In the UK, the UK Expert Panel on Air Quality Standard has recently recommended a limit value for PM of 50μg/m³ measured as PM10 over a 24 hour running average period [EPAQS, 1995 (cited in Harrison, et al, 1997)]. Unfortunately, there is no Indonesian standard or guideline specified for PM10 measurements.

4.4 Particulate matter in Yogyakarta

As mentioned earlier, the major source of particulate matter in Yogyakarta is street traffic. To provide data of particulate matter concentrations in Yogyakarta, where published data is not available, field measurements were taken in some places within Yogyakarta city centre. The measurements were taken in three different types of streets. All these streets are adjacent to residential areas that might represent street types that are commonly found in Yogyakarta. Those streets are Sagan St. (a residential street that is unofficially used as a public street), Tendean St. (a primary street that accommodates local and regional transport) and Jogokaryan St. (a residential street that also accommodates local public transport). Particulate matter concentrations were measured for two days (each day 24 hours) at the kerb of each street. The device used for this sampling was a "standard low volume air sampler" (LVS), a flow controlled unit combined with a cascade impactor with one cut size of 10μm. The LVS is owned by Bureau of Environmental Health (*Balai Teknik*

Kesehatan Lingkungan/BTKL) and the sampling was carried out by this bureau under the supervision of the Department of Health, Province of Yogyakarta, based on time and measurement points specified by the author. This bureau has carried out all particulate matter measurement within Yogyakarta and other neighbouring cities, including when setting the regional standard of total suspended particulate matter within Yogyakarta City. Specifications of the device can be seen in Appendix 5.

The principle of this measurement can be explained as follows. Particulate matter mass loading on the glass fibre was obtained by weight on an analytic scale with the filter being weighed before and after sampling under similar room temperature and relative humidity conditions. Desiccation (2 days) followed by balance room equilibration (3 minutes) was applied to remove the unwanted moisture absorbed on site due to humidity [Zou and Hopper, 1997].

Result

The particulate matter concentrations within Yogyakarta City as the average of two days measurement in each street are shown in the following tables.

Indonesian Standards (24 h)	Concentration at Sagan St.	Concentration at Tendean St.	Concentration at Jogokaryan St.
260 $\mu g/m^3$	143 $\mu g/m^3$	117 $\mu g/m^3$	86.5 $\mu g/m^3$

Table 4.5. Particulate matter concentration in some locations in Yogyakarta, measured over 24 hours (Source: *BTKL* Yogyakarta, March 1998)

Whilst the above measurements in the three street types are for a 24 hour period, another measurement was also carried out in one street type (Sagan St.) for 10 days each for 8 hours. Therefore, in this second measurement, the standard is assumed to be 1/3 of the 24 hour = 87 $\mu g/m^3$ per 8 hour. According to the *BTKL* team, the 8 hour measurement is considered indicative of the 24 hour particulate matter concentrations in a certain place, particularly if the measurement was carried out continuously more than 3 times, each in a different day.

day 0	day 1	day 2	day 3	day 4	day 5	day 6	day 7	day 8	day 9
57$\mu g/m^3$	54$\mu g/m^3$	89$\mu g/m^3$	100$\mu g/m^3$	50$\mu g/m^3$	88$\mu g/m^3$	73$\mu g/m^3$	55$\mu g/m^3$	125$\mu g/m^3$	53$\mu g/m^3$

Table 4.6. Particulate matter concentration in Sagan St., Yogyakarta, measured over 8 hours (0800-1600) (Source: *BTKL* Yogyakarta, November 1998)

Due to limited resources, it was not possible to chemically analyse the collected samples. However, it was possible to obtain the chemical properties of the samples collected from similar research done earlier in Jakarta, given that traffic (vehicle types and road surfaces) conditions in Jakarta are similar to those in Yogyakarta. Soil origin is generally similar to Yogyakarta, apart from a slightly salt content, as Jakarta is close to Jawa Sea.

This study shows that most of the particles collected in Jakarta are of very fine diameter (particles with diameter < 7.2 μm was 83% from the sample collected and 17% was for particle with diameter >7.2 μm) with metal chemical properties. They were caused by incomplete combustion of poorly maintained vehicle engines. This type of particle was very fine, with metal content mostly Pb and Zn, indicating traffic emissions from vehicles using leaded petrol and vehicles using diesel engines. Despite the metal contents, both coarse and fine particulate in Jakarta have common crustal element of Al, Si, and Ca [Zou and Hopper, 1997]. Another important analysis from this research is that diesel vehicles emit loosely structured particle conglomerate to the atmosphere, which breaks readily into extremely fine particles after emission and can stay suspended for a considerable time [Zou and Hopper, 1997].

4.5 Conclusion

By comparing particulate matter concentration in Indonesia (Section 2.5.3) including particulate matters in Yogyakarta (Section 4.4) and the standards, it can be seen that in some locations, fine particle concentrations are still below both the Indonesian standard and the newest EPA standard. However, this does not mean that attempts at reducing the concentration of fine particulates should stop, because there are also some places where the concentration is already above the standards. Even though the concentration is still below the standard, there is earlier research indicating particulate matter should be reduced, based on the reason that most particles collected from traffic pollution are very fine particulate with metal content that has detrimental effects on human health. It is likely that sooner or later those areas which are currently below the standards will experience a rapid rise, as the use of motorised vehicle increases in growing cities as well as in metropolitan cities.

CHAPTER 5

NOISE LEVELS

Hearing is one of man's most important channels of communication, second only to vision. But whilst eyes can be shut when there is too much light or unwanted scenes, ears are open throughout life to unwanted noise as well as to wanted sound. The major concern of this study is particulate matter emitted from vehicle exhaust, but as vehicles also generate noise, it is likely that reducing noise pollution will bring many benefits.

5.1 Traffic noise

Road traffic is the major noise source for people living in city centres. As space for permitting noise reduction by natural means is usually limited, the noise level in city centres is surprisingly high. This describes the conditions in most Indonesian cities, including Yogyakarta. Traffic noise is mostly generated by motorised vehicles. Each motorised vehicle has its specific frequencies depending on the type of engine and cubic capacity of the engine. Figure 5.1, which is derived from the ISO test [Road Research Laboratory report, 1970, cited in White 1982], shows the averaged noise spectra for various types of motorised vehicle (only for the engine noise), when their engines start to accelerate. The use of a low gear (2nd or 3rd depending on the vehicle) ensures the maximum engine speed is reached at or shortly after passing the microphone (10 m from the start of the acceleration).

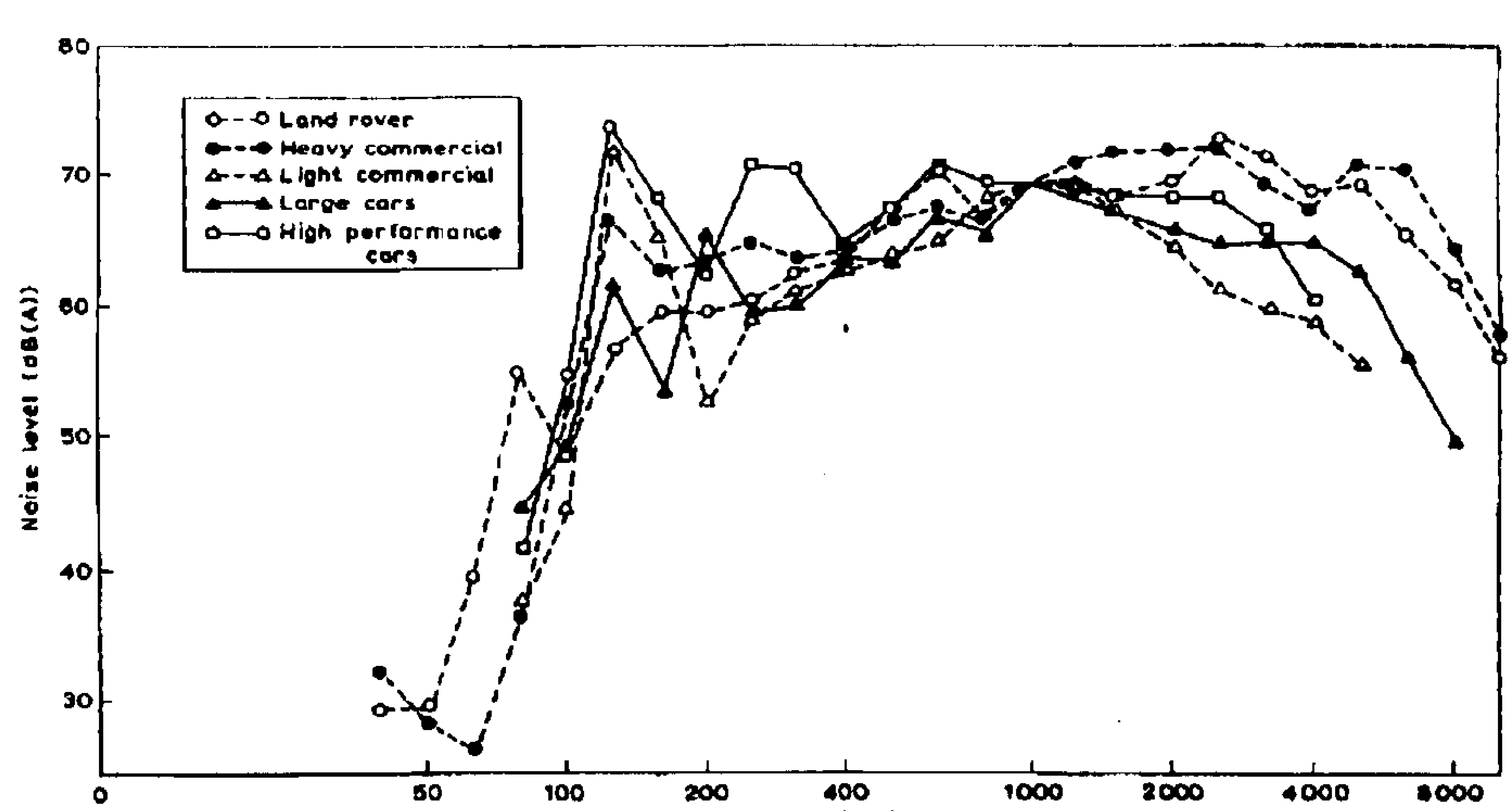


Figure 5.1. Typical vehicles' noise spectra (After White, 1982)

Figure 5.1 shows that almost all motorised vehicles have peak noise levels between frequencies of approximately 100 Hz and 7000Hz. The source of traffic noise is not merely from vehicle engines, but also from [White, 1982]:

- engines, tyres, braking systems, silencers or mufflers, and horns (for trucks, buses, and private cars);
- engines, silencers or mufflers, and horns (for motorcycles).

In addition to the above sources, there are road/street conditions, including density of vehicles, traffic signals, road shapes, and road surfaces. These can be explained by the following [White, 1982]:

- the higher the density of vehicles on the streets, the more noise will be generated;
- the slower the vehicle motion, the higher and longer the noise that will be generated (e.g. traffic jams);
- vehicles need more power to climb slopes, hence more noise is generated;
- gravelly or stony streets will generate more noise, especially in wet conditions.

5.2 Principles of sound

- Types of sound source

Two types of sound sources are the major concern of this study: point source and line source. In the case of point source, a point in a space represents the sound, which is radiated equally in all directions. Energy is constant for all points described by a sphere centred at the source. Every time the distance from the source is doubled, the level decreases by 6 dB. In the case of line source, the source is represented by large numbers of point sources arranged in close spacing along an infinitely long straight line. The sound energy at an observer's position now relates to the area of a cylinder centred on the line. Every time the distance from the source is doubled, the level is decreased by 3 dB. Free flowing traffic on a busy road is an example of line source, as long as the observer is not too close [BRE/CIRIA Report, 1993].

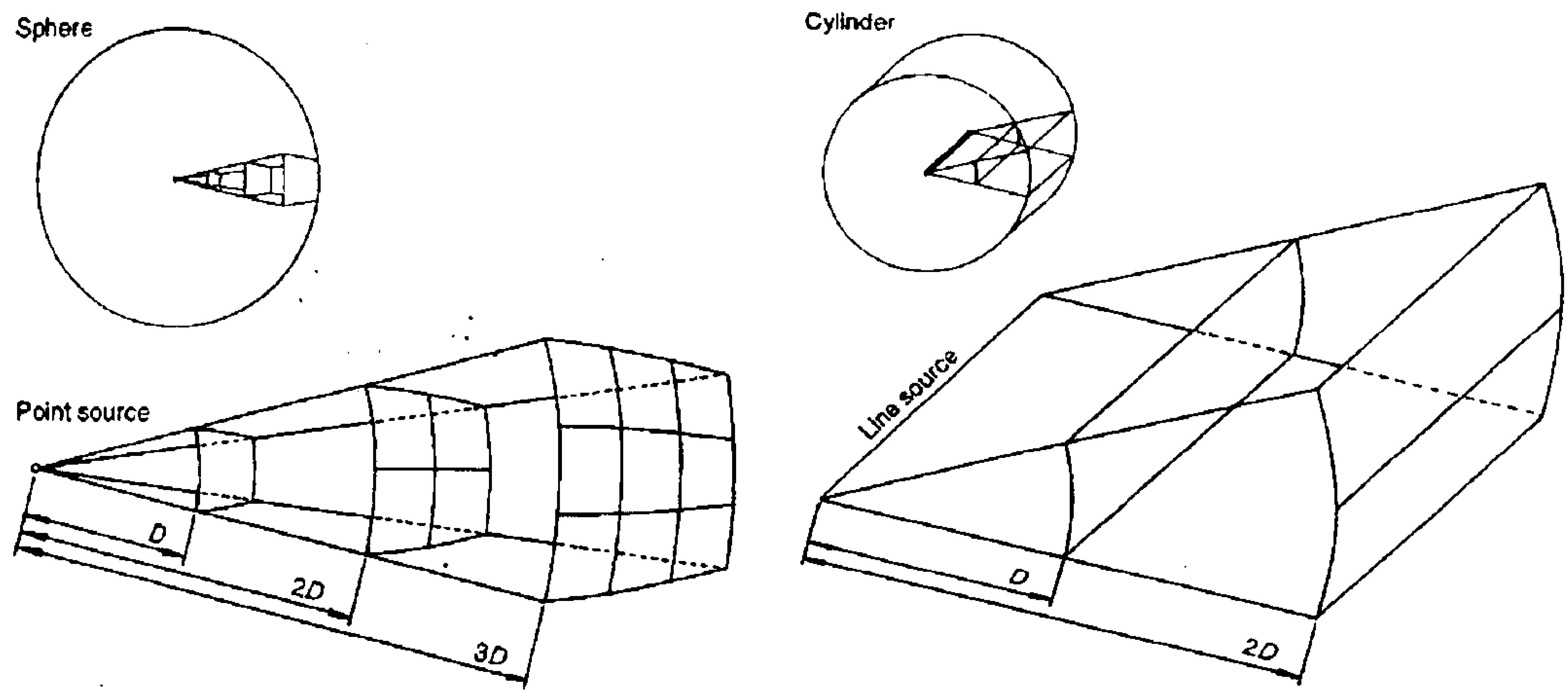


Figure 5.2. The shapes of sound sources
(Source: BRE and CIRIA Report, 1993)

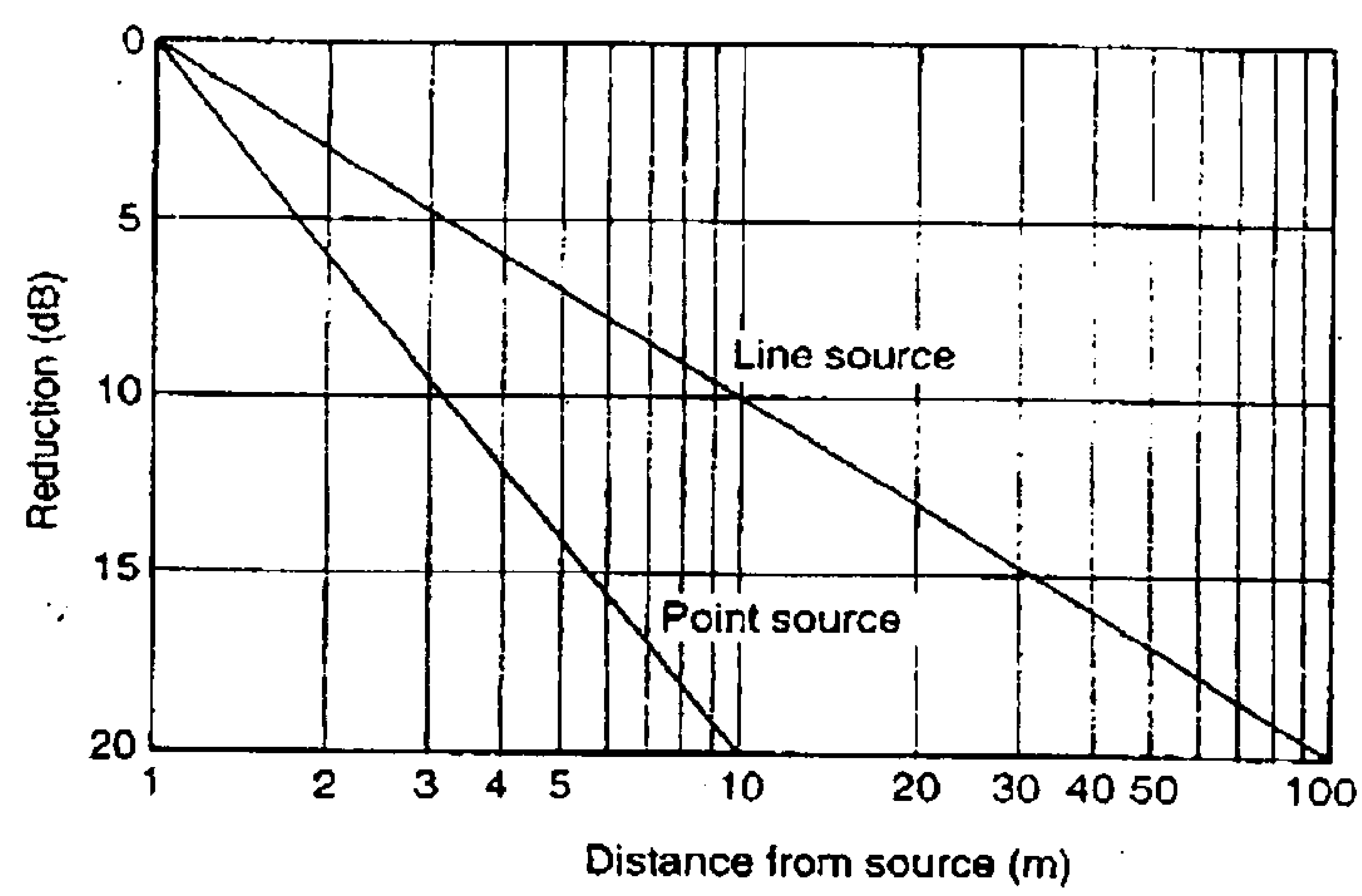


Figure 5.3. Natural sound reduction by distance depending on the sound source
(Source: BRE and CIRIA Report, 1993)

- Frequency

Each noise has its specific frequencies. Each frequency will affect the hearing process differently. The onset of noise-induced hearing loss is often first noticed in the threshold shift at more or less 4,000 Hz, where the ears appear most sensitive to noise. Unfortunately, 4,000 Hz lies between 100 Hz and 7000 Hz, which is the peak level of traffic noise (Figure 5.1). Hence, it will readily induce hearing loss for people living close to traffic, dependant upon the levels of noise and time of exposure.

- Intensity

Sound intensity (I) is sound power distributed over unit area. This is a measurement of the rate at which energy is received in a given surface [McMullan, 1992]. Below is the formula for calculating the sound intensity of a point source (sphere), which is also a basic formula to calculate sound intensity for different source shapes.

$I = P/4\pi r^2$ or for more general $I = D(\emptyset)P/4\pi r^2$

Where:

I = sound intensity at given distance (watt/m^2)

D (Ø)= directivities of angle from the source

P= sound power (watt)

r = distance from the source (m)

The above formula determines that sound intensity depends on its distance from the source. Sound intensity is measured in decibel (dB) which is a logarithmic ratio of two quantities. The quantity is either a comparison of two different intensities or two different pressures, as shown by the following formula:

$N = 10\log_{10}(I_2/I_1) = 10\log_{10}(p_2/p_1)^2$

Where:

N= number of decibels

I_1 and I_2 = the intensities being compared or,

p_1 and p_2 = the pressures being compared

This explains that sound is measured on a logarithmic scale not a linear scale. For example a sound of 70 dB is ten times louder than 60 dB and a hundred times louder than 50 dB.

- Weighting

There are four weighting networks in measuring sound, which are use to emphasise or give 'weight' to the frequency content of sound in the same manner as the human hearing system [Chunnif, 1977 and McMullan, 1992]:

- A-weighting network: human response for low sound levels;
- B-weighting network: human response for moderate sound levels;

- C-weighting network: human response for high sound levels;
- D-weighting network: human response to noise around airports.

The A-weighting network has been adopted in many laws and ordinances to compensate for human hearing characteristics regardless of the sound intensity level. Many measurements of sound incorporate decibels also measured on the A-scale, including traffic noise. Reading on a weighting network should indicate the particular weighting network in use. For example, if we read 65 dB on the meter when using the A-weighting network, we record this as 65 dB (A) or simply 65 dBA [Chunnif, 1977].

- Duration/Continuity

Duration and continuity of sound exposure is also an important factor to be considered. A low level of sound with long exposure can be as dangerous as a high level of noise with short duration of exposure [Sanders and McCormick, 1987]. Table 5.1 shows the permissible noise exposure determined by Occupational Safety and Health Administration (OSHA) of the USA Department of Labour (1983). Other national and international standards follow this recommendation rather closely [Sanders and McCormick, 1987]. The data in this table were not tabulated for exposure to traffic noise but for exposure to industrial works, where the distance between the source and the receiver is close. However, this data is useful as it gives some ideas of the level of traffic noise permissible for people living very close to traffic, which as a source of noise is quite similar to the noise source in industrial work (i.e. engines/motors)

Noise levels (dBA)	Noise rating number	Permissible exposure time (min/day)
90	85	500
95	90	140
100	95	50
105	100	30
110	105	17
115	110	10

Table 5.1. Permissible noise exposure time
(Exposures above 115 dBA are not permitted regardless of duration)
(Source: Sanders and McCormick, 1987)

- C-weighting network: human response for high sound levels;
- D-weighting network: human response to noise around airports.

The A-weighting network has been adopted in many laws and ordinances to compensate for human hearing characteristics regardless of the sound intensity level. Many measurements of sound incorporate decibels also measured on the A-scale, including traffic noise. Reading on a weighting network should indicate the particular weighting network in use. For example, if we read 65 dB on the meter when using the A-weighting network, we record this as 65 dB (A) or simply 65 dBA [Chunnif, 1977].

- Duration/Continuity

Duration and continuity of sound exposure is also an important factor to be considered. A low level of sound with long exposure can be as dangerous as a high level of noise with short duration of exposure [Sanders and McCormick, 1987]. Table 5.1 shows the permissible noise exposure determined by Occupational Safety and Health Administration (OSHA) of the USA Department of Labour (1983). Other national and international standards follow this recommendation rather closely [Sanders and McCormick, 1987]. The data in this table were not tabulated for exposure to traffic noise but for exposure to industrial works, where the distance between the source and the receiver is close. However, this data is useful as it gives some ideas of the level of traffic noise permissible for people living very close to traffic, which as a source of noise is quite similar to the noise source in industrial work (i.e. engines/motors)

Noise levels (dBA)	Noise rating number	Permissible exposure time (min/day)
90	85	500
95	90	140
100	95	50
105	100	30
110	105	17
115	110	10

Table 5.1. Permissible noise exposure time
(Exposures above 115 dBA are not permitted regardless of duration)
(Source: Sanders and McCormick, 1987)

5.3 Noise and human discomfort

Noise is any unwanted sound, usually associated with human discomfort. Everyone feels noise as annoyance. However, the extent to which noise irritates people (and the reason it does so) is the most intangible aspect of the subject of noise control. The psychological and physiological aspects of noise are so complex and so variable from one person to another, that any theoretical attempts to anticipate people's reactions to noise seem impossible.

- Criteria for noise

Each person has different feelings about noise. An unwanted sound for one person can be a wanted sound for another. The most obvious example is music. However, there are some noises that are regarded as unwanted sound by nearly all people, such as industrial noise and traffic noise [Sanders and McCormick, 1987].

- Characteristics of noise

Noise is divided into two categories: single noise and community noise. Single noise is noise from single sources such as conversation between two persons, single neighbouring music, and noise from one mechanical vehicle. Community noise is noise from complex sources such as discussion/conversation amongst many people, music concert, and busy traffic. Urban noise is categorised as community noise [Chunnif 1977 and Sanders and McCormick, 1987].

5.3.1 Annoyance of noise and community response

Annoyance is not like loudness. It is true that a louder noise is more annoying than a softer noise, but there are exceptions. In particular cases, soft noise can be more annoying than louder noise. One example is the rhythmic drip of water from a tap that will annoy more than the roar of the ocean surf. In most cases, people are more annoyed by aircraft and other motorised vehicles than by loud neighbouring noise.

Annoyance is measured by having subjects rate noise on a verbal scale, such as 'noticeable', 'intrusive', 'annoying', 'very annoying', or 'unbearable'. The level of annoyance is also determined by two factors: acoustic and non-acoustic [Sanders and McCormick, 1987], as can be seen in Table 5.2:

Acoustic factors	Non-acoustic factors
sound level	past experience with the noise
frequency	listener's activity
duration	predictability of noise occurrence
spectral complexity	necessity of the noise
fluctuations in sound level	listener's personality (inc. culture)
fluctuations in frequency	attitudes toward the source of the noise
rise time of the noise	time of year
-	time of day
-	type of locale

Table 5.2. Annoyance related to acoustic and nonacoustic factors
(After Sanders and McCormick, 1987)

Attempts have been made to relate noise exposure to community reactions such as complaints, threats, and legal actions, and it was found there is a giant step between being annoyed and taking action. A host of sociological factors, political factors, and psychological factors intervene in a decision to do the latter [Sanders and McCormick, 1987].

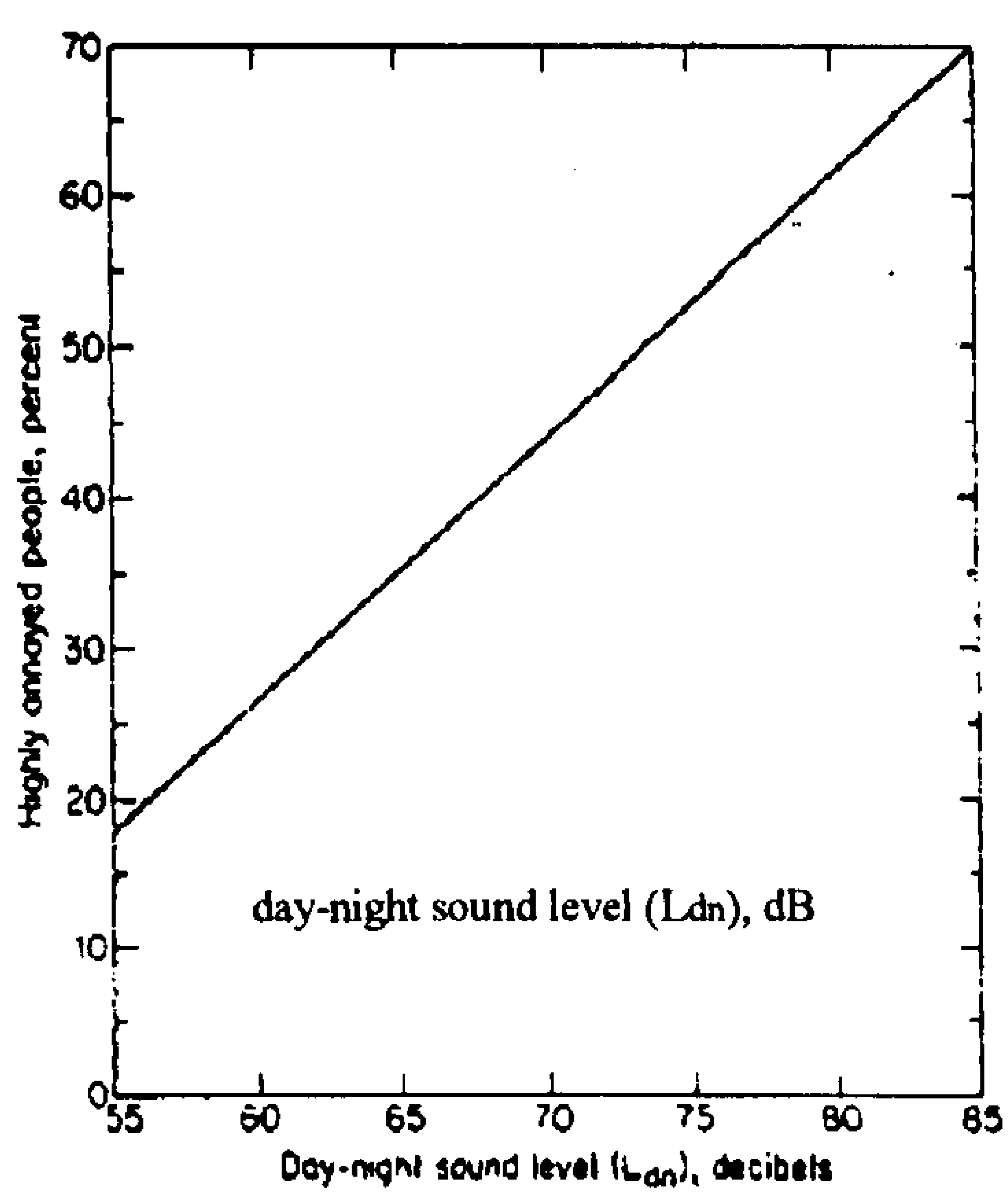


Figure 5.4. Day-night sound levels and community response
(After Sanders and McCormick, 1987)

Ldn is the average noise level in a 24-hour day, with a correction of 10 dB added to noise levels occurring in the night time (10 pm to 7 am). Generally, a normalised day-night sound level of 55 dBA or lower will not result in complaints. However, these predictions are not precise, but rather are only rough indications of the probable community reactions.

Another way of determining the degree of annoyance is by identifying some factors [JE. Moore, 1966], as can be seen in Table 5.3.

CATEGORIES	FACTORS
a	worried, sick and psychologically disturbed people seem to be most affected
b	differences of susceptibility to noise in otherwise 'normal' people, probably connected with emotional character, stamina, and general out-look
c	in certain circumstances, some people find noise exciting and emotionally satisfying, others hardly at all
d	in comparable circumstances, young people are less likely to be irritated than older people
e	the level of noise to which people have been accustomed will influence their attitude towards it
f	people are more likely to complain of new noise than one they have heard before
g	if people think of noise as being avoidable, they may be less irritated than if they consider it unnecessary
h	other associated ideas seem to play apart, for example : personal dislike of a neighbour who happens to make the noise, associations of fear, or unsatisfied curiosity
i	the degree of annoyance caused is not directly related to its intensity, its frequency spectrum, periodicity, and the information contained in it may be more important
j	generally, high frequency, harsh or unmusical sounds, sounds of fluctuating pitch, sound of unpredictable rhythm seem to cause most annoyance

Table 5.3. Degrees of annoyance (After J.E.Moore, 1966)

5.3.2 Noise in residential areas

Compared to other factors, noise is a leading source of annoyance in residential neighbourhood. In 1973, research drawn primarily from community noise in the city centre experienced in the USA showed that street noise was cited by 34% of the 60,000 respondents as a "condition existing in this neighbourhood", 60% "disturbing, harmful or dangerous", and 18% "it is so objectionable that they would like to move" [Eldred, 1990].

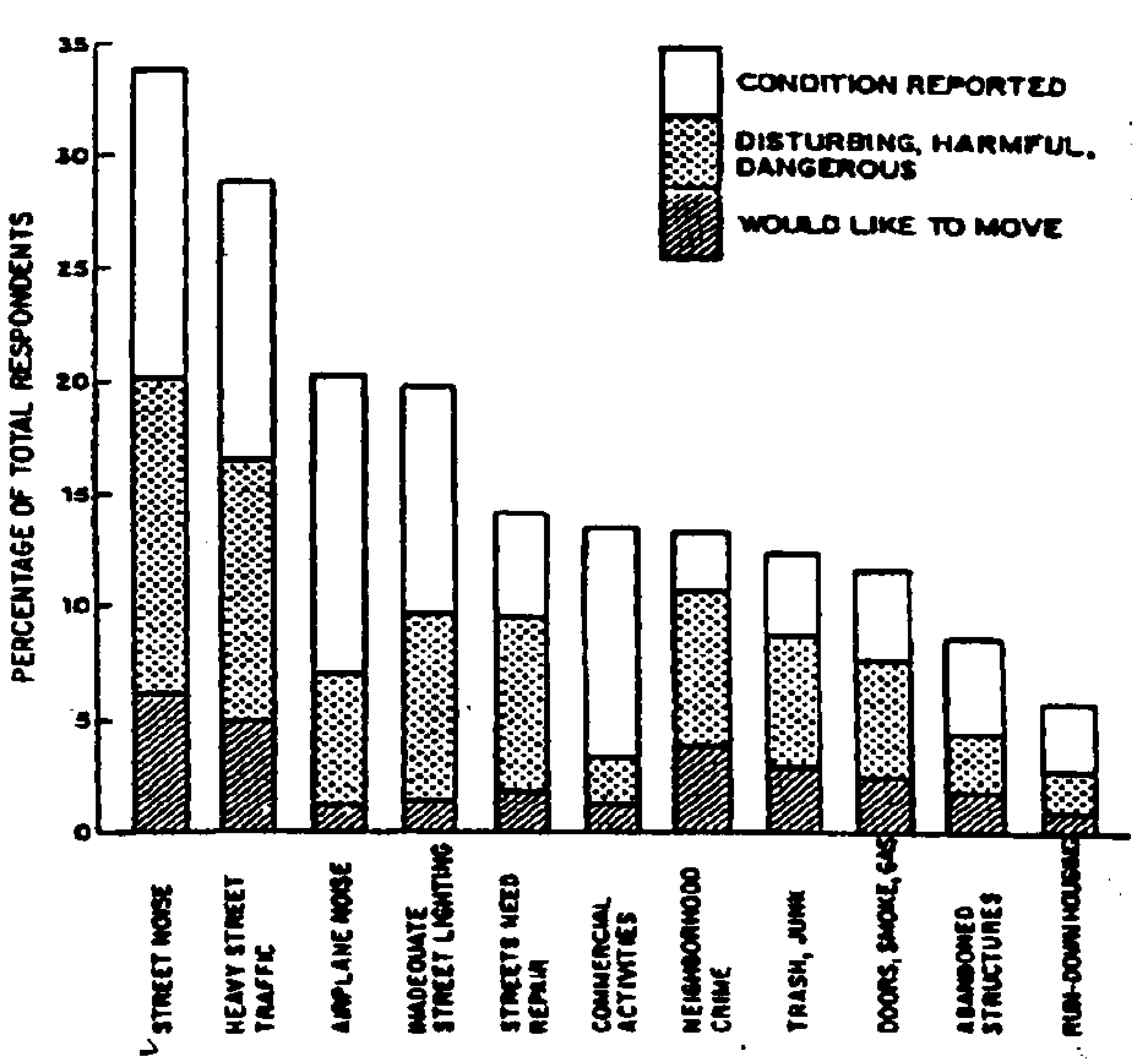


Figure 5.5. Result of annoyance surveys (After Eldred, 1990)

Following the increase of noisy conditions in recent years, several standards have been determined, which are specifically related to indoor noise level, as follows:

1. Recommended noise ratings by CIBSE (1986):

Function	Noise Rating values
bedroom	25
living room	30
toilet	40
kitchen	45

Table 5.4. Recommended noise ratings (Source: CIBSE Guide, 1986)

Noise rating (NR) is one method of specifying acceptable levels of sound at different frequencies. Noise rating is based on standard curves (plot of sound pressure level against a set of frequencies), which are based on the sensitivity of the human ear. The aim is to produce an index or criterion which is a single- figure rating for the noise. The average indoor NR in a house according to Table 5.4 is approximately 35.

2. Noise standard for residences by BRE/CIRIA (1993)

Room classification	Suggested design background noise level arising from external sources ($L_{Aeq,T}$ measured in dB)
sensitive room : bedroom living room dining room	 < 35 8h (23.00-07.00) <40 16h (07.00-23.00) <40 16h (07.00-23.00)
less sensitive room : kitchen, bathroom, utility room, wc, internal and communal circulation area	< 50 16h (07.00-23.00)

Table 5.5. Noise standard for residences
(Based on British Standard 8233 and BRE Digest 266)

$L_{Aeq,T}$ is the level of a notional sound which (over a defined period) would deliver the same A-weighted sound energy as the fluctuating sound. According to Table 5.5, the average $L_{Aeq,16}$ is approximately 43 dBA. The 16-hour (day time) noise equivalent is used as a reference due to some activities that need protection from noise during day time (e.g. studying and working) as the noise levels during this time is usually higher than those during night time (23.00-07.00).

3. Standards of indoor noise levels in residential building in some countries

FUNCTION	France (L_{50})	Japan (L_{50})	USA (L_{10})	USA ($L_{eq,24}$)
residences, schools	40-45 dB(A)	40-55 dB(A)	55 dB(A)	45 dB(A)

Table 2.7. Noise standard in some countries (Source: Chunnif 1977 and Watkins, 1981)

A summary of the above standards show that the most commonly adopted indoor noise level in residential buildings is approximately 45 dBA for either day time (15 to 16 hours) or for 24 hour. Some countries express their indoor noise level for residential building in day-night noise equivalents ($L_{eq,dn}$) of 45 dBA [Chunnif, 1977]. Therefore, within these countries, there is a guideline for environmental noise (outdoor noise in residential areas) L_{dn} of 55 dBA. This is derived from L_{eq} of 45 dBA within a house which provides 100% speech intelligibility, adding 15 dBA to account for the average noise reduction of an interior wall with a partially open window, and subtracting 5 dBA as a margin of safety to account for other effects [EPA, 1974, cited in Chunnif, 1977 and Eldred, 1990].

Following this guideline, it has been shown that for the average urban residential neighbourhood with some prior exposure to intruding noise of non special character "no reaction", is expected when the L_{dn} of the intruding noise is 55 dBA or less [Eldred, 1990]. This result is consistent with the selection of 55 dBA as a long-term goal for the average urban residential environment. In these circumstances therefore, an L_{dn} of 65 dBA would be expected to prompt "widespread complaints" [Eldred, 1990]. This result is consistent with the identification of an L_{dn} of 65 dBA as the upper limit of acceptability for single family residence.

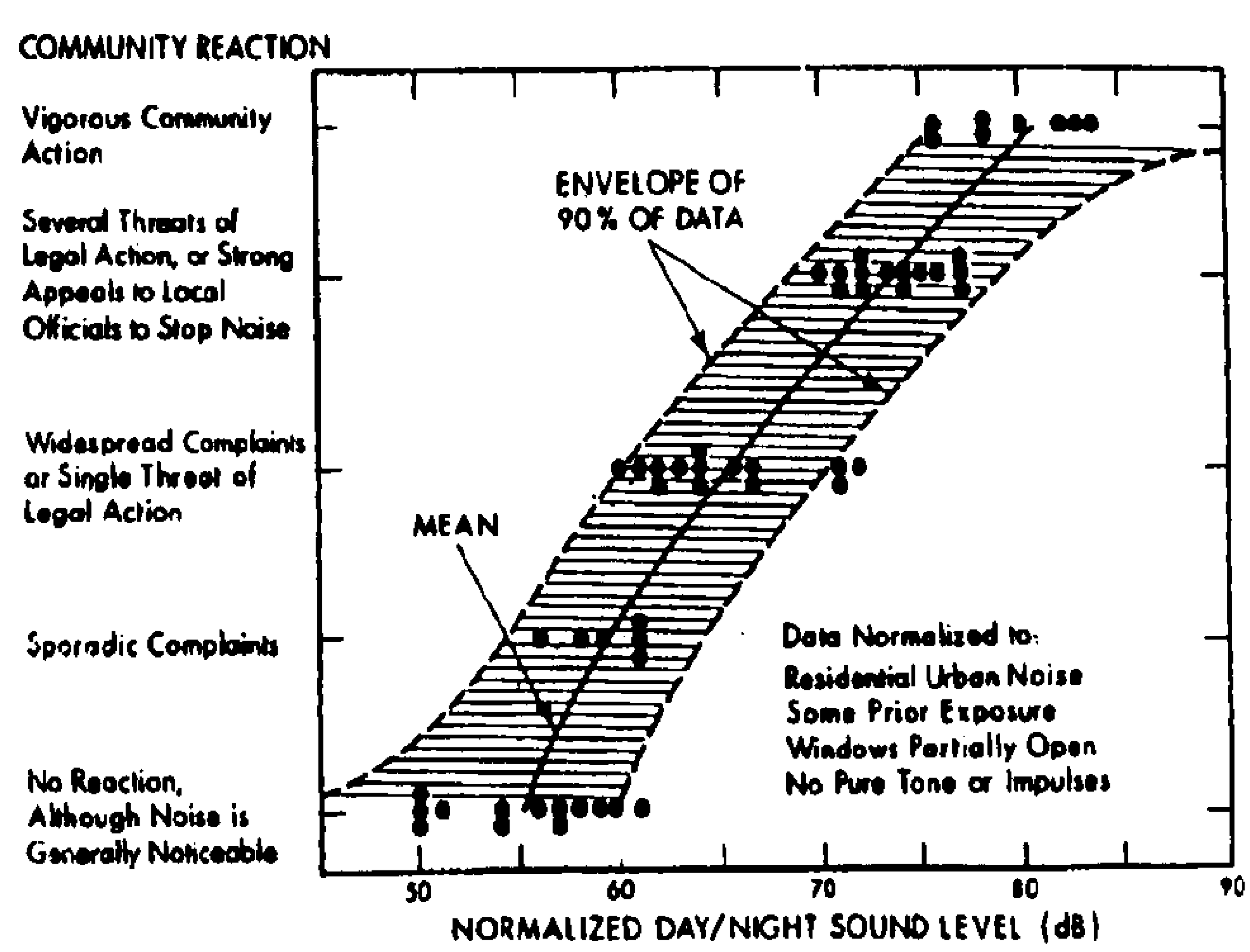


Figure 5.6. Community reaction due to noise
(After Eldred, 1990)

As the above figure represents one area or one country (i.e. USA), the curves may vary for other areas or other countries.

5.4 Noise conditions in Yogyakarta

Yogyakarta has five districts, namely Kotamadya Yogyakarta (Yogyakarta), Sleman, Bantul, Gunungkidul, and Kulon Progo. The first district and parts of the second district are located in the city centre. The city centre mostly contains schools/universities, offices, public services (hotels, shopping malls, markets, and bus/railway stations), industries and residences, hence the noise level in this area is extremely high.

5.4.1 Noise details

The noise types in Yogyakarta are:

1. Road traffic

Yogyakarta is growing more slowly compared to other Indonesian cities [Soegijoko, 1992]. The condition of the city has changed little in recent years. There has been no huge development in the city's facilities including roads/streets. The increase of vehicles has not been followed by an increase in street widths and lengths. This organic (unplanned) growth has resulted in a lack of zoning as between quiet and noisy areas, so that for example, buildings are always close to busy roads. The widths of the streets in Yogyakarta are normally as follows:

- main streets: 8m-12m;
- secondary streets: 6m-8m;
- small (housing) streets: 3m-6m.

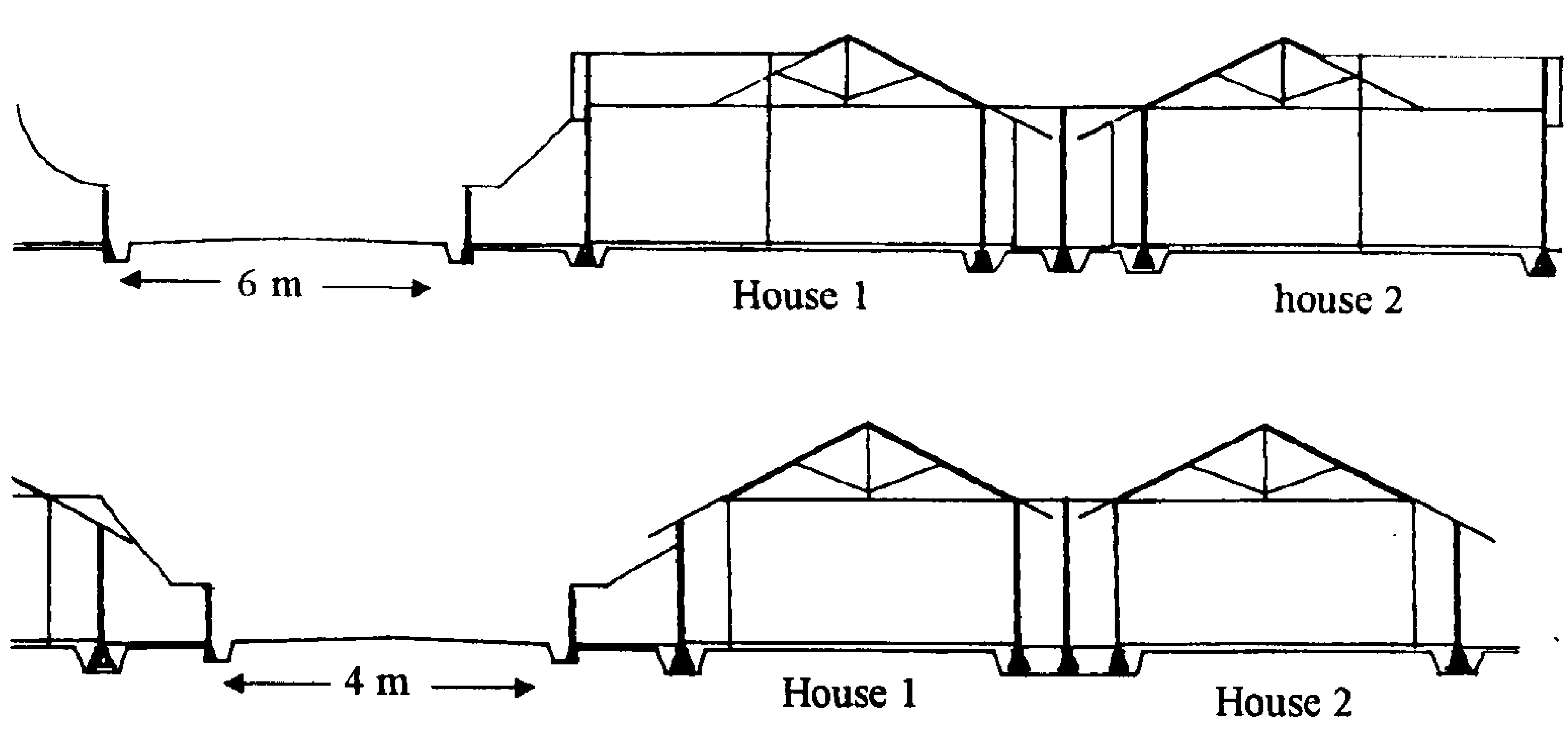


Figure 5.7. Common street widths adjacent to low cost housing
6 m (above) and 4 m (below)

All the above street types accommodate various vehicles: *andongs* (a two-or four-wheeled vehicle without engine, used for carrying passengers and pulled by a horse), *becaks* (a three wheeled vehicle without engine, used for carrying passengers and pedalled by a person sitting in the back seat (Figure 5.11)), bicycles, buses, trucks, cars, and motorcycles. Almost all these streets have no limitation for vehicle types, so that any vehicles can pass through any streets at any time.

Figure 5.8. and 5.9. Two stroke motorcycle is a common type of private vehicle in Yogyakarta

Figure 5.10. and 5.11. Motorised vehicles, "Becaks" and bicycles

Traffic noise occurs during the day between 7 am-5 pm., with peak levels at approximately 7 am - 8 am and 1 pm - 2 pm. Traditionally operated public transport and highly use of motorcycles compared to cars cause these high noise levels. The traditional public transport that uses driver's assistants to shout out the routes also causes loud noise. As noise levels of shouting can reach up to 65 dB from 2-m distance (Figure 5.12 and Table 5.6), street noise that is made up of engine noise, tyre noise, shouting, etc. will be very high.

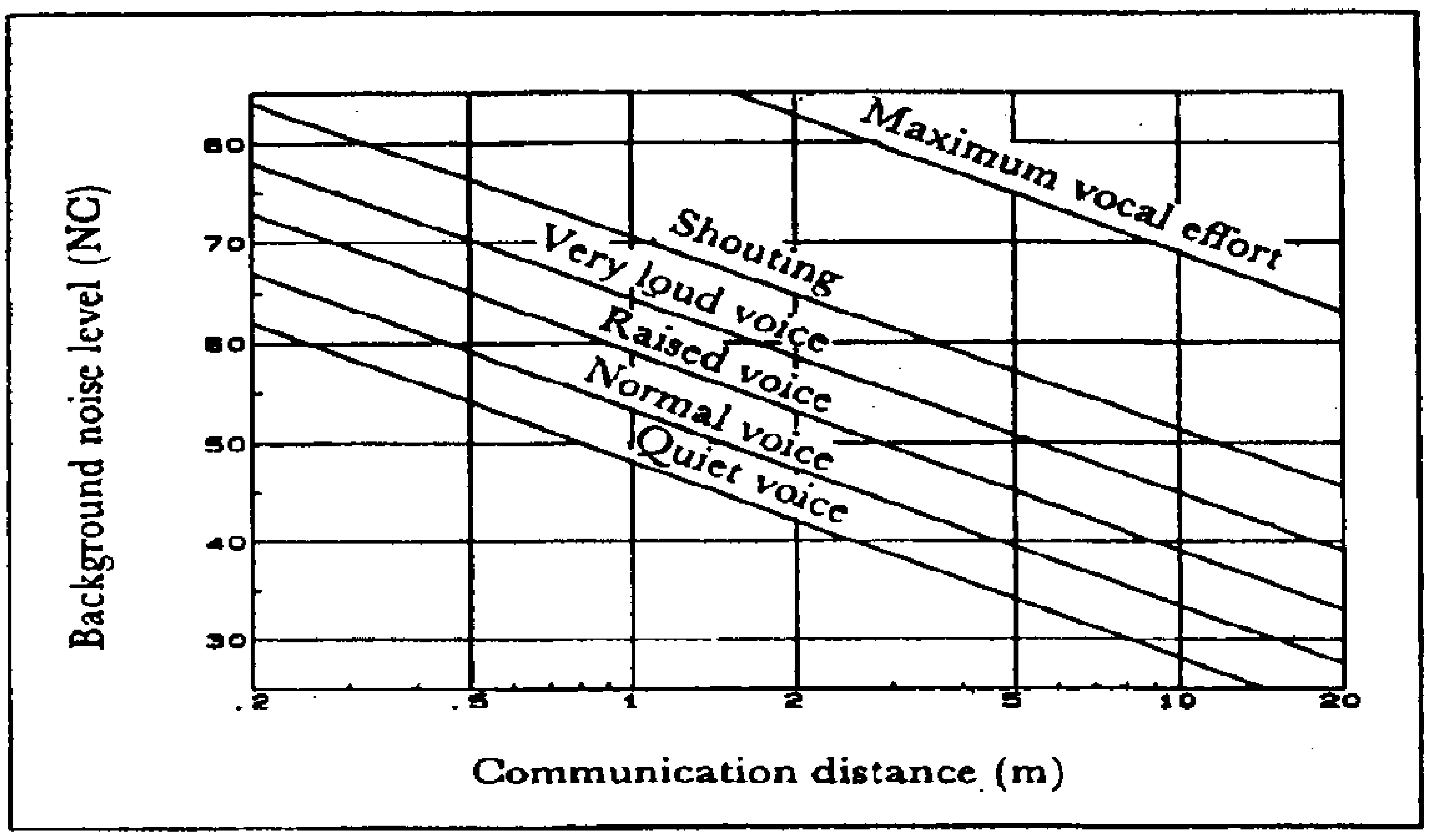


Figure 5.12. Noise levels of voice
(After Templeton and Saunders, 1987)

Values of speech interference level for steady continuous noise in which speech communications is barely possible (dB):

Distance between talker and listener	Voice levels (dB)			
	normal	raised	very loud	shouting
0.15	71	77	83	89
0.3	65	71	77	83
0.6	59	65	71	77
0.9	55	61	67	73
1.2	53	59	65	71
1.5	51	57	63	69
1.8	49	55	61	67
3.7	43	49	55	61

Table 5.6. Voice levels (After Templeton and Saunders, 1987)

2. Railway noise

Railway noise in Yogyakarta can be ignored as the numbers of railway stations and railway lines are small. Trains in Yogyakarta are not provided for city transportation, but only for regional transportation.

3. Aircraft noise

As well as railway noise, aircraft noise in Yogyakarta is also negligible due to the small number of flights.

4. Industrial noise

Although Yogyakarta has not separated noisy from quiet areas, industrial noise is small compared to traffic noise. Some industries are still located within the city centre and create noise for the neighbouring residential areas, but their effects are only locally and much lower compared to the effects of traffic noise.

5.4.2 Noise levels

As current data on noise levels in Yogyakarta, particularly those that might represent noise levels in main streets and residential streets are not published, the noise level data were taken from primary data derived from field measurements. The field measurements were carried out by the Faculty of Engineering at Atma Jaya Yogyakarta University (UAJY), based on time and measurement points as specified by the author. The specifications of sound level meters used for this measurement can be seen in Appendix 5.

The data on noise conditions in Yogyakarta was collected during a period of seven days, eleven hours for each day, in main streets and secondary streets adjacent to housing. Conditions in the secondary streets differ from other streets, as at busy times the street is used for short-cut routes. Hence this short-cut street is as busy as the main streets.

L_{eq} (dBA) is the most important and frequently used evaluation parameter in road traffic noise assessment. Measurement equipment that allows direct acquisition of this value, known as integrating sound level meters, is suggested for measurements. However, because the only sound level meter available for use in the field trial was not of this type, the noise was measured as a series of instantaneous sound levels. Below is a street map of Yogyakarta City indicating the locations where the measurements were taken.

Figure 5.13. North part of Yogyakarta's city centre block-plan, the arrow shows the area where the noise data was taken
(Source: Yogyakarta Block Plan)

Figure 5.14. Detailed location of noise measurements within the arrow zone of Figure 5.13
(Source: Yogyakarta Block Plan)

The noise and the density of vehicles were measured from the end of September 1997 to early October 1997 for street type A (main streets) and street type B (secondary streets for short-cut routes). Refer to Figure 5.14, the sound level meters were set adjacent to one of street type A (♦) and one of street type B (•), at the kerb, at approximately 1 -1.5 m above the ground (1 m is standard for sitting activities and 1.5 m is standard for standing activities) and 3 m from the front walls (Figure 5.15).

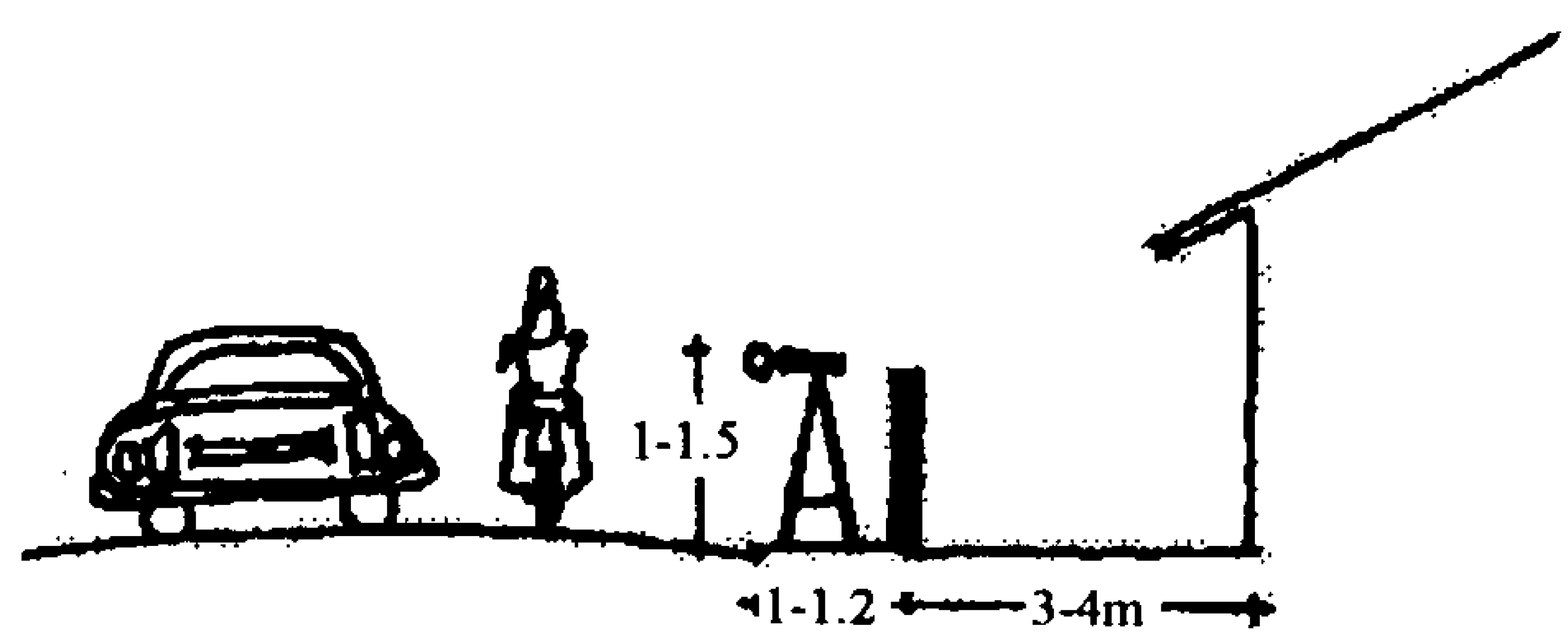


Figure 5.15. Detailed position of the sound level meter

- Street type A

1. Number of vehicles

Types of Vehicles	Types of Engines	Numbers/ hour	
		Peak Hours (approximately from 7.30 am to 1.30pm)	Normal Hours (other than the peak hours)
Trucks	diesel	5	3
Small Commercial cars (similar to vans)	50% diesel 50% gasoline	540	300
Buses	diesel	40	40
Small Buses	diesel	30	30
Private cars	3% diesel 97% gasoline	660	360
Motorbikes	gasoline	960	540
Total/hours		2,235	1,300
Approx. total in18 hours		26,205	
Average/hour (18 h)		1,456	

Table 5.7. Numbers and types of vehicles in street type A
(Source: Faculty of Engineering, UAJY, September 1997)

2. Noise levels measured over seven days

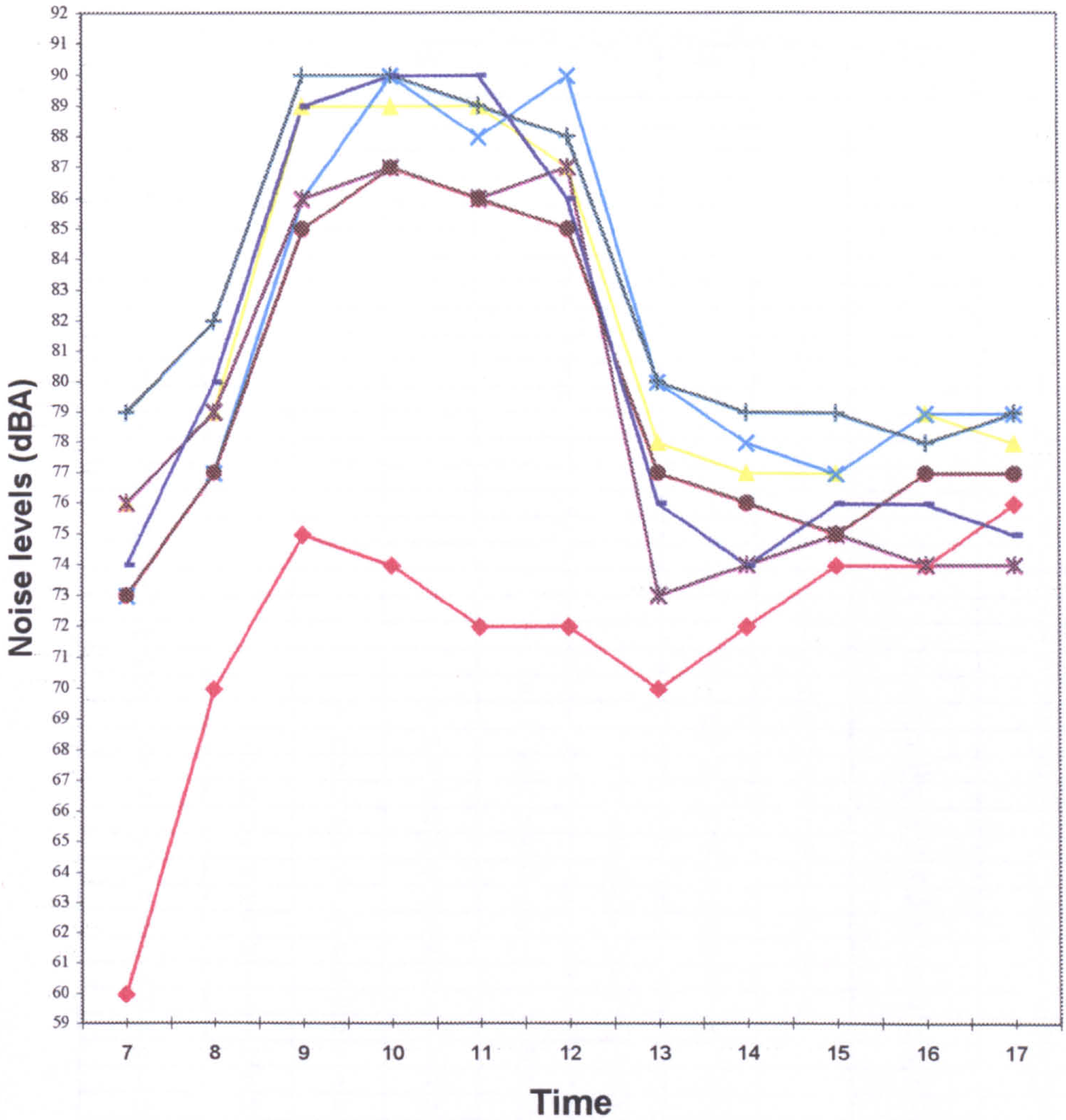


Figure 5.16. Seven days noise levels of street type A

Day	Average noise levels (dBA) at:										
	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00
Sunday ♦	60	70	75	74	72	72	70	72	74	74	76
Monday ▲	76	79	89	89	89	87	78	77	77	79	78
Tuesday x	73	77	86	90	88	90	80	78	77	79	79
Wednesday x	76	79	86	87	86	87	73	74	75	74	74
Thursday •	73	77	85	87	86	85	77	76	75	77	77
Friday +	79	82	90	90	89	88	80	79	79	78	79
Saturday –	74	80	89	90	90	86	76	74	76	76	75

Table 5.8. Noise levels measured over seven days in street type A
(Source: Faculty of Engineering, UAJY, September 1997)

3. Distribution of noise levels which are the detailed noise levels of Figure 5.16 (measured every 60 seconds over 11 hours = 660 data/day).

Keys:
Weekdays = Monday-Saturday
Weekend = Sunday

dBA	Number of instances/ day (6.30-17.30)								
	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Total A (weekdays)	Total B (7 days)
48							3		3
49									
50							1		1
51							3		3
52									
53									
54									
55							2		2
56									
57							2		2
58							3		3
59							3		3
60							13		13
61							15		15
62							11		11
63							1		1
64							1		1
65							7		7
66							3		3
67							3		3
68							7		7
69						4	15	4	19
70			1	3		5	44	9	53
71		4	7			14	54	25	79
72	2	15	10			18	133	45	178
73	27	16	20	18	2	26	74	109	183
74	76	15	32	77	17	63	95	280	375
75	36	13	65	55	71	43	74	283	357
76	56	9	134	73	25	43	28	340	368
77	69	12	64	129	84	22	15	380	395
78	81	47	31	56	55	16	3	286	289
79	31	151	20	12	93	63	28	370	398
80	27	67	20	1	57	70	13	242	255
81	6	16	15		10	31	3	78	81
82	5	20	6		5	2	3	38	41
83	7	18	2	2	7	8		44	44
84	15	4	8	17	3			47	47
85	45	4	48	31	3	16		147	147
86	53	20	16	17	16	63		185	185
87	54	70	55	48	40	38		305	305
88	44	42	57	12	44	50		249	249
89	23	28	17	26	20	17		131	131
90	3	46	23	52	75	27		226	226
91		36	4	20	24	13		97	97
92		7	5	5	9	8		34	34
93				5				5	5
94				1				1	1
TOTAL	660	660	660	660	660	660	660	3960	4620

Table 5.9. Distribution of noise levels in street type A

- Street type B

1. Number of vehicles

Types of Vehicles	Types of Engines	Numbers/ hour	
		Peak Hours (approximately from 7.00am to 8.00am and from 1.00pm and 2pm)	Normal Hours (other than the peak hours)
Trucks	diesel	0.36	0.006
Small Commercial Cars (similar to vans)	50% diesel 50% gasoline	360	120
Buses	diesel	0.162	0.0027
Small Buses	diesel	0.3	0.005
Private cars	3% diesel 97% gasoline	480	120
Motorbikes	gasoline	660	300
Total/hours		1,500.822	540.0137
Approx. total in18 hours		12,603	
Average/hour (18 h)		700	

Table 5.10. Numbers and types of vehicles in street type B

2. Noise levels measured over seven days

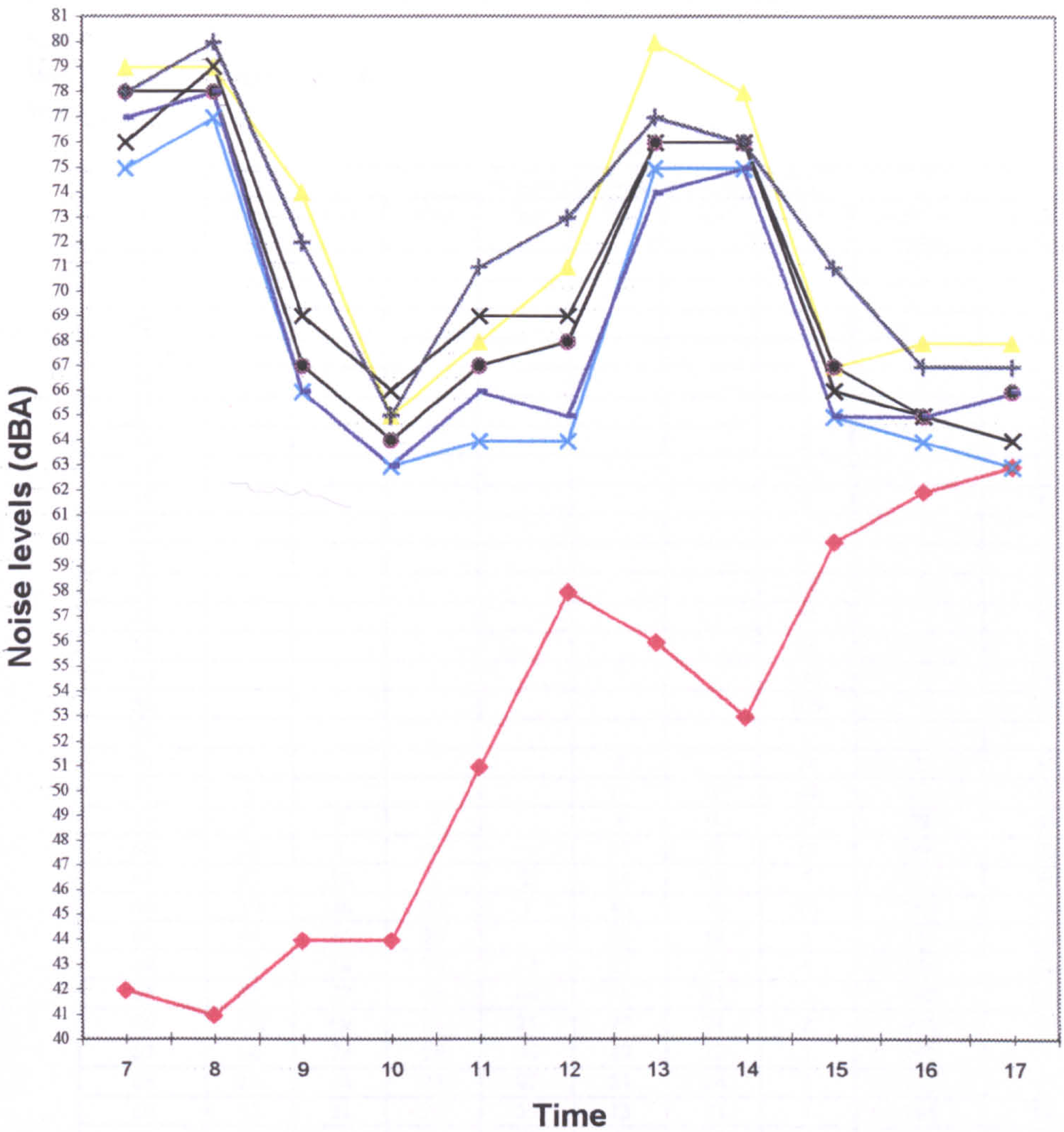


Figure 5.17. Seven days noise levels of street type B

Day	Average noise levels (dBA) at:										
	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00
Sunday ♦	60	70	75	74	72	72	70	72	74	74	76
Monday ▲	76	79	89	89	89	87	78	77	77	79	78
Tuesday x	73	77	86	90	88	90	80	78	77	79	79
Wednesday x	76	79	86	87	86	87	73	74	75	74	74
Thursday •	73	77	85	87	86	85	77	76	75	77	77
Friday +	79	82	90	90	89	88	80	79	79	78	79
Saturday –	74	80	89	90	90	86	76	74	76	76	75

Table 5.11. Noise levels measured over seven days in street type B
(Source: Faculty of Engineering, UAJY, September 1997)

3. Distribution of noise levels which are the detailed noise levels of Figure 5.17 (measured every 60 seconds over 11 hours = 660 data/day).

Keys:
Weekdays = Monday-Saturday
Weekend = Sunday

dBA	Number of instances/ day (6.30-17.30)								
	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Total A (weekdays)	Total B (7 days)
40									
41							1		1
42							1		1
43									
44							5		5
45							2		2
46							5		5
47							14		14
48							6		6
49							2		2
50							13		13
51							31		31
52							56		56
53							88		88
54							136		136
55							109		109
56									
57					2		78	2	80
58	1				13	3	44	17	61
59	1	3	4		8	6	11	22	33
60	16	1	8		17	17	13	59	72
61	21	12	3	2	24	21	7	63	90
62	39	46	33	1	46	54	19	219	238
63	64	35	59		53	34	1	245	246
64	55	38	78	12	27	66	4	276	280
65	41	77	66	64	76	43	2	367	369
66	121	69	81	25	79	71	2	446	448
67	66	73	99	96	47	12	1	393	394
68	23	44	32	87	21	24	3	231	234
69	25	21	20	53	13	53	1	185	186
70	30	21	17	37	9	44	3	158	161
71	51	68	57	102	11	64	2	353	355
72	30	54	24	71	41	32		252	252
73	11	37	17	35	55	17		172	172
74	19	25	23	8	63	23		161	161
75	9	11	5	14	22	21		82	82
76	18	6	13	19	8	33		97	97
77	5	4	9	6	7	9		40	40
78	3	4	3	11	2	5		28	28
79	2	2	6	7	4	2		23	23
80	5	3	1		1			10	10
81		1			1	2		4	4
82	2	3	2	1	3	3		14	14
83	2			2	4	1		9	9
84		2		7	2			11	11
85									
86					1			1	1
TOTAL	660	660	660	660	660	660	660	3960	4620

Table 5.12. Distribution of noise levels in street type B

The characteristics of road traffic are termed in sound pressure level (L), which mainly comprises of:

- L_{10} - the sound pressure level exceeded 10 percent of a time period;
- L_{50} - the sound pressure level exceeded 50 percent of a time period;
- L_{90} - the sound pressure level exceeded 90 percent of a time period.

The L_{50} is normally equal to the mean noise level throughout the measured period, while the L_{90} is sometimes called the residual noise level. In some cases, such as highway noise, an L_{10} is an indication of the nuisance level from the noise.

The energy equivalent sound level, L_{eq}, equals the constant sound level. The acoustic energy of the latter is equivalent to the acoustic energy of a fluctuating sound over a certain time interval. In the case of street traffic, the nuisance level of noise is indicated by the L_{eq}, as the standards for the living spaces from noise traffic are set in L_{eq}.

Based on the series of instantaneous sound levels collected above, the main characteristics of road traffic during major noise conditions were to be calculated below (L_{10}, L_{50}, L_{90} and, L_{eq}) [Chunnif, 1977].

To do the calculations for L_{10}, L_{50}, L_{90} and, L_{eq}, the data in Tables 5.9 and 5.12 has first to be transformed into a histogram. In order to gain the best results, the weekdays and weekend, which in this case means Sunday, are calculated separately, as there are very different noise levels between weekdays and weekend. Therefore, four histograms are shown.

1. Calculation of weekdays noise levels in street type A

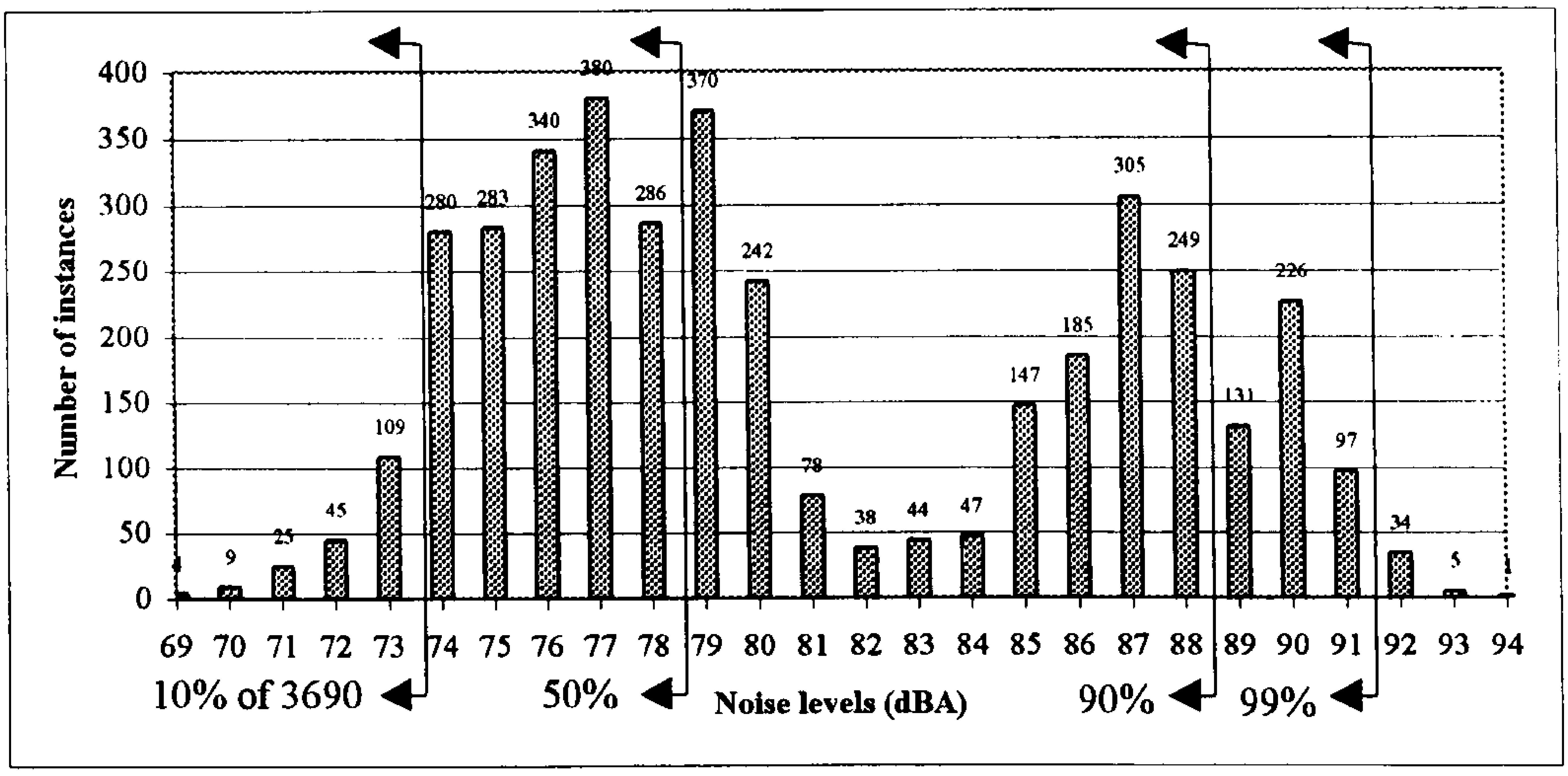


Figure 5.18. Histogram of weekday noise levels in street type A

Total area under the histogram is 3960 units.

L_{90} calculation: equates to 10% of the area under the histogram starting from the left to 10% of the total area. Referring to Figure 5.18.

$$192 + 280x = 396$$
$$280x = 204$$
$$x = 0.729$$

Where 396 is 10% from 3960
192 is the total below 10%
280 is the area above 10%
x is the area that we need to find to comply with the 10% ratio

So that

$$L_{90} = 73 + 0.729$$
$$= 73.729 \text{ dBA}$$

By using the same calculation method, the other L values can be calculated as follows:

L_{50} = 78.59 dBA (equates to 50% of the area under the histogram starting from the left)

L_{10} = 88.74 dBA (equates to 90% of the area under the histogram starting from the left)

L_1 = 91.01 dBA (equates to 99% of the area under the histogram starting from the left)

So that L_{eq} for street types A is

$$L_{eq} = L_{50} + 0.43(L_1 - L_{50}) \text{ [Chunnif, 1977]}$$
$$\mathbf{= 83.93 \text{ dBA}}$$

2. Calculation of Sunday noise levels in street type A

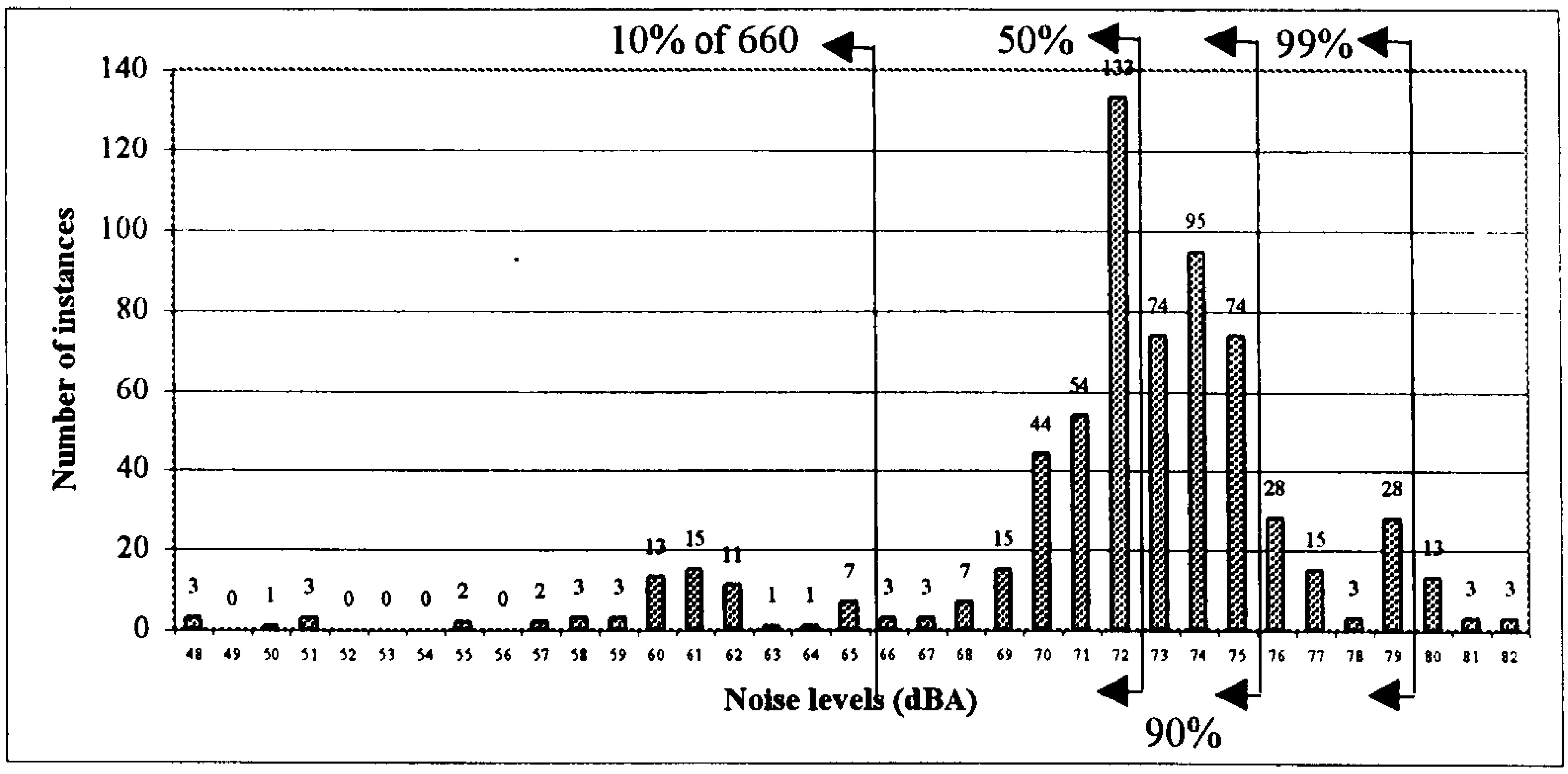


Figure 5.19. Histogram of Sunday noise levels in street type A

Total area under the histogram is 660 units.

Calculation of L_{90}:

$$65 + 3x = 66$$
$$3x = 1$$
$$x = 0.33$$

So that

$$L_{90} = 65 + 0.33$$
$$= 65.33 \text{ dBA}$$

By using the same calculation method, the other L values can be calculated as follows:

L_{50} = 72.08 dBA
L_{10} = 75.96 dBA
L_{1} = 79.95 dBA

So that L_{eq} for street types B is

$$L_{eq} = L_{50} + 0.43(L_1 - L_{50})$$
$$= \mathbf{75.46\ dBA}$$

3. Calculation of weekdays noise levels in street type B

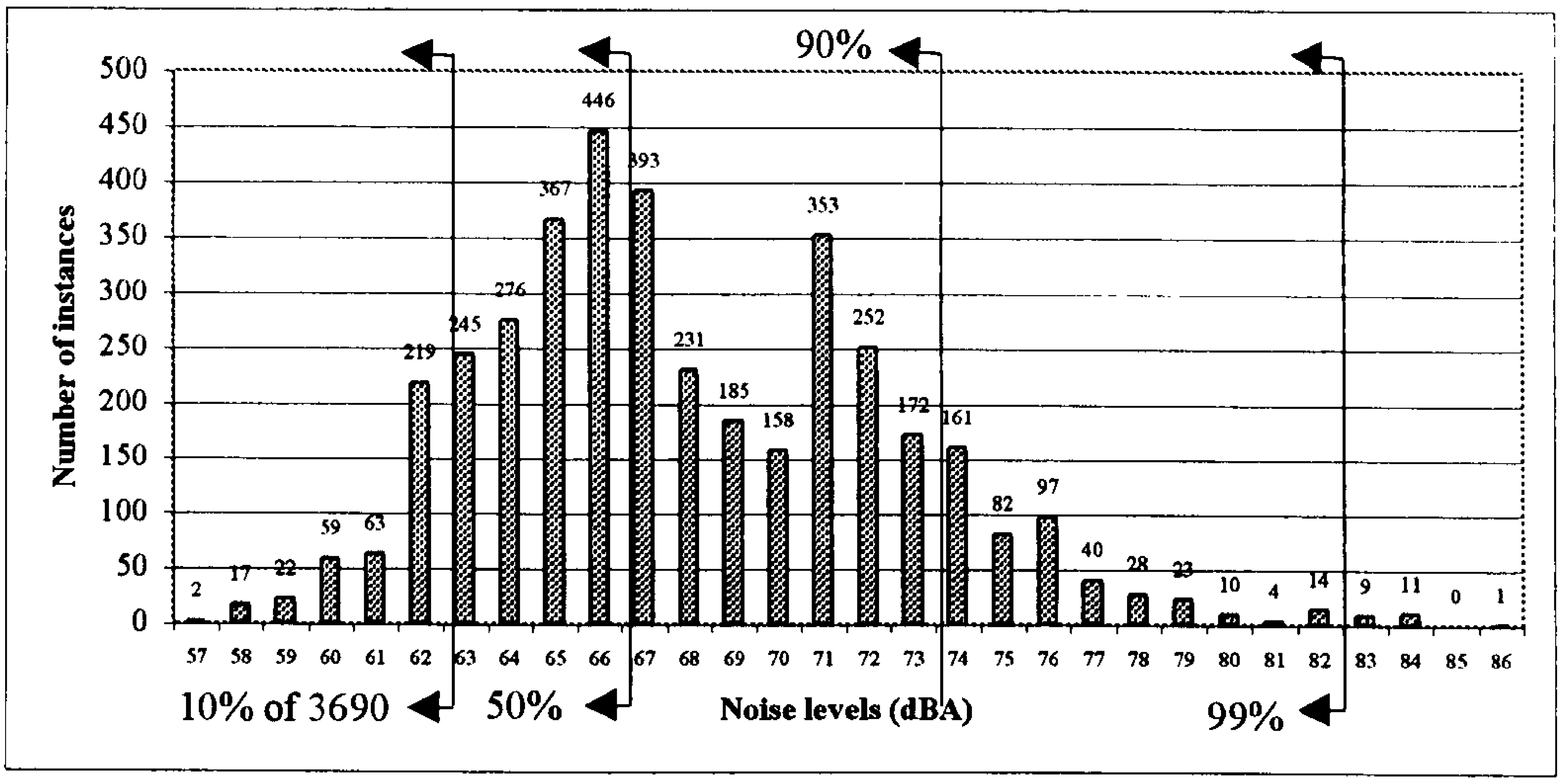


Figure 5.20. Histogram of weekday noise levels in street type B

By using the same formula of calculation for street types A, the L- values of street types B can be calculated as follows:

Total area under the histogram is 3960 units. L_{90} calculation: equates to 10% of the area under the histogram starting from the left to 10% of the total area. Referring to Figure 5.20.

$$382 + 245x = 396$$
$$245x = 14$$
$$x = 0.06$$

So that

$$L_{90} = 62 + 0.06$$
$$= 62.06 \text{ dBA}$$

By using the same calculation method, the other L values can be calculated as follows:

$$L_{50} = 66.67 \text{ dBA}$$
$$L_{10} = 73.65 \text{ dBA}$$
$$L_{1} = 82.16 \text{ dBA}$$

So that L_{eq} for street types B is

$$L_{eq} = L_{50} + 0.43(L_1 - L_{50})$$
$$= \mathbf{73.33\ dBA}$$

4. Calculation of Sunday noise levels in street type B

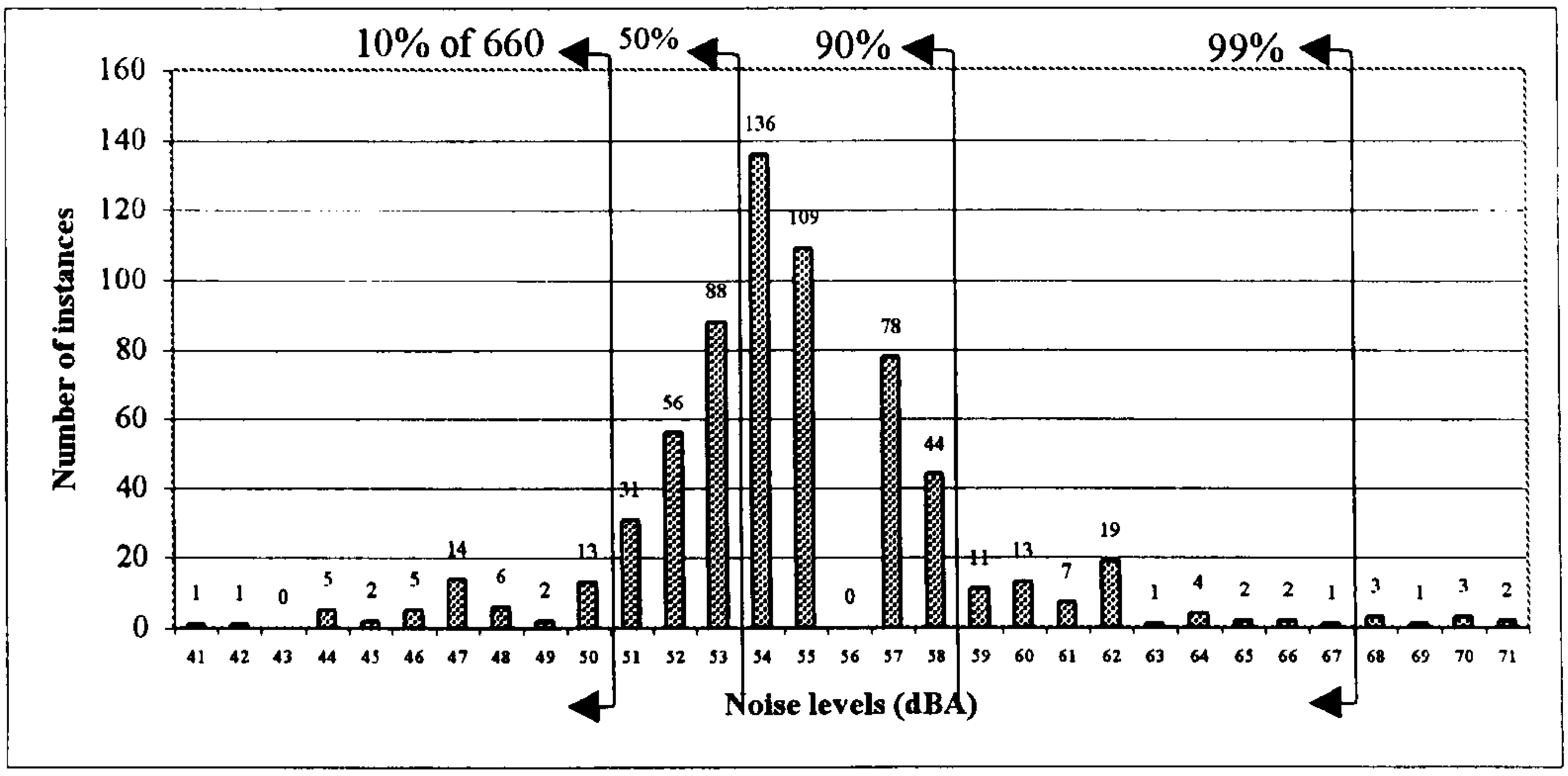


Figure 5.21. Histogram of Sunday noise levels in street type B

Total area under the histogram is 660 units.

Calculation of L_{90}:

$$49 + 31x = 66$$
$$31x = 17$$
$$x = 0.55$$

So that

$$L_{90} = 50 + 0.55 = 50.55 \text{ dBA}$$

By using the same calculation method, the other L values can be calculated as follows:

$$L_{50} = 53.78 \text{ dBA}$$
$$L_{10} = 58.27 \text{ dBA}$$
$$L_{1} = 67.80 \text{ dBA}$$

So that L_{eq} for street types B is

$$L_{eq} = L_{50} + 0.43(L_1 - L_{50})$$
$$= \mathbf{59.81\ dBA}$$

Values of these noise characteristics (L_{10}, L_{50}, L_{90} and, L_{eq}) are principles for further planning considerations.

5.5 Conclusion

It is probably their culture and limited education that encourage Indonesians, particularly Yogyakartanese and the low-income families, to passively accept poor physical conditions of the house and poor environmental conditions surrounding the house. They have not complained about the noise conditions, at least not in a formal manner, yet. However, it is obvious that the traffic noise is extremely high, up to 80 dBA (L_{eq}) (and that sooner or later this may well impair the health of local populations) is well above recommended noise levels for residential districts.

PART III

POSSIBILITY OF USING BOTH NATURAL VENTILATION AND POLLUTANT ATTENUATION IN THE DESIGN

CHAPTER 6

PRINCIPLES OF PROVIDING INDOOR THERMAL COMFORT

The study of pollutants involves three factors: sources, mediums, and receivers. All these factors are important in attempts to reduce the pollutants. The result of this study will show where building design can reduce the effect of pollutants in particular climatic conditions, effectively, whether it is at source, as they travel through the air or at the receiver's point of impact. Before a building is designed to effectively reduce outdoor pollution, the most important factor to include in the design is indoor thermal comfort, which for buildings in tropical climate mostly depend on ventilation.

6.1 Mechanism of natural ventilation

As mentioned in Chapter 3, ventilation is the replacement of internal air with outside air. A low cost building will mostly depend on natural ventilation to maintain indoor comfort. Natural ventilation occurs when there is a pressure difference between inside and outside, which is induced by wind and temperature differences. Wind pressure on a building depends on wind direction, building shape, and wind velocity. In most cases, this is also affected by obstruction from neighbouring buildings or walls. Temperature differences between indoors and outdoors cause density differences in the air, which in turn cause pressure differences. Airflow rate through openings is not linearly related to pressure difference, so for any openings, wind induced and stack induced flows cannot readily be added together. The pressure generated (wind and/or temperature) is used to balance the resistance to airflow of all the openings on the air route through the buildings.

The type of ground cover affects the wind speed gradient. Wind speed increases with height. Due to their surface conditions, in suburban areas (rough wooded country) and city centres, the rate of increase in speed with height is lower than that in an open country or sea. Figure 6.1 shows how these principles operate graphically.

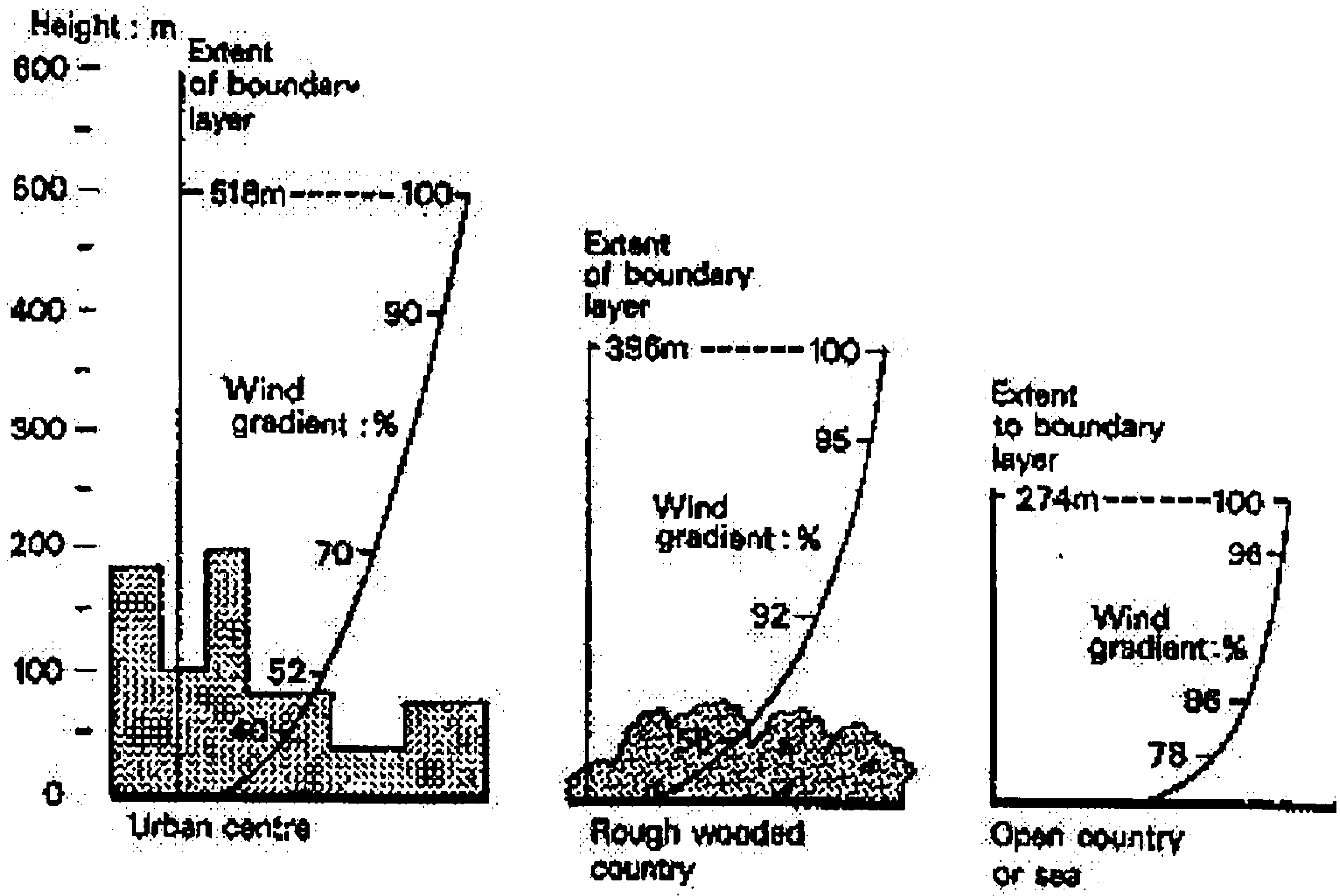


Figure 6.1. Wind velocity gradients
(After O.H. Koenigsberger, et al, 1973)

Figure 6.1 represents the reduction of wind speed gradient as a general condition, which can be used as a reference for a particular region.

6.1.1 Design planning

Environmental concepts are important in building design. Design based on environmental concepts will give more chance for the building to provide indoor comfort. There are several factors to be considered in discussing environmental concepts for building design.

A. Building layout

In order to optimise the natural ventilation potential of a design, wind direction and the possibility of obstruction, especially in urban areas, need to be considered. The following figures show detailed descriptions of the above conditions.

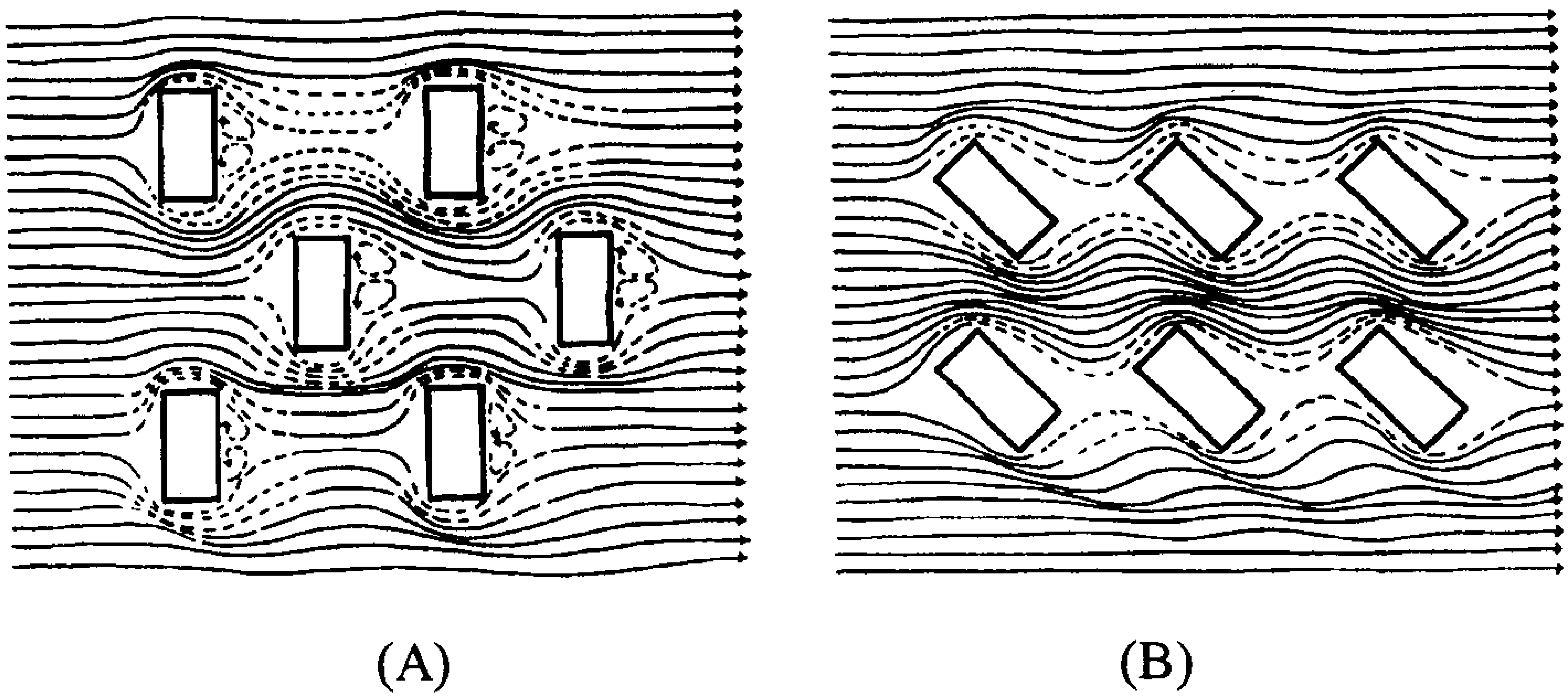


Figure 6.2. Building layout and wind impact
(A) Linear building layout will obstruct air movement caused by wind shadows
(B) Staggered building layout reduces the areas of wind shadows
(After F.Moore, 1993)

B. Openings orientation and position

Orientation and position of openings are important for buildings with natural ventilation. Good building layout is unlikely to be able to provide the required air change if the orientation and position of the openings are imperfect: for example when openings are wrongly oriented to low wind speed, installed lower or higher than body height, or installed to face pollution sources. When wind direction is oblique to opposite openings, the wind can reach most of the room's corners. On the other hand, when wind direction is perpendicular to opposite openings, the air simply passes through the rooms. Thus, an oblique wind direction induces better distribution of air within rooms using opposite openings and a perpendicular wind direction induces better distribution of air within rooms without opposite openings.

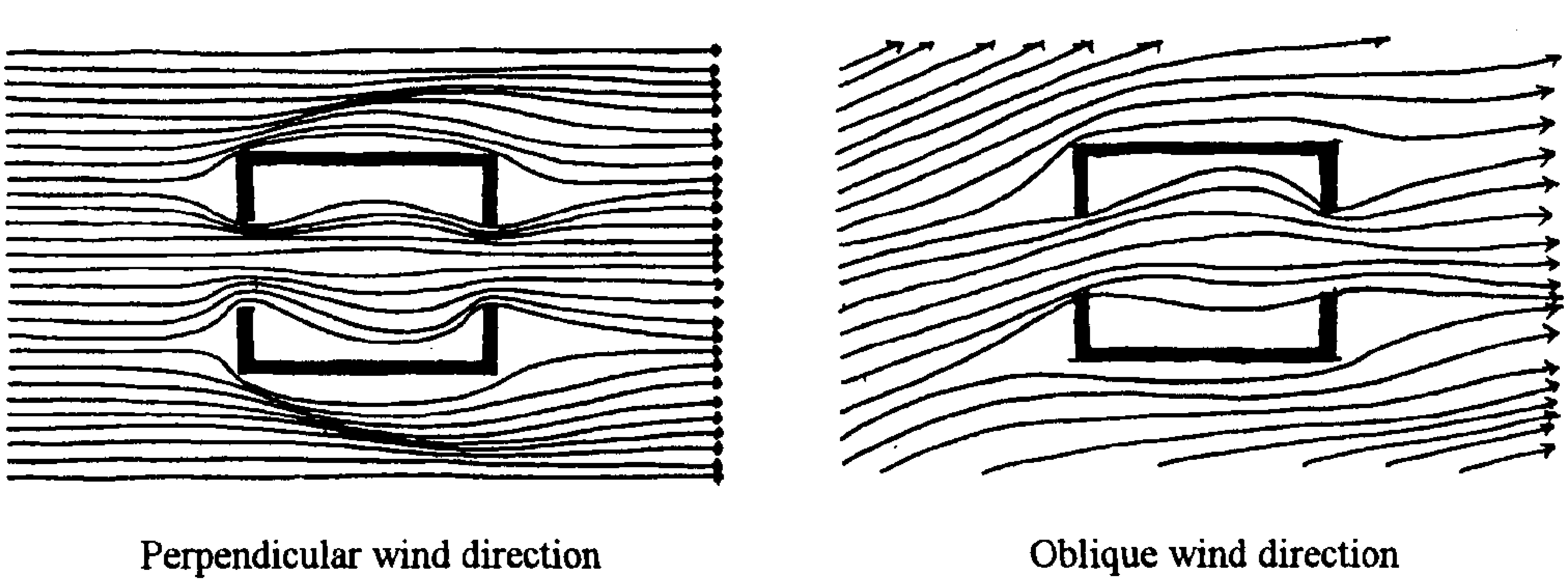
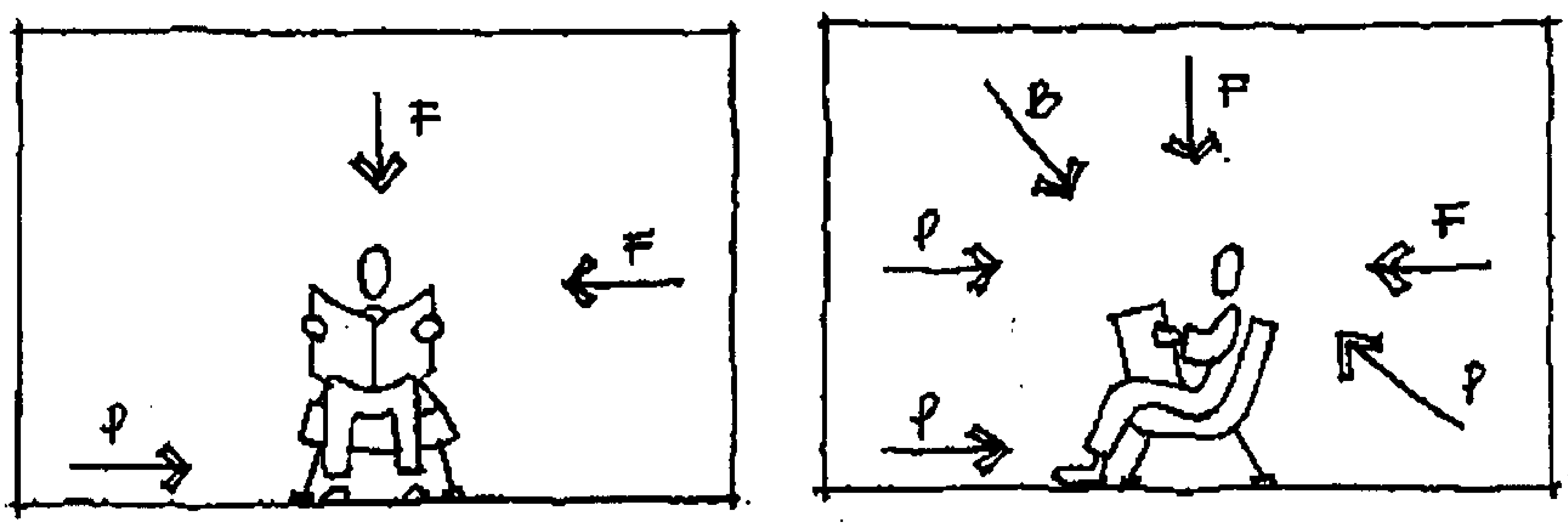


Figure 6.3. Air stream within a room related to prevailing wind direction
(After F.Moore, 1993)

Openings should be positioned at levels appropriate for man's activities, which is approximately 100 to150 cm for standing activities and 80 cm for sitting activities. Wind, particularly high wind speed, should also not blow directly onto the neck [Egan, 1975], the forehead and the ankles [McMullan, 1992] as they are the most sensitive part of the human body to wind.



B = best, F = fair, P = poor

Figure 6.4. Wind direction to maintain human comfort according to sitting activities (After Egan, 1975)

C. Types of openings

Each building may have different types of opening according to a certain amount of required air changes per hour, which is derived from the functions of the building, areas provided on the walls and possibilities of neighbouring obstruction. There are several types of opening, such as roof/ceiling openings and wall openings. A roof opening can be a traditional jack roof or a chimney that will create a stack effect.

- Roofs

Air circulation through roofs occurs by infiltration by the use of small-fabricated roof materials (clay, asbestos, or wood). Intentional air circulation in the roof can be achieved by using small openings along the joints between roofs and roofs (if using double roofs, refer to Figure 6.5) or between roofs and walls. In principle, natural ventilation through roofs is effective when there are openings underneath the roof openings as this will create cross ventilation, replacing hot air inside the rooms with cool air from outside. A jack roof with louvres is very effective in encouraging ventilation by stack effect. There are several advantages in using roof openings, such as minimising direct air and noise pollution. However, these types of opening are difficult to control whether closed or opened.

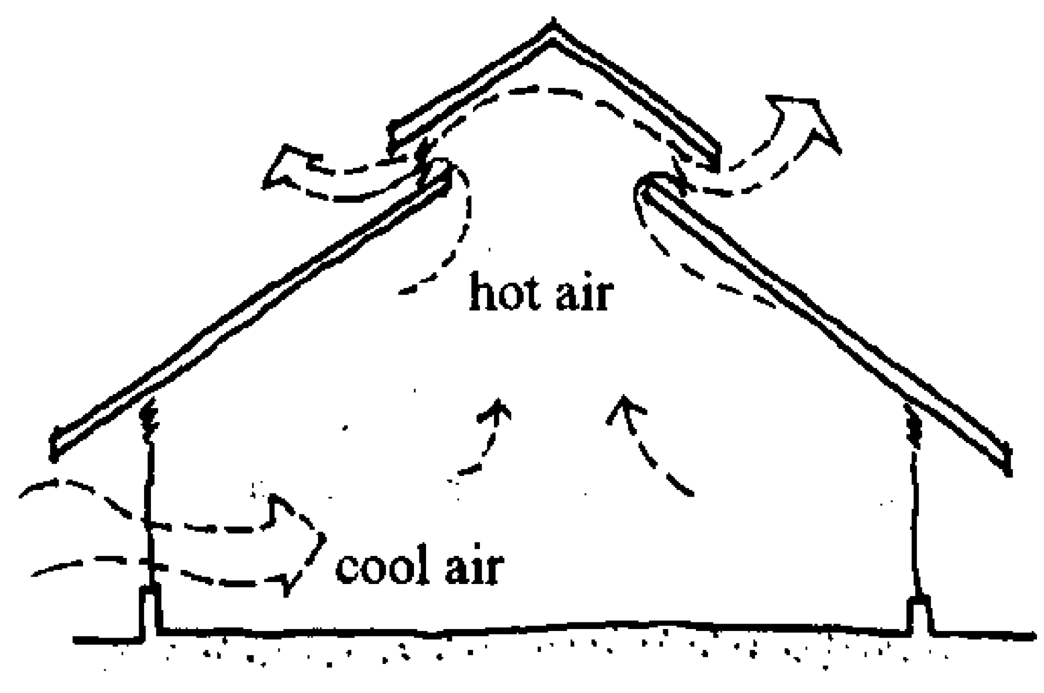


Figure 6.5. Jack roof
There are openings between lower roof and upper roof.

- Ceilings

Natural ventilation through ceilings must be designed together with roof openings. The provision of fixed openings above the window head at the ceiling level helps to draw hot air and moisture out of the rooms, whilst cool outside air replaces the hot air through openings at lower levels.

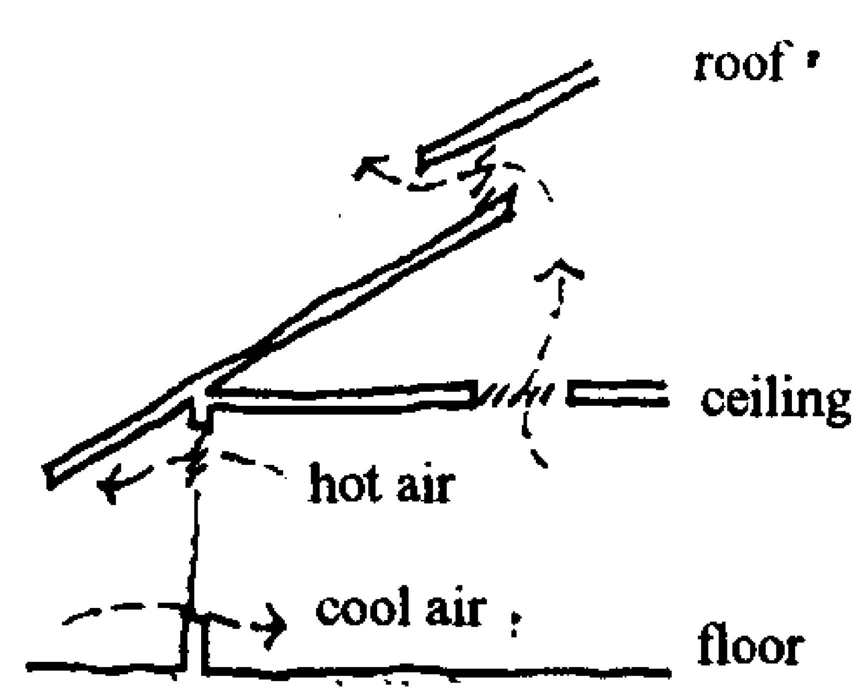


Figure 6.6. Roof and ceiling openings

- Windows

Windows are types of opening that permit ventilation. Windows also permit the entry of air pollution and noise. However, windows are still preferred, as they are easier to control according to people's needs. Windows have various functions, such as for ventilation, light and view. Windows may vary in style and function; for example in a hot humid climate and crowded urban areas, windows are mostly used for natural ventilation, whilst in a moderate climate, they are used for providing solar light and view. Windows that are mostly used for natural ventilation need to fulfil the following criteria [BRE Digest 399, 1994]:

- provide sufficient ventilation rates for comfort cooling but not to cause draughts;
- provide sufficient glare-free daylight and adequate outside views;
- keep out excessive solar gains;
- provide good insulation and avoid condensation;
- allow occupants to adjust finely the openable areas;
- easy to operate.

For openable windows, the maximum achievable air velocity in the inner areas is determined by the distance from an open window and by the degrees of obstruction in the air path. Occupants near windows with control over the windows may tend to open or close the windows to suit only their own comfort. To prevent this, distance and window style/type are also important to consider. Several window types with percentage of airflow are shown in Figure 6.7.

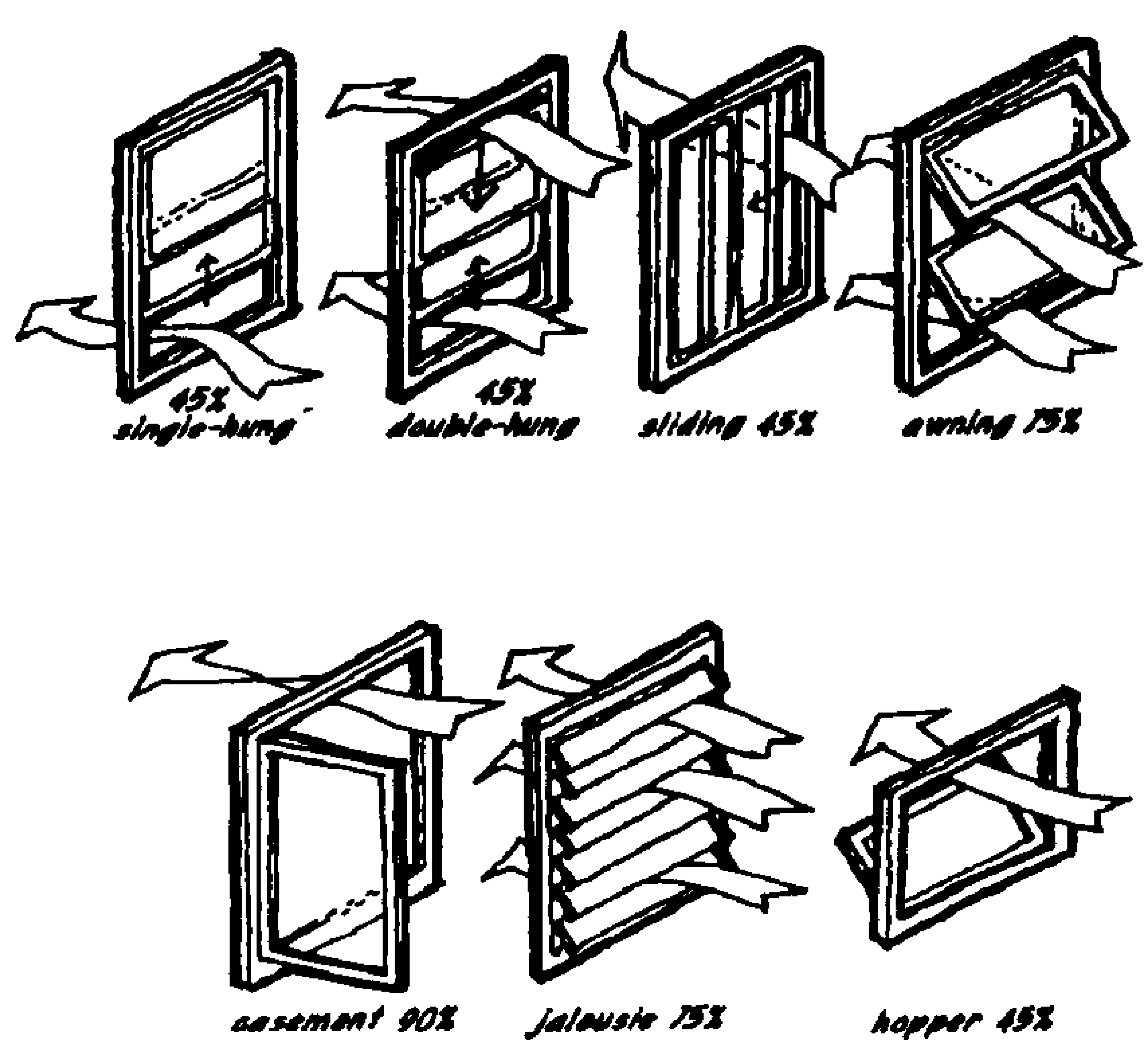


Figure 6.7. Porosity of various types of window
(After F.Moore, 1993)

In urban areas, a good window design should be able to reduce air and noise pollution. Particular window designs which reduce pollution will be discussed in later chapters. In detail, important factors to consider in using window for natural ventilation are discussed below.

1. Orientation

   It is important to orientate windows to face good prevailing wind and to avoid direct sunlight, which quickly increases indoor heat. When the window orientation for the prevailing wind makes it difficult to avoid direct sunlight, the use of a sun screen is suggested. In Indonesia, winds mostly blow from the south east to the north west, hence north-south is the preferred orientation for houses and windows to gain the benefit of the prevailing winds and to avoid east west direct sunlight.

2. Position

   Windows, particularly the inlet windows, should be placed at the height of occupant activities, for comfort reasons. The outlets are better placed higher than the inlets to permit hot air to leave the rooms easily. The preferred heights of inlets is about 60cm to 80cm above ground due to the height of occupant activities at approximately 80cm (sitting) and 150cm (standing).

3. Dimension

   In any climatic conditions, the bigger the windows the greater the number of air changes per hour. Window dimensions that offer the air changes per hour required for indoor comfort (approximately 30 ach) [F.Moore, 1993] and, as much as possible, minimise pollutant intrusion are preferred. Ratios of dimensions between inlets and outlets mostly affect indoor air velocities. In general, inlet and outlet sizes should have similar dimensions, since values of ventilation are mainly a function of the smaller openings. However, when one of the openings is to be smaller, this should be the inlet, as smaller inlets will maximise the velocity of indoor streams. With these types of openings, the velocity of incoming air near the inlet window can exceed that of the outside, and then reduce accordingly toward the centre and the end of the rooms [Lechner, 1991 and F. Moore, 1993]. When the air temperature is lower than the skin temperature, air velocity is the most significant factor that affects indoor comfort in naturally ventilated buildings, as it will expand the comfort zone.

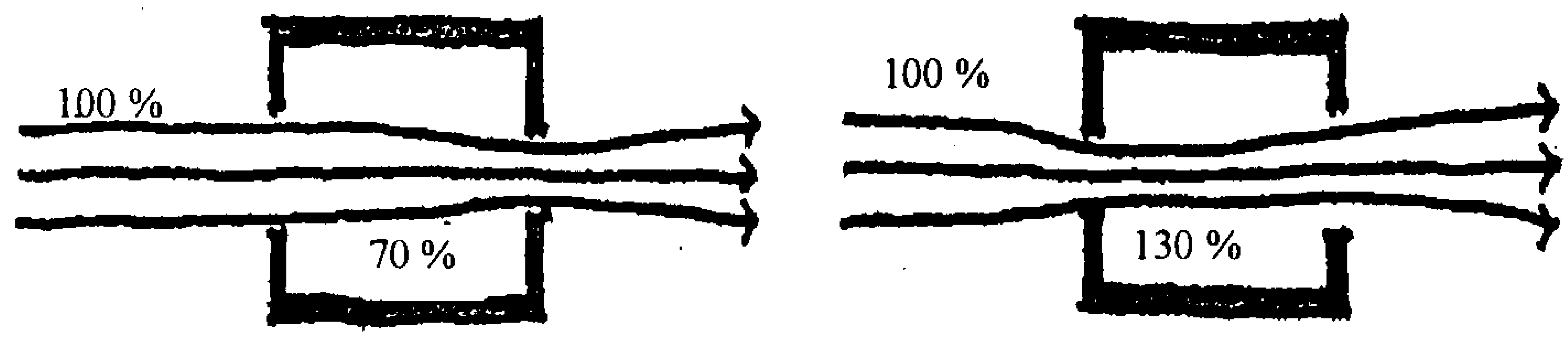


Figure 6.8. Particular dimensions of inlet and outlet
in relation to indoor air velocities measured just after the inlet
(After Lechner, 1991)

It is also possible to create greater indoor airflow by using different window styles, even when both the inlets and outlets have similar dimensions. As one of the examples is to use window types which permit 75 % effective open areas (louvre/jalousie or awning windows) as the inlets and window types which permit 90 % effective open areas (casement windows) as the outlets [F. Moore, 1993].

4. Material

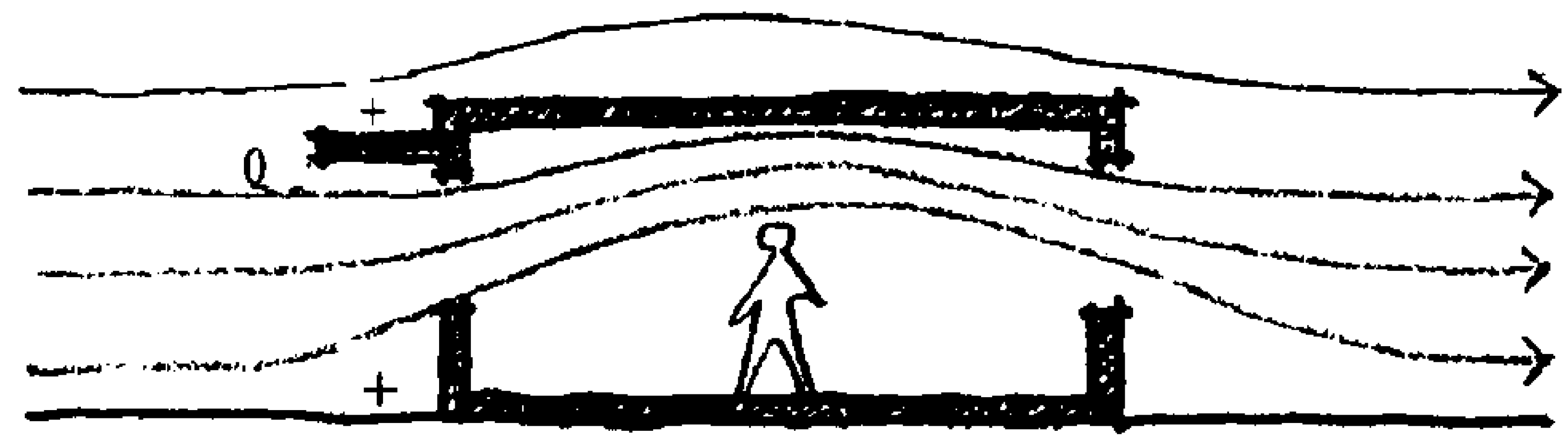
Materials have no significant effect on the pattern of indoor airflow. However, it is better to use materials which will not absorb and transmit heat from solar radiation. When such materials are utilised, indoor heat can be minimised and thus fewer air changes per hour are required.

5. Style

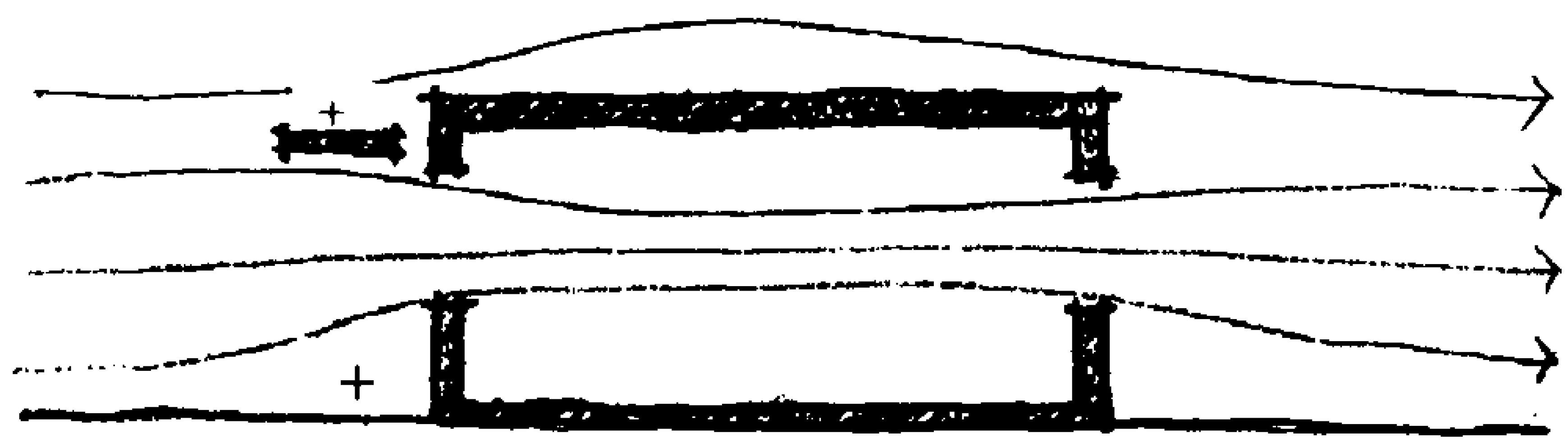
Each style or type of window, particularly openable windows, requires particular dimensions. For example, based on safety and ease of operation, the width of an openable side-hung window should not exceed 100cm and the height of an openable top-hung window should not exceed 175cm. In using natural ventilation, it is suggested that window types which offer larger effective open areas such as casement (90%) and jalousie or awning (75%) are chosen. Window styles that offer both natural ventilation and noise reduction are preferred.

6. Window accessory

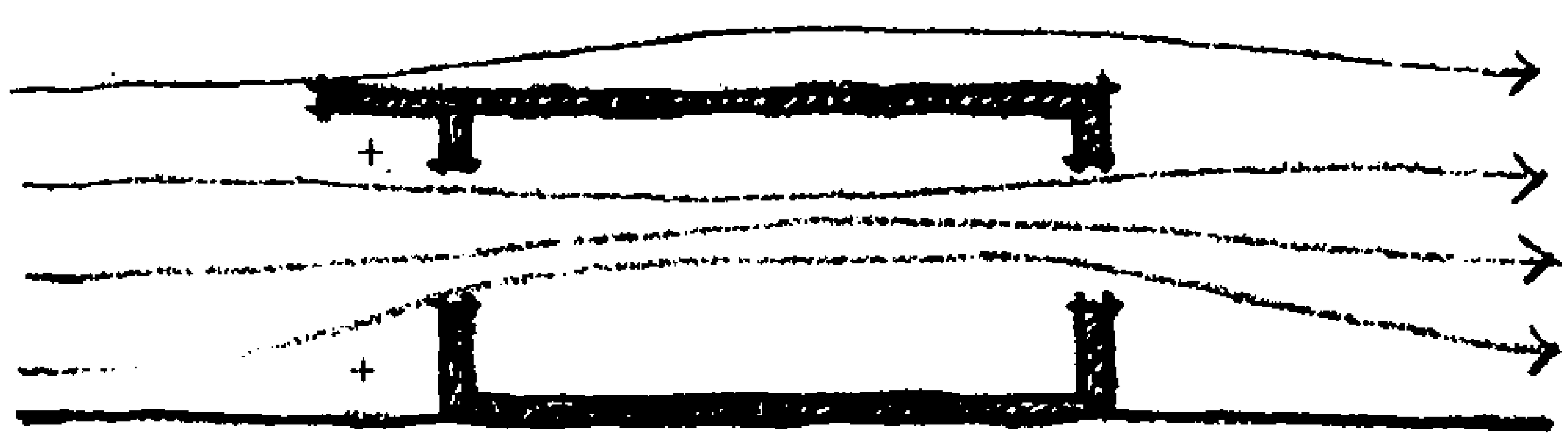
Buildings in hot tropical countries need to complete their windows with accessories that can reduce direct light and heat from solar radiation. This sun screen should not obstruct airflow, nor deflect airflow above or below occupant comfort levels.



a. A horizontal overhang causes the air to deflect upward



b. A gap about 15 cm as a minimum in a horizontal overhang will ventilate occupant comfort areas



c. A solid horizontal overhang that is placed high above the windows (about 30 cm as a minimum) will also ventilate occupant comfort areas

Figure 6.9. Position of overhangs as sun screens
(After Lechner, 1991)

A horizontal overhang just above the window causes the air stream to deflect toward the ceiling, as the solid overhang prevents the positive pressure above it from balancing the positive pressure below the windows. However, a gap of about 6 in (15 cm) or more will allow the positive pressure above it to affect the direction of the airflow. An overhang that is placed high above the windows will also direct the air stream down to the occupants [Lechner, 1991]. Another alternative is to use opaque jalousie windows, which automatically create sun screens for themselves.

6.2 Planning strategies in using natural ventilation by considering human comfort

6.2.1 Standards of human comfort

Ideally, human comfort is the first factor to consider in every design process. The main factor to be considered is the occupant's feelings about indoor comfort.

However, human feelings always seem subjective. Hence, only physical factors that induce indoor comfort are considered in this study.

- Physical factors of occupant comfort

As mentioned in Chapter 3, occupant feelings about warmth depend on air temperatures, radiant temperatures/surface temperatures, air movements, level of air freshness (whether or not it is polluted), humidity, and physical personal factors such as clothing and activities [Fanger, 1973 and McMullan, 1992]. On the other hand, occupant's feelings about noise mainly depend on location (in this case within houses) and activities. Factors of air temperature, radiant temperature, air movement and humidity will be discussed in further sections. Clothing factors will not be considered here because they are not regarded as a design issue, whilst occupant activities, as one of the factors that affect occupant comfort, need to be taken into account.

- Occupant activities

Occupant activities are important to study in designing buildings, especially in providing ventilation and noise comfort. Once the activities are determined, the best design can be achieved. In developing countries, low-income families commonly do their jobs at home. They are mostly engaged in simple home industries, such as making crafts, cooking snacks to be sold to neighbouring shops and doing traditional laundry (handwashing). Most of the activities being mentioned are hard working activities which automatically will significantly increase indoor heat during and at the end of the period of the activity. Sufficient ventilation rates are required to remove the indoor heat to maintain indoor comfort and health of the occupants. For these reasons, it is important to design low-cost housing with adequate openings that provide the required ventilation rates. Types of indoor activities in low cost housing in Yogyakarta are shown in Figures 6.10 and 6.11:

1. Adults' and children's activities both indoors and outdoors:

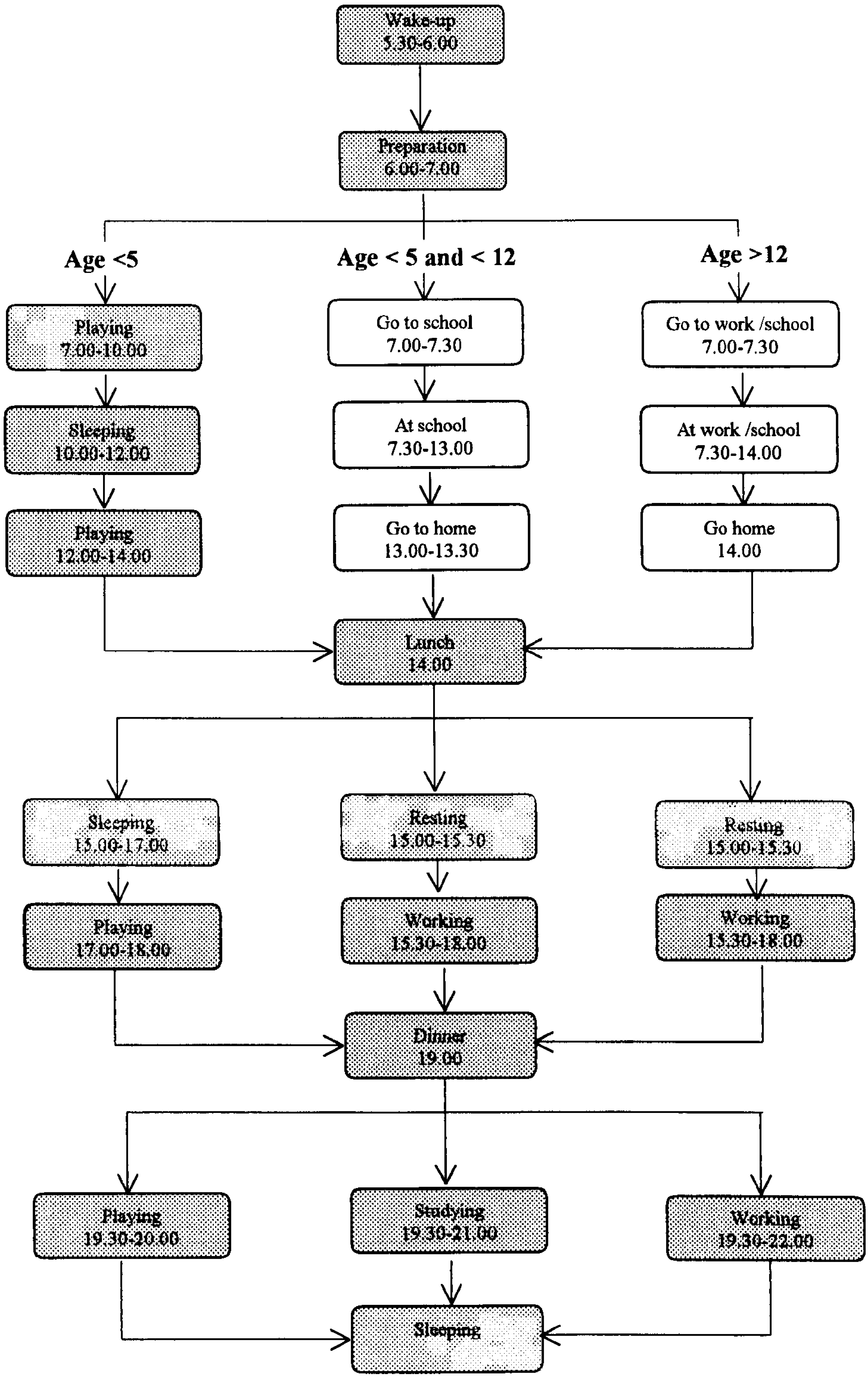


Figure 6.10. Occupant activities inside the house and elsewhere.

2. Adults' and children's activities mostly indoors:

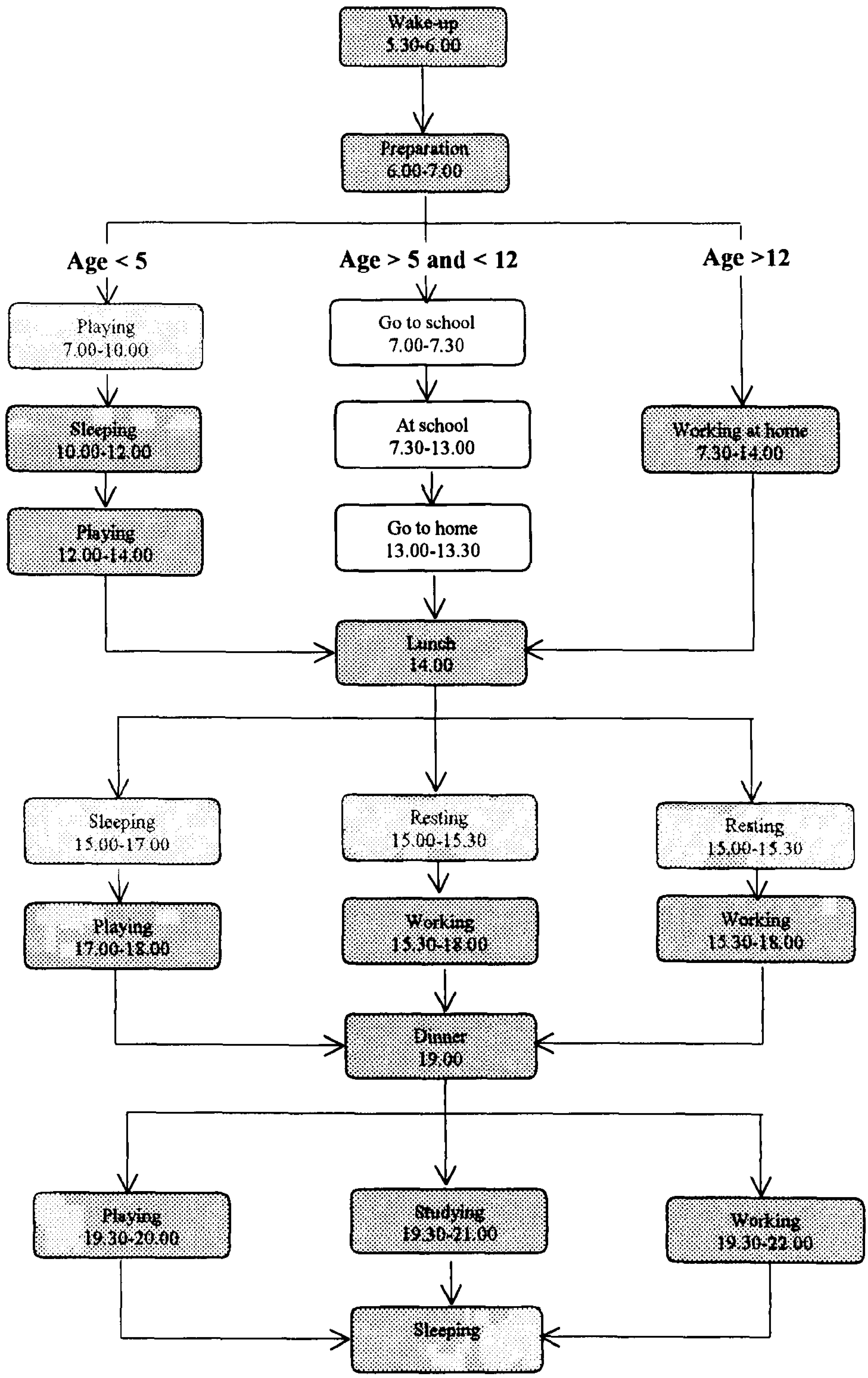


Figure 6.11. Occupant activities mostly inside the house.

Home activities   Elsewhere

Figures 6.10 and 6.11 show that the main activities of low income families differ between those families where most members work outside the house and those where most members work inside the house. However, from these figures, it can be seen that even in the families where main work is done outside the house, there are still many activities carried on inside the house after working hours. Thus, providing indoor comfort and protecting the occupants from pollution are very important in this type of housing.

6.2.2 Planning strategies using natural ventilation

It is very important to consider air quality issues, as many people live in buildings which are close to pollutant sources.

6.2.2.1 Air quality issues

Indoor air quality is a major determinant of personal exposure to pollutants in today's world. People spend much of their time in numerous different indoor environments, particularly occupants of low cost housing who spend most of their times within houses, either for work/study or for leisure. Moreover, it is the old, the very young, the infirm and also housewives who are most susceptible to the effect of pollutants. Indoor pollutant concentrations are sometimes higher than the heavily polluted outdoors. This is because of the accumulation from outdoor pollutants and domestic pollutants within the houses. However, this study is narrowed only to consider indoor air pollution caused by the intrusion of outdoor pollutants (i.e. from adjacent road traffic).

6.2.2.2 Design strategies with regard to air quality issues

The first consideration in providing fresh air by natural ventilation in polluted areas is location, i.e. the distance of housing from adjacent pollution sources. When the distance is very short, obstructing pathways of the pollutant is a possible solution, as it will obstruct pollutant pathways and therefore reduce the concentration. The best screening will obstruct pollutants, but will not cause too much obstruction to airflow for natural ventilation purposes.

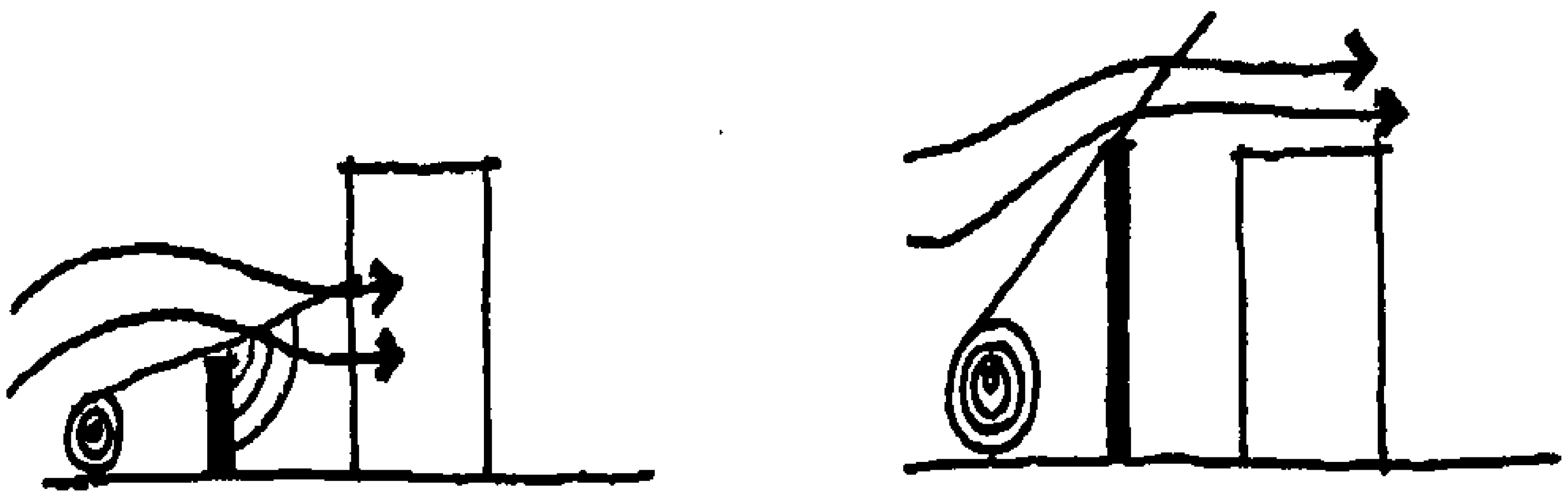


Figure 6.12. Dilemmatic barrier dimensions.
Low barrier permits natural ventilation as well as pollutants, whilst high barrier will obstruct both pollutants and natural airflow.

A further plan is to improve receiver conditions by considering orientation, building layout, and detailed design. All these receiver conditions should bring buildings in a sufficient distance from pollutant sources, avoid direct solar radiation which increases indoor heat, and also most importantly improve air movement. Building orientation affects indoor climates in two respects:

- solar radiation and its heating effect on walls and rooms facing different directions;
- ventilation problems associated with the relation between direction of prevailing winds and orientation of the buildings.

A. Orientation and solar radiation

Building orientation affects external surface temperatures depending on surface colour and materials. In addition, it affects internal surface temperature depending on colour, materials and wall thickness. In the case of low cost housing in Yogyakarta, since the houses are always very close one to each other in very limited area and, therefore, the walls are not much exposed to solar radiation, the effect of solar radiation on orientation (i.e. walls) can be ignored. It is mostly the colour of the roof that affects the room heating due to solar radiation. Clay tile is the most common roofing material, which unfortunately has naturally brown/reddish colour that will absorb considerable heat from solar radiation. A study of roofing material for warm humid climates shows that the use of brown/reddish clay tile caused the temperature just under the roof to be approximately 55°C. However, according to this study a horizontal ceiling fixed under the roof would reduce the temperature in the attic to approximately 36°C (the excess of ceiling temperature over the indoor air temperature is approximately 7.5°C) [Koenigsberger, O. and Lynn, 1965].

B. Orientation and ventilation

The ventilation conditions and the degree of efficiency of the opening's shading largely determine the effects of opening orientation on indoor temperatures. Research carried out by the Building Research Establishment (BRE), UK, showed that when there are only one or two openings, both on the leeward side of the buildings, the average indoor air velocity is very low. In this case, the velocity is almost independent of wind direction, and is approximately 10 % to 15% of the external wind speed. When the openings are placed on both windward and leeward sides, the average indoor velocity is much greater, ranging from 30% to 50% of the external speed, depending on the inlet and outlet sizes and on the relation between wind direction and the axis between inlet and outlet. When the wind is parallel to this axis, air flows straight through the room, ventilating only a limited section, particularly when the velocity is high. In the case where an opening is positioned at an angle of up to 60° to the direction of the wind, it is possible to create cross ventilation only from one exterior wall [Givoni, 1976].

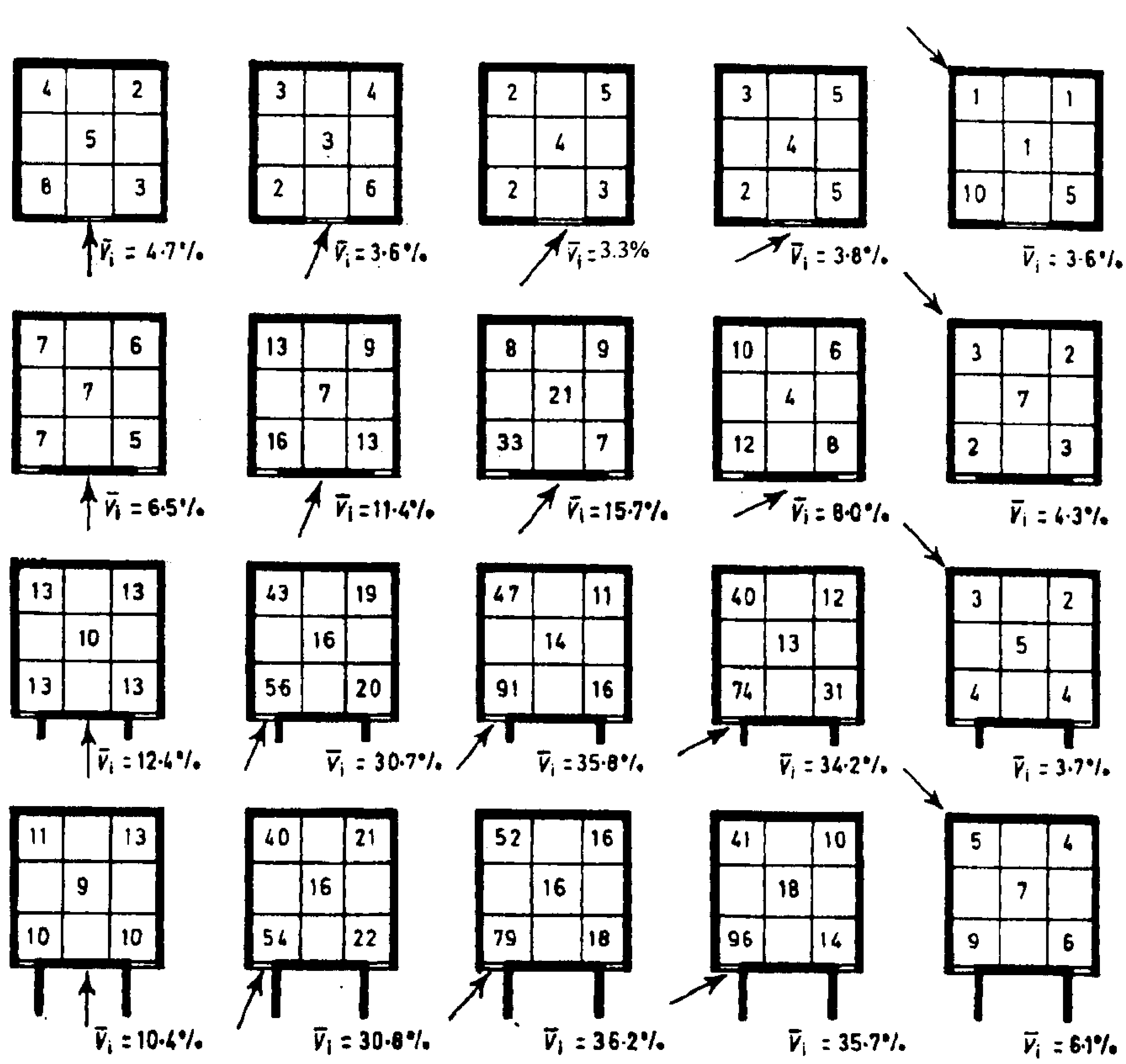


Figure 6.13. Percentage of indoor air velocity from outdoor air in using one wall cross ventilation system (After Givoni, 1976)

Figure 6.13 shows that cross ventilation may occur only by using one side wall (with the help of vertical side wings adjacent to the openings) with leeward wind direction (oblique wind). These specific opening apertures give the average indoor air velocity, as a percentage of external velocity (*Vi*), up to 36.2%.

C. Building layout

Building layout is also more important for inducing air motion than for affecting the pattern of solar radiation, particularly in high-density areas. A wise design should take account of air motion and acoustics in the layout. In the case of low cost housing with limited floor areas of 21m² or 36m², building layout is usually a term for room layout or the arrangement of rooms. Rooms that demand more air changes per hour and smaller protection from noise, such as a kitchen, are placed in the outer layers of the house. On the contrary, rooms that require more protection from noise, such as bedrooms, are placed in the inner layers of the house.

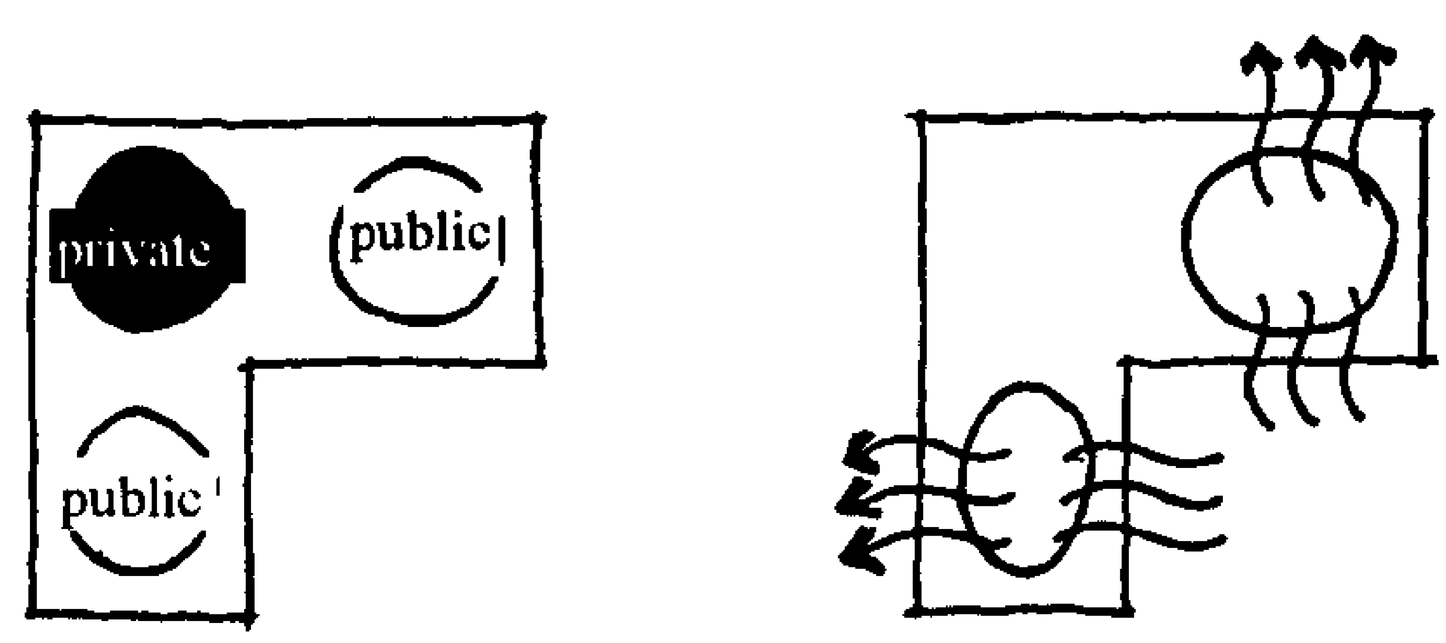


Figure 6.14. Position of public and private rooms with regard to ventilation demand

D. Building detailed design

Building detailed design can induce air velocity through the use of particular roof shapes, particular openings, and particular materials. Research carried out by J. Kindangen explored the relationship between roof shapes and ventilation rates. Kindangen showed that roof shapes impact on potential affective factors in inducing indoor air motion. Ten roof shapes were tested. Fortunately, the shape that is commonly used in Indonesia (the triangular roof (refer to model 7 in Figure 6.15) is categorised as a roof type that induces indoor air motion, according to Kindangen.

Kindangen's Research

In this study, "Effects of Roof Shapes on Wind-Induced Air Motion Inside Buildings" [1997], Kindangen investigated indoor airflow pattern in relation to different roof shapes by making use of computational fluid dynamics (CFD) codes. For this study, simulations were carried out on 10 models, as can be seen in Figure 6.15. Window sizes were identical at inlet and outlet, 1.5 m high and 3.78 m wide, corresponding to a wall porosity of 30%. This window size remained constant for all models. For this purpose, the models tested had the same dimensions: 7.2m x 7.2m x 2.7 m.

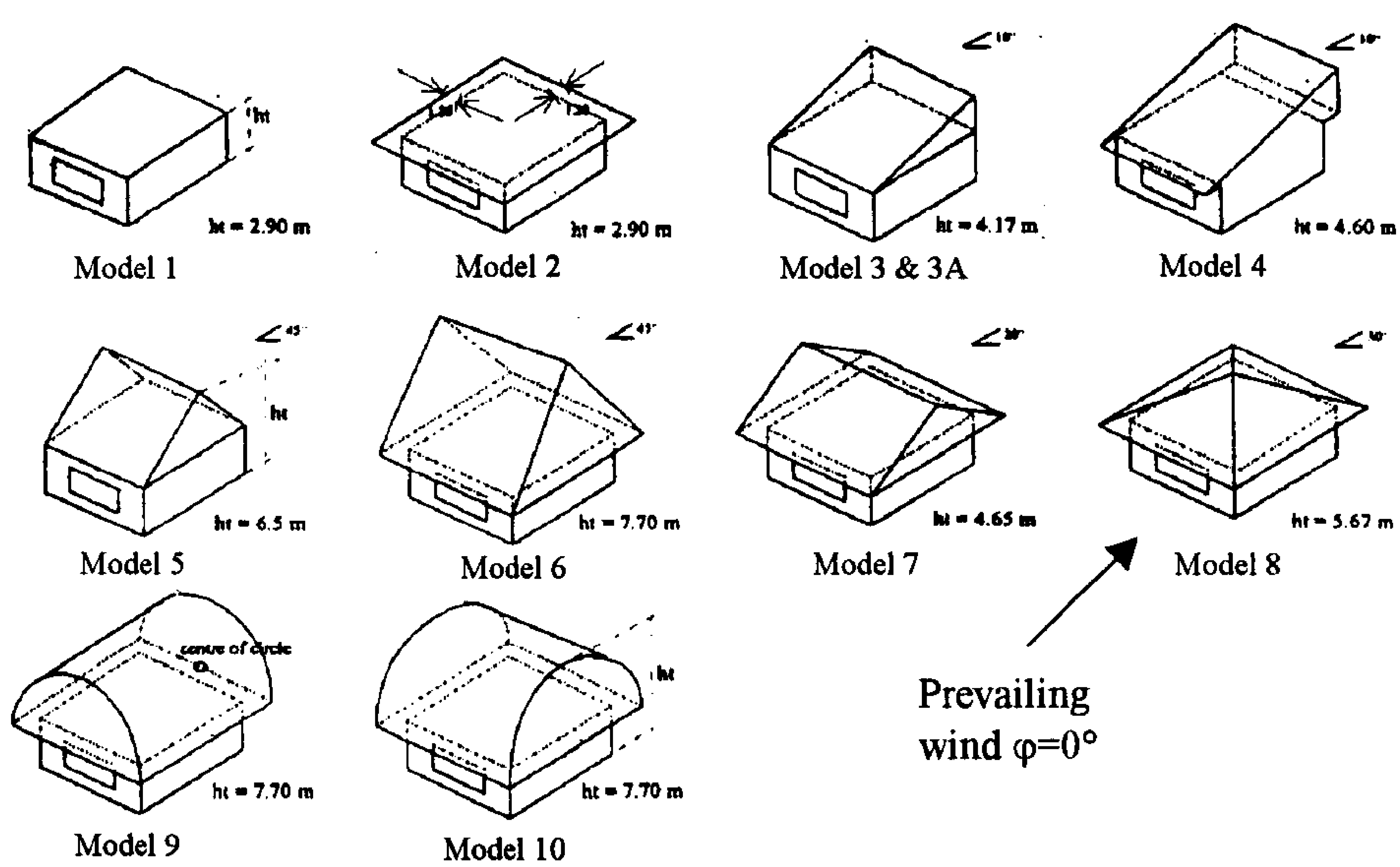


Figure 6.15. Roof types in Kindangen's research
(After Kindangen et al, 1997)

The result of this research showed that several roof types had a considerable effect on indoor air motion in particular wind directions. However, the best roof shapes are those which can induce higher air motion as an average of several wind angles, such as 30°, 45°, or 60°, even though not in extremely high values. Table 6.1 shows the average velocity coefficient (a non-dimensional indoor air motion parameter) and the average indoor air velocity with different roof shapes and several wind angles that were calculated based on a mean outdoor reference free-stream velocity of 5.843 m/s at the height of 4.25m.

Roof shapes	Average velocity coefficient (Cv) in relation to wind direction						Average indoor air velocity m/s in relation to wind direction (in the centre of the room at height of 1.35m)					
	0°	30°	45°	60°	90°	$\bar{x}$	0°	30°	45°	60°	90°	$\bar{x}$
1	0.28	0.32	0.30	0.27	0.06	0.25	1.2	1.5	1.4	1.3	0.3	1.14
2	0.38	0.35	0.32	0.27	0.06	0.28	2.3	1.8	1.6	1.3	0.3	1.46
3	0.32	0.34	0.31	0.27	0.06	0.26	1.5	1.6	1.5	1.3	0.3	1.24
3a	0.36	0.36	0.33	0.29	0.06	0.28	1.8	2.0	1.6	1.3	0.3	1.40
4	0.43	0.36	0.33	0.29	0.10	0.30	2.4	2.0	1.6	1.3	0.6	1.58
5	0.51	0.40	0.35	0.28	0.06	0.32	3.0	2.0	1.8	1.3	0.3	1.68
6	0.62	0.42	0.34	0.28	0.04	0.34	3.7	2.2	1.6	1.3	0.3	1.82
7	0.50	0.40	0.31	0.25	0.04	0.30	2.9	2.1	1.6	1.3	0.3	1.64
8	0.40	0.38	0.31	0.26	0.05	0.33	2.3	2.0	1.8	1.2	0.3	1.52
9	0.53	0.39	0.38	0.28	0.05	0.33	3.1	1.9	1.6	1.2	0.3	1.62
10	0.56	0.41	0.38	0.32	0.17	0.37	3.4	2.2	1.9	1.5	0.9	1.98

Table 6.1. Results of Kindangen's research (After Kindangen et al, 1997)

Table 6.1 shows that the roof shapes of models 6 and 10 give higher indoor air velocities (approximately 0.33% of outdoor air velocities) compared to others, specifically to wind directions of 30°, 45° and 60° (which mostly occur in Indonesia). In Indonesian conditions, narrow streets are unlikely to generate a perpendicular wind direction (0°). Koenigsberger [O.H. Koenigsberger et al, 1973] determined that a spacing of six times the building height is necessary to ensure adequate air movement for the second row. This means that in narrow streets, with narrow front courtyards and high building density, the wind will mostly flow over the houses, hence a perpendicular wind toward the house or wind with an angle of 90° is unlikely to occur. Thus, wind mostly travels along the narrow streets and generates oblique wind, with a probable angle of 30°, 45° and 60°.

Kindangen also concluded that there was a strong relationship between roof shapes, roof heights, position of inlet and outlet, roof overhangs and wind direction.

- Roof shapes and wind directions

  Generally, roof shapes that are not flat such as sloping (triangular) or spherical induce greater indoor air motion. However, this also depends on wind direction. The greatest air motion can be gained at 0° and lowest at 90° and varied with roof shapes and wind direction of angles 30°, 45°, and 60°.

- Roof heights

  From the models, those with higher roofs have a higher velocity coefficient (C_v). Thus, height is one of the factors that can improve indoor airflow, specifically for sloped roofs. However, these exclude a wind angle of 90° in particular roof shapes.

- Overhangs

  The use of roof overhangs in certain roof shapes with certain wind directions will induce indoor airflow. The presence of roof overhangs is adequate for protection against rain and glare, common natural conditions in hot humid regions.

- Inlet and outlet

  Position of inlet and outlet are important in relation to the roof itself. Roof shape induces indoor airflow, but has little influence on the pattern of inside airflow direction. In this case, configurations of the window or opening are entirely responsible for different indoor airflow patterns. This means that both roof shapes and configurations of inlet and outlet need to be considered in the same proportions.

Kindangen's research shows that roof shapes that are triangular or semi-circular in section (models 6 and 10) induce a high indoor airflow. Most Indonesian buildings use triangular roof shape for inducing indoor airflow. However, the existing Indonesian roofs need to be improved regarding roof heights and roof materials to fulfil both natural ventilation and acoustic requirements.

Roof materials affect indoor heat caused by solar radiation. In tropical countries, roof materials, which mostly reflect direct sunlight to minimise heat transmittance, are preferred. Roof materials which can minimise noise during windy and rainy seasons, are also preferred [O. Koenigsberger and Lynn, 1965]. A reflective roof can be achieved by particular roof colours and materials, such as light colour and solid surfaces. Moreover for acoustic reasons, small and heavy roof tiles offer better resistance against wind and noise from rain compared to light asbestos or zinc materials.

Using clay tiles places a limitation on the slope of the roof. The safest slopes are between 30° and 35°. Indonesian roofs usually have a 30° slope. This means that it is still possible to improve the roof height by using slopes of 35° to gain higher indoor airflow rates.

E. Passive cooling strategies for hot-humid climate

The main principle in improving an uncomfortable climate is to understand the discomfort factors. Figure 6.16 shows that a hot humid climate is far above the comfort zone. Attempts to improve this uncomfortable climate can extend the comfort zone [Lechner, 1991], as can be seen in Figure 6.17. According to this figure, appropriate improvements for a hot humid climate are comfort ventilation, conventional dehumidification and air conditioning. Hence, for microclimatic conditions in low cost Indonesian housing, the most appropriate treatment is likely to be comfort ventilation, which will expand the comfort zone by increasing air movement.

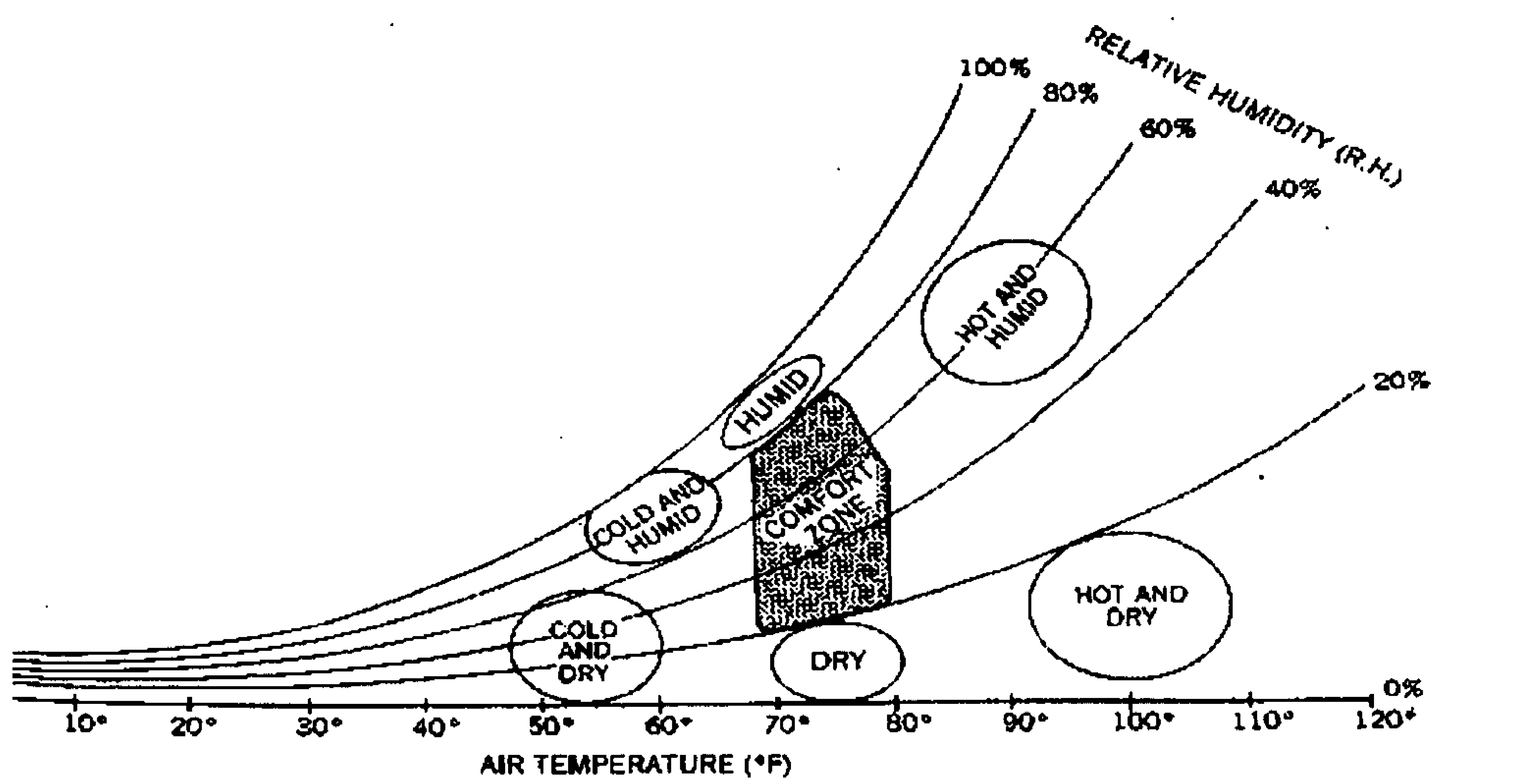


Figure 6.16. The comfortable and uncomfortable zones (After Lechner, 1991)

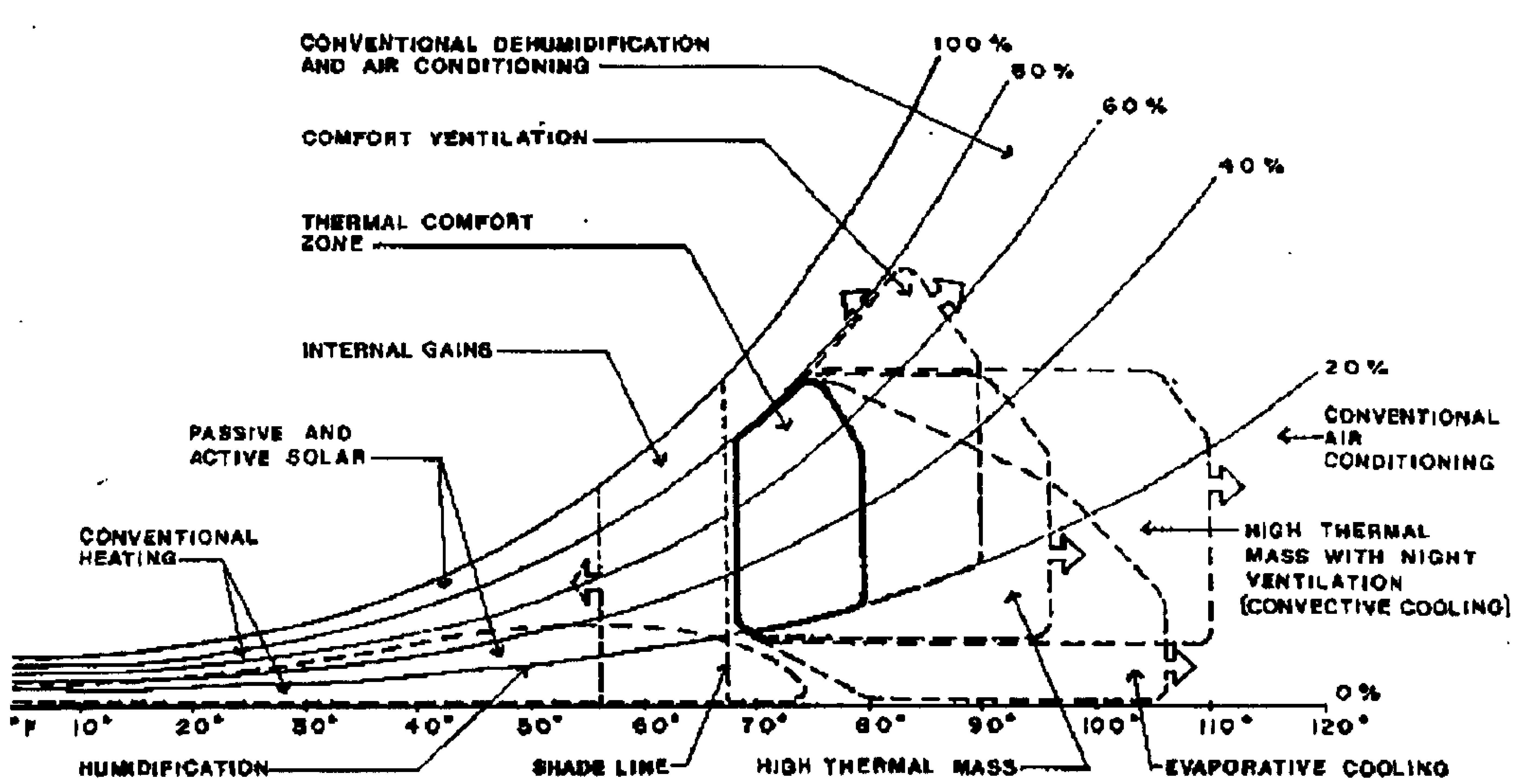


Figure 6.17. Attempts to improve the uncomfortable zones (After Lechner, 1991)

A passive cooling strategy is more appropriate for low cost housing. The first stage in improving thermal conditions in hot-humid climates is heat avoidance. At this level, the designer makes an attempt to minimise heat from solar radiation. Strategies at this stage consist of appropriate use of shading, orientation, colour, vegetation, insulation, daylight and control of internal heat sources. Since heat avoidance is usually not sufficient by itself to keep the temperature low enough in a hot climate, the second stage of response, passive cooling, is applied. With passive cooling, temperatures are not only minimised as in the case of heat avoidance but also lowered.

There are several types of passive cooling system. The most familiar and practical is cooling by using ventilation, hence comfort ventilation. Comfort ventilation has two aspects: day ventilation to increase evaporation from the skin and night ventilation by using convective cooling to precool the buildings for the next day. Unfortunately, this latter principle is only useful if the buildings have thermal mass or an inner courtyard, as is usually found in hot arid climates. Furthermore, with the many insects acting as an additional irritant, night convective cooling by opening windows is not suggested for tropical countries.

6.2 Conclusion

The principles in providing indoor thermal comfort discussed in this Chapter show that there are some possibilities of inducing the required air changes per hour within natural ventilated buildings in a hot climate. These are related to the use of specific orientation, position and type of openings, building layouts, overhangs and roof shapes. All these principles then become basic considerations for further discussion of the use of these specific apertures to also reduce particulate matter and noise.

CHAPTER 7
THE PRINCIPLES OF PARTICULATE MATTER REMOVAL PROCESS

The principles of particulate matter removal from the atmosphere are important in relation to the optimisation of vertical building elements to reduce the intrusion of particulate matter into living spaces. Vertical building elements that are designed with regard to these principles are expected to effectively reduce the indoor concentrations of particulate matter.

7.1 Particulate matter behaviour that leads into removal processes

Each type of particulate matter has its specific behaviour, especially in relation to deposition processes. There are four major types of particulate matter removal from the air: gravitational settling, impaction, dry deposition and wet deposition [EPA, 1982].

7.1.1 Gravitational settling

The ability of particles to remain suspended in the air depends essentially on particle size, shape and density. Large particles fall rapidly because of gravity. Particulate matter within this type is usually larger than 20 μm and its deposition will create a nuisance on surfaces.

7.1.2 Impaction

In the absence of turbulence or when laminar flow dominates, particles are deposited on surfaces, which are parallel to the flows, by sedimentation. If the surfaces are across the flow, deposition by impaction will occur. Within the process of deposition, impaction is a complex process. It depends on factors such as: particle size, wind speed and direction, surface condition and shape of surface. Particles with low inertia (i.e. short relaxation time = time that is required by particles to adapt themselves to an applied force [Bache & Johnston, 1992]) are able to adjust rapidly to the changing curvatures and follow the streamlines round the objects exactly, thereby failing to be captured. In contrast, particles with significant inertia are unable to adjust themselves quickly enough to the changing direction of motion because of their greater relaxation time. In consequence, they will withdraw from the streamlines, tending to maintain their original direction of motion. This will cause them to impact when they approach objects [Bache & Johnston, 1992].

7.1.3 Dry deposition

Dry deposition is the process of deposition in the absence of precipitation. Fine particles can be deposited by dry deposition process. Lu and Howarth described how particles with diameter ≥ 4μm would deposit much faster than particles with diameter ≤ 2 μm [Lu and Howarth, 1996]. Particles are transported down to the surface of the earth where they are removed. Continual atmospheric turbulence brings particles into close proximity to the earth's surface, where they may diffuse across a thin layer of stagnant air to the surface itself. Actual removal at the surface depends on the affinity between the airborne substances and the surface elements (e.g. ground, body of water, vegetation surface, etc.). Dry deposition is a complex process but, briefly, it comprises three steps [EPA, 1982]: (1) transport down to the vicinity of the earth by turbulent mixing processes; (2) diffusion across a thin quasi-laminar layer of air; and (3) attachment to the surface itself. Dry deposition of particles is a strong function of particle size, atmospheric conditions and terrain physiography. For large particles (e.g. above 10 μm in diameter), gravitation also contributes significantly to the overall dry deposition processes.

Dry deposition is commonly parameterised by the deposition velocity, Vd (m/s) which is defined as the coefficient relating the pollutant deposition flux F (g/m^2s) and the pollutant concentration c (g/m^3) at a certain reference height above the surface, i.e. [EPA, 1982],

$$\boldsymbol{F} = \mathbf{Vd}\boldsymbol{c}$$

The deposition velocity can be expressed as the inverse of a sum of resistance in three layers adjacent to the surface [Sehmel, 1980 & Hicks, 1984 (cited in EPA, 1982)]:

1. The aerodynamic layer (i.e., the layer in which atmospheric turbulent fluxes are constant [typically extending to about 20 m above the ground]). In this layer, the

transfer of pollutants whether gases or particles is controlled by atmospheric turbulence.

2. The surface (or quasi-laminar) layer, a thin layer (~1 mm) just above the surface in which transport occurs by molecular diffusion. In this layer, gases transfer to the surface by molecular diffusion and particles undergo Brownian diffusion and inertial impaction.
3. The earth/canopy/vegetation surfaces, at which gases or particles are removed from the air by attachment to the surfaces.

In gases, the deposition velocity is a function of the above three types of resistance. The formula is as follows [Sehmel, 1980 & Hicks, 1984 (cited in EPA, 1982)]:

$$\mathbf{Vd = 1/(ra + rs + rc)}$$

Where:

ra = atmospheric resistance
rs = surface layer resistance
rc = canopy/ vegetation resistance

In particles, the deposition velocity is strongly influenced by the particle mass or, assuming similar densities, the particle size.

Fine particles and Brownian motion

Brownian motion is a constant random movement along an irregular path caused by the bombardment by surrounding molecules [EPA, 1982]. Brownian diffusion is important for small particles, whereas gravitational settling is important for large ones. In the absence of wind, during a time period of 1 second a particle with diameter of 0.1 μm will travel a total distance of about 40 μm due to Brownian motion, while it will fall about 1 μm due to gravity. In the same 1 second time period, a 1 μm particle will travel a total distance of about 8 μm due to Brownian motion and will fall 35 μm due to gravity [EPA, 1982].

For the smallest particles, deposition velocity increases as particle size decreases, because diffusion by Brownian motion increases as particles get smaller. For the largest particles, gravitational settling becomes important as particles get larger. The deposition velocity increases as particles increase in size. A characteristic minimum in deposition velocity results in the range of 0.1 to 1.0 μm diameter where neither Brownian diffusion nor gravitational settling is strong enough to control removal [EPA, 1982].

Fine particles	Coarse particles
Deposited by Brownian diffusion	Deposited by impaction and gravity

Table 7.1. Deposition process of particulate matter (Source: EPA, 1982)

If the aerosol can be assumed to have a uniform concentration between the ground and a height *h*, then the residence time relative to removal by dry deposition is *h/Vd*. For example, for a 1000 m atmospheric layer and a particle deposition velocity of 0.1 cm/s, the estimated residence time is 11.5 days [EPA, 1982].

7.1.4 Wet deposition

Wet deposition is the process of deposition in the presence of precipitation. Table 7.2 shows the detailed processes of wet deposition depending on particle sizes.

Fine particles	Coarse particles
Scavenged in cloud as nuclei for the formation of cloud droplets	Scavenged below clouds when they are intercepted by falling hydrometeor (i.e. meteor composed of water, such as snow and rain)

Table 7.2. Wet deposition process of particulate matter (Source: EPA, 1982)

Falling raindrops remove larger particles by impaction and smaller particles by diffusion [EPA, 1982]. Colbeck et al. (1970) showed that soot aggregates could collapse because of the humidification which then results in a decrease in both the optical scattering and extinction of the particles [Colbeck et al., 1970 (cited in EPA, 1982)].

7.1.5 Particulate resuspension

Particle resuspension is the process whereby particulates which have already been deposited are suspended again in the atmosphere. There are two ways of resuspension: aerodynamic and mechanical resuspension. Aerodynamic resuspension is mostly caused by natural wind blow, while mechanical resuspension is mostly caused by disturbance. Research carried out in Birmingham (UK) showed that a high wind speed is more likely to cause particle resuspension, especially coarse particles (dusts), but this strong wind speed would also disperse the particles to a wider area and thus the total concentration was reduced. On the other hand, in an area with low wind speed the particle concentrations remained relatively high, even though particle resuspension might not have occurred [Harrison, et al, 1997].

Research by Garland showed that resuspension by mechanical disturbance is greater compared to resuspension by wind. Particles resuspended by driving cars are an example of mechanical resuspension. The fraction increases with speed and size of vehicles [Garland, 1979 (cited in EPA, 1982)].

The physical and chemical properties of resuspended particles depend partly on the properties of the particles that were deposited on the surface in the initial stage of resuspension. The deposited particles probably lose their individual identity by becoming attached to host (soil) particles. When the particle is transported downwind, it is usually attached (aggregated) to this host particle. Furthermore, the host particle is most likely an aggregate itself. [Sehmel, 1973 (cited in EPA, 1982)].

7.2 Possible design of vertical building elements to reduce particulate matter by considering its behaviour

When all the factors that guide the use of natural ventilation in polluted areas have been considered, the next consideration is the pollutant itself. This is important for designing buildings that will provide both natural ventilation and pollution reduction. It is mostly the vertical elements of the house that will significantly prevent pollutants from entering the house, as vertical elements are likely to be the elements that create obvious boundaries between outdoors and indoors. Possible vertical elements to reduce pollutant are fences, vertical elements within the front courtyard (e.g. vegetation), and walls/windows.

As mentioned above, particulate matter is removed from the atmosphere in several ways, such as by deposition and impaction. Vertical elements remove particulates by impaction. Large particles are removed by impaction and followed by either dry deposition on the surface of vertical elements or by falling to the ground. Fine particles seem to ignore these processes, as fine particles tend to follow the air stream, hence impaction rarely occurs. However, there is still a prospect for vertical elements at particular heights to reduce fine particulate matter to some degree, as there is a possibility for fine particles to follow a deposition process [Lu and Howarth, 1996], a process which is usually initialised by impaction. Detailed description of fine particulate matter dispersion is to be seen in Part Four (Design propositions with CFD simulations and field trials).

7.2.1 Fencing

For security reasons, many Indonesian buildings are fenced. This can be simple fencing or modern fencing with an automatic gate. Usually a house is surrounded with a simple single fence, which creates a boundary for the housing areas and protects it from uninvited guests. For this reason, it seems worthwhile to consider fences as pollutant barriers, too. A fence can thus also act as a barrier to particulate matter and noise.

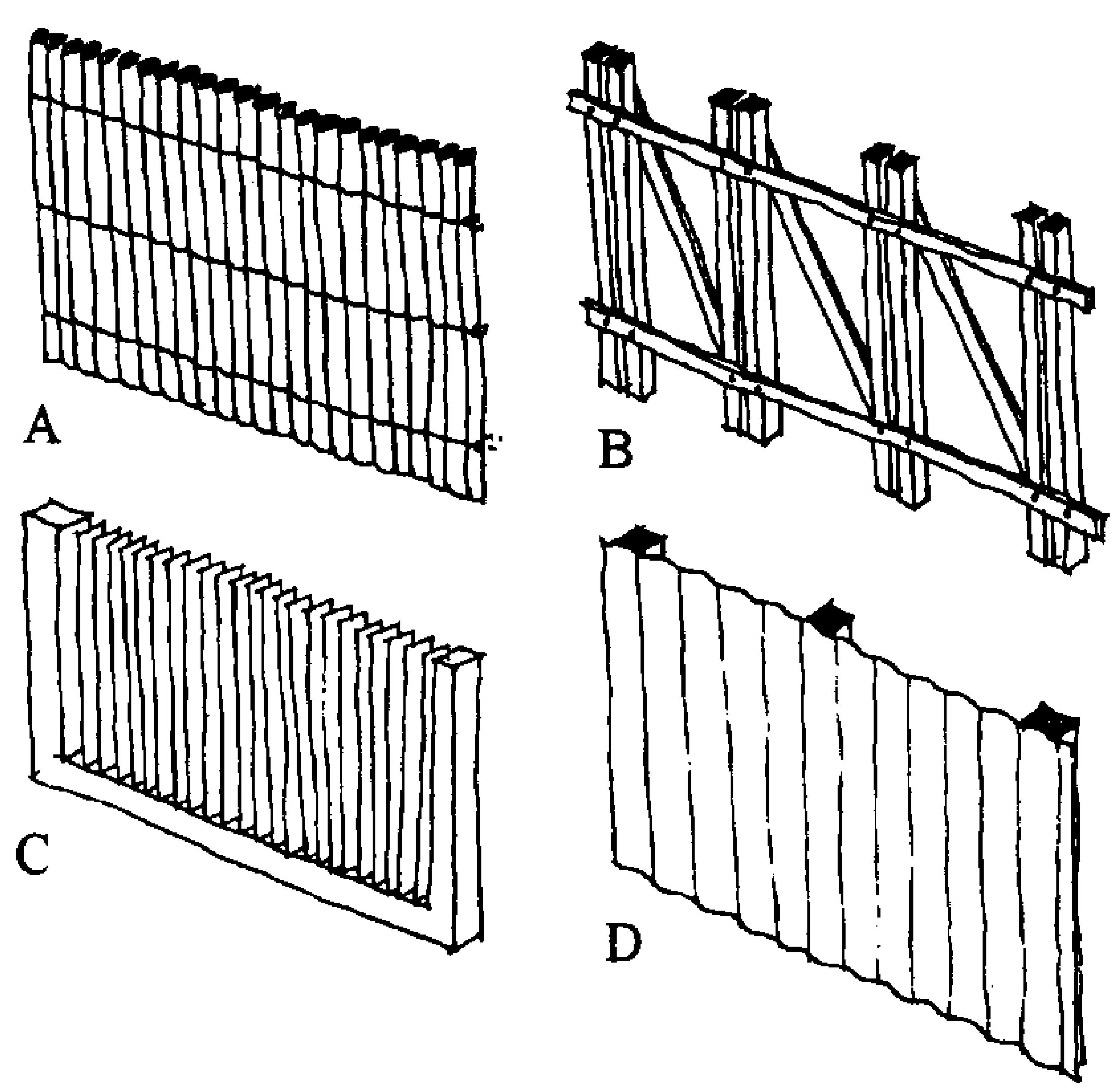


Figure 7.1. Common traditional fencing in Indonesia
A. Bamboo fences
B. Timber frame fences
C. Brick-steel fences
D. Timber frame-fibre fences

As the outermost element of a house, a fence is the first vertical element to obstruct particulate matter pathways. Dimensions and surface characteristics of fence are the most significant factors. The larger the dimensions of a fence, the more particulates will be impacted on its surface. However, a very high and massive fence is probably not practical for a low cost house, as it will entirely obstruct airflow for natural ventilation purposes and create an unsatisfactory facade for the house. Thus, it is important to design the most appropriate dimensions of a barrier for both reducing particulates and permitting natural ventilation. More details on fence designs to reduce particulates are discussed in Part IV (Design Propositions).

7.2.2 Vegetation

The second potential vertical element to reduce particulate matter is vegetation, which may be planted in the front courtyards. This is commonly used to enhance the appearance of the building. Fortunately, it was found that vegetation could also give many benefits to the buildings, such as reducing some types of pollutant, and creating shadow to reduce sunlight and solar radiation. It is also expected that vegetation will help fences to obstruct and thus reduce particulate matter, especially with the natural surface of the leaf whether furry or shiny.

As with fences, it is important to find the appropriate dimension of vegetation to permit both natural ventilation and particulate matter reduction. It is important to find species that have a high durability for planting close to polluted areas, which are also easy to regenerate and maintain.

Research, some of which will be discussed below, has determined the capacity of particular plants to reduce particular pollutant types. There is a history of plants reducing water and gas pollution. There are also some principles of plant use, which seem to hold out the prospect of reducing particulates. However, these principles have not been tested in field experiments, particularly in the case of hot-humid regions.

Several studies, as cited below, have described the process of pollutant removal from the air by using vegetation. Vegetation can reduce gas pollutants by oxygenation, absorption, dilution and filtration, and remove particulates by deposition and filtration. Vegetation is also capable of absorbing gas pollutants through stomata and of adsorbing particles on the leaf surfaces [Shriner, 1991]. Dry deposition of particulates on surfaces occurs through impaction and gravitational sedimentation/ deposition [Shriner, 1991].

A study was carried out in Indonesia into the use of trees in reducing gas pollutants [Kusmaningrum, 1997/1998]. This proved that some trees along Padjadjaran Street (in Bogor) and Cinere Street (in Jakarta Selatan) were capable of reducing gas pollutants, notably NO_x, SO_x, and CO. This research also studied the relationship between types of leaf and their ability to absorb gas pollutants. Kusmaningrum concluded that particular types of leaf (i.e. shiny, thin, soft, with lots of stomata) reduce more NO_x compared to others. Kusmaningrum also concluded that Felicium (trees) and *Puring*/Codiaeum variegatum (shrubs) reduced more NO_x compared to other types of vegetation.

The above principles and research suggest the possibility of using vegetation as particulate barriers. It is postulated that leaf surfaces would deposit some particulates, hence reduce its concentration before entering the houses. The principle of using vegetation to reduce airborne particulates is that vegetation will obstruct the airflow that carries particulates. Vegetation is a unique obstruction device, as surfaces have natural characteristics (e.g. furry, shiny, waxy, etc.), which make vegetation more able to deposit particulates than other types of surfaces. However, there are many types of vegetation, therefore it is important to investigate particular types that will effectively reduce pollutants according to local environments.

7.2.2.1 Types of vegetation

One theory predicts that vegetation close to pollutants with rapid wind speeds will distribute the pollutants to higher levels of air [Grace, 1977]. In Yogyakarta, where wind speeds are generally low, particles remain at lower levels and thus can easily be trapped by low-growing types of vegetation (shrubs or bushes). Besides, taller trees will not reduce pollutants effectively, as is explained by the following process: when pollutants are carried into a plant canopy, wind speeds and turbulence will determine the extent of penetration into the canopy. Edges of a canopy (upper and outer edges) receive more deposition in many cases, as wind speed is usually greater in these areas. Decreases in net through fall (NTF) by more than 50% were noted as distance from the canopy increased from 5 to 15 m. For very reactive pollutants, concentration will be much higher at canopy edges [Shriner, 1991]. Two dominating driving forces for particle dry deposition in plant canopy are particle size and friction velocity. The bigger the particle size and thus the friction velocity, the greater the deposition velocity and thus the deposited particles into the plant canopy [Ruijgrok, et al, 1997].

The use of low-growing vegetation would be more effective for particulate trapping, as explained by an investigation carried out in Loughborough (UK). A decrease in concentration of particles (i.e. PM2.5 and PM10) was found according to the increase of height from the ground. The concentration varied from 0 to 3 m, but generally was higher at 1 to 2m and decreased at 3m. Variation in concentration at a given height depends on several factors, including vehicle generated (thermal and mechanical) turbulence, environmental (convective and mechanical) turbulence and variation in traffic flow [Micallef and Colls, 1998]

Low-growing vegetation will also give better facades, as tall vegetation usually is unsuitable for narrow courtyards and small houses and thus will perform poorly for the whole house. Other considerations when choosing vegetation are leaf abilities to deposit particles, local species, durability and ease of maintenance and regeneration.

7.2.2.2 Vegetation response to wind and other environmental conditions

It is important to study how vegetation responds to wind as deposition and impaction processes may be strongly influenced by surrounding conditions, such as wind blow. There are two types of response to wind: by the whole plant and by leaves [Grace, 1977]. The first occurs as the plant responds to very rapid wind and the second occurs in insignificant wind speeds. Low wind speeds that mostly affect leaf movements are more important, as they may affect impaction and deposition processes.

Leaves and stems of plants differ from each other in size and shape, and thus in the manner in which air flows over the surfaces. Turbulence usually occurs over the surfaces of leaves, but even in fully developed turbulent boundary layers, there is a thin laminar sublayer adjacent to the surface [Grace, 1977], as shown in Figure 7.2. The nature of the cuticle and stomata will also affect airflow over the surface. Experiments have shown that stomata close over a period after a warm prevailing wind. It also showed that stomatal resistance is not a constant but may vary according to tissue water content or leaf damage [Grace, 1977].

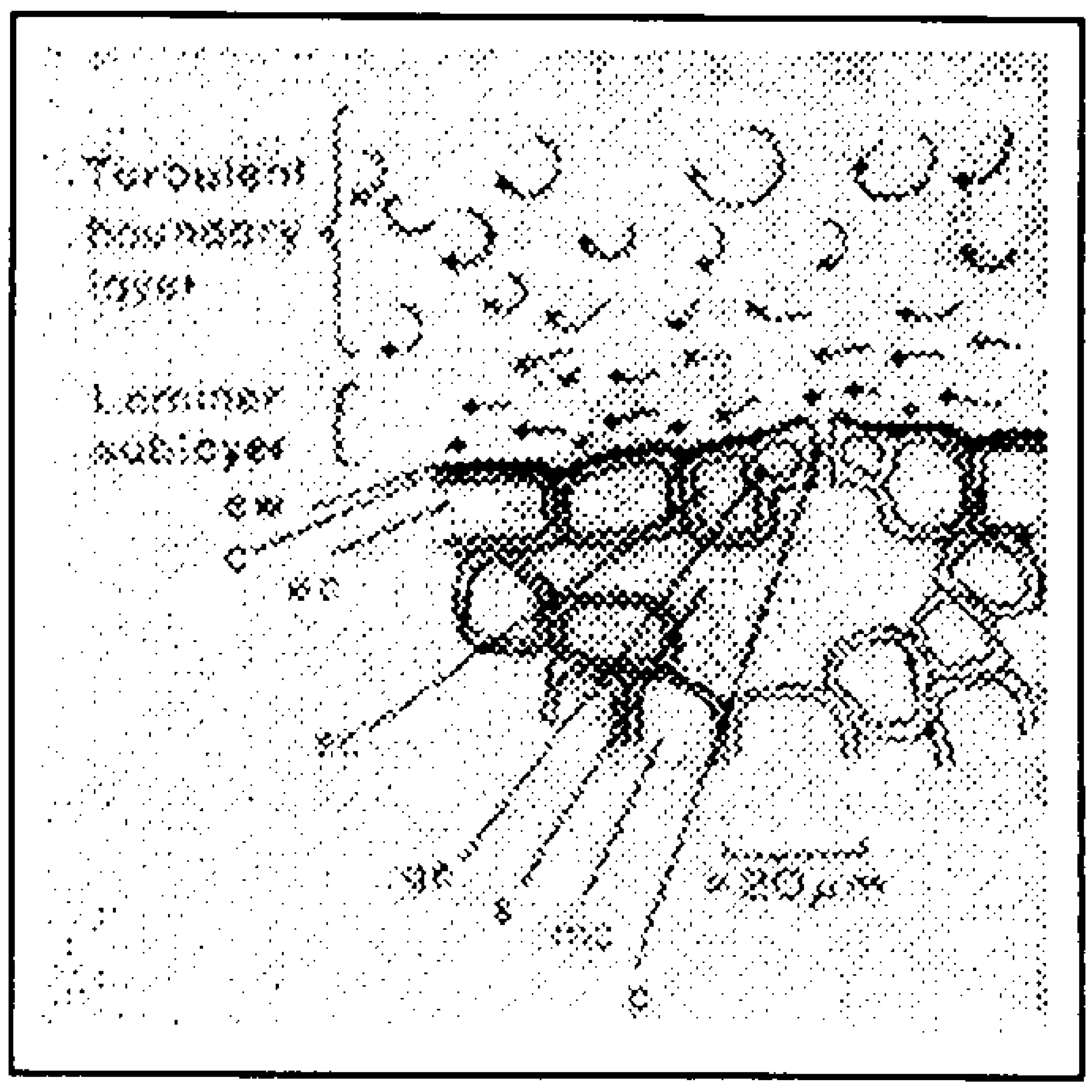


Figure 7.2. Airflow over a leaf surface
(After J. Grace, 1977)

When airflow is rapidly deflected on a large body, a very small suspended particle may be swept around the lines of flow and escape impaction on the surfaces. In contrast, a larger particle might be carried on by its own momentum, through the stagnant zone near the surfaces, and so be impacted. However, when the particle strikes the surfaces at a very high velocity it might be bounced off, unless the surfaces or the particles are sticky or soft so that the momentum of particles can be absorbed [J. Grace, 1977].

The trapping efficiency of a surface is high at high wind speeds but varies when the surface is inclined at various angles to the airflow. At low wind speeds ($\cong$ 0.5 m/s), the upper surface of a horizontal surface received a spore deposition very close to that expected by sedimentation, whilst the lower surface received no deposit of particles. At high wind speeds ($\cong$ 9.5 m/s) with turbulent airflow, particles were observed to be deposited almost equally on both the upper and lower sides of a horizontal surface. This is interpreted as almost pure turbulent structures of the air flowing along both surfaces which caused particles that move with the eddies to be thrown against the surfaces and thus be deposited [J. Grace, 1977].

7.2.2.3 Leaves

Wet and dry depositions of pollutants follow separate pathways in their interactions with plants as can be seen in Table 7.2.

	plant community	plant canopy	individual leaf	leaf interior
site of deposition	vegetation	vegetation	leaf surface	substomatal chamber
	soil	soil	leaf interior	mesophyll tissue
resistance to deposition	aerodynamic	aerodynamic	cuticular	gas liquid interface
	canopy	surface	stomatal	
	surface		residual	

Table 7.2. Site and resistance of particle deposition on vegetation
(After Shriner, 1991.)

Table 7.2 shows the importance of studying detail of leaf surfaces in regard to ability to trap particles.

A. The nature of leaf

Stomata are one of the most important parts of leaves. It can be found both on the adaxial (top surface) and the abaxial surface (bottom surface), depending on the type of leaf. However, most leaves have their stomata on the abaxial surface. The primary function of the stomata is to permit the exchange of gas and water between leaf and the atmosphere [Fahn, 1982]. Stomata close and open automatically based on water exchanges functions. Stomata in tropical humid trees are more open compared to those in the arid leaves [Fahn, 1982].

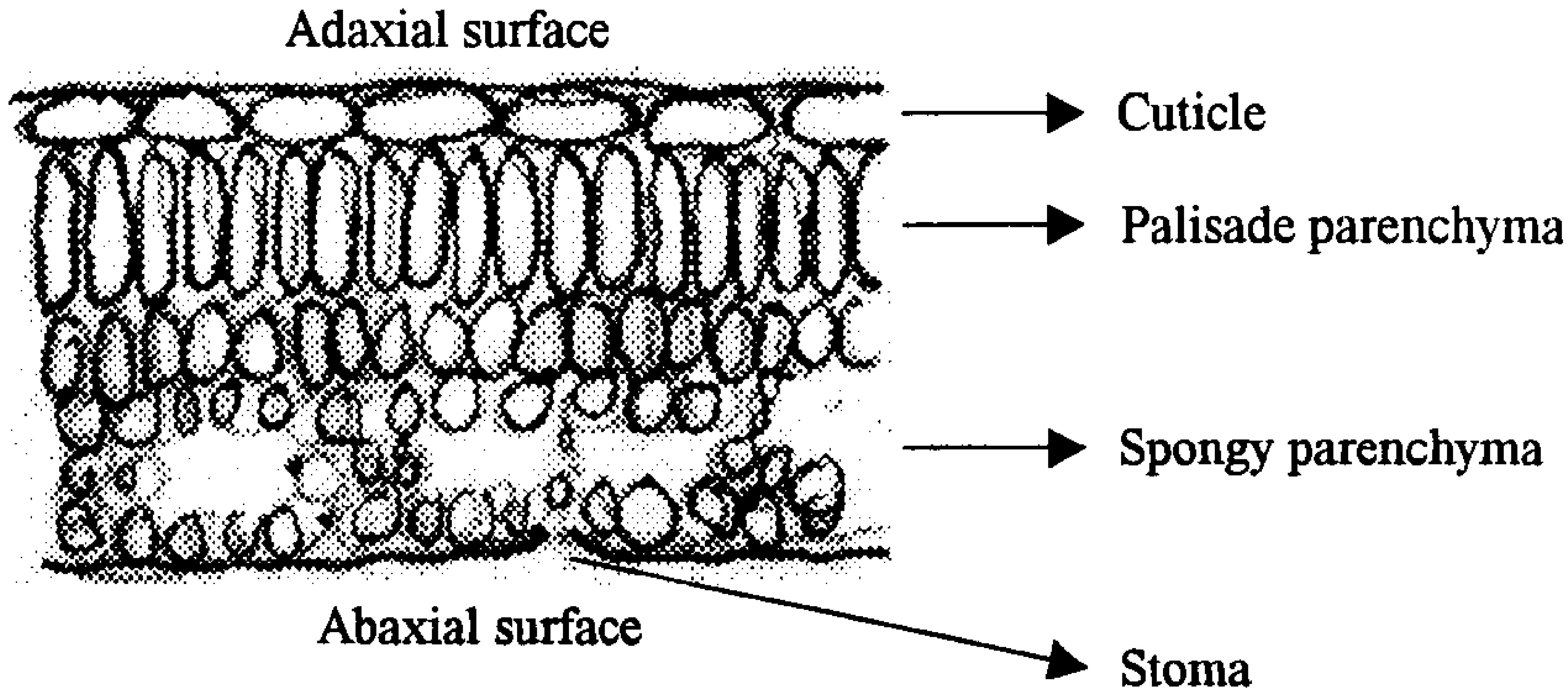


Figure 7.3. Leaf anatomy
(After Fahn, 1982)

Another important layer of leaf is the cuticle. This first layer of the leaf surface protects the inner layers. The nature of the cuticle differs from one leaf to another. One leaf may have a furry cuticle surface, whilst others may have shiny cuticle surfaces. Furry cuticles are more often found in cold arid climates. They protect leaves from extremely low temperatures and from uncontrolled moisture loss, other than that done by the stomata. On the other hand, most tropical humid cuticles are thin and shiny. Some cuticles are naturally covered by wax to provide more protection for the inner layers.

B. Wax on leaf surfaces

The wax layer on leaf surfaces is part of its cuticle. It consists of an outer layer (epicuticular wax) and an inner layer (intracuticular wax). As the outermost layer, epicuticular wax takes significant role on deposition processes. Thus, it is important to study the morphology and chemistry of wax.

De Bary (1871) [cited in Cutler, 1982] attempted the earliest classification of plant waxes. This was based on observations made with light microscopes. He identified four main structural forms: needles, rods, granular layers, and film. From these main forms, he derived wax to platelets, tubes, ribbons, filaments, and dendrites.

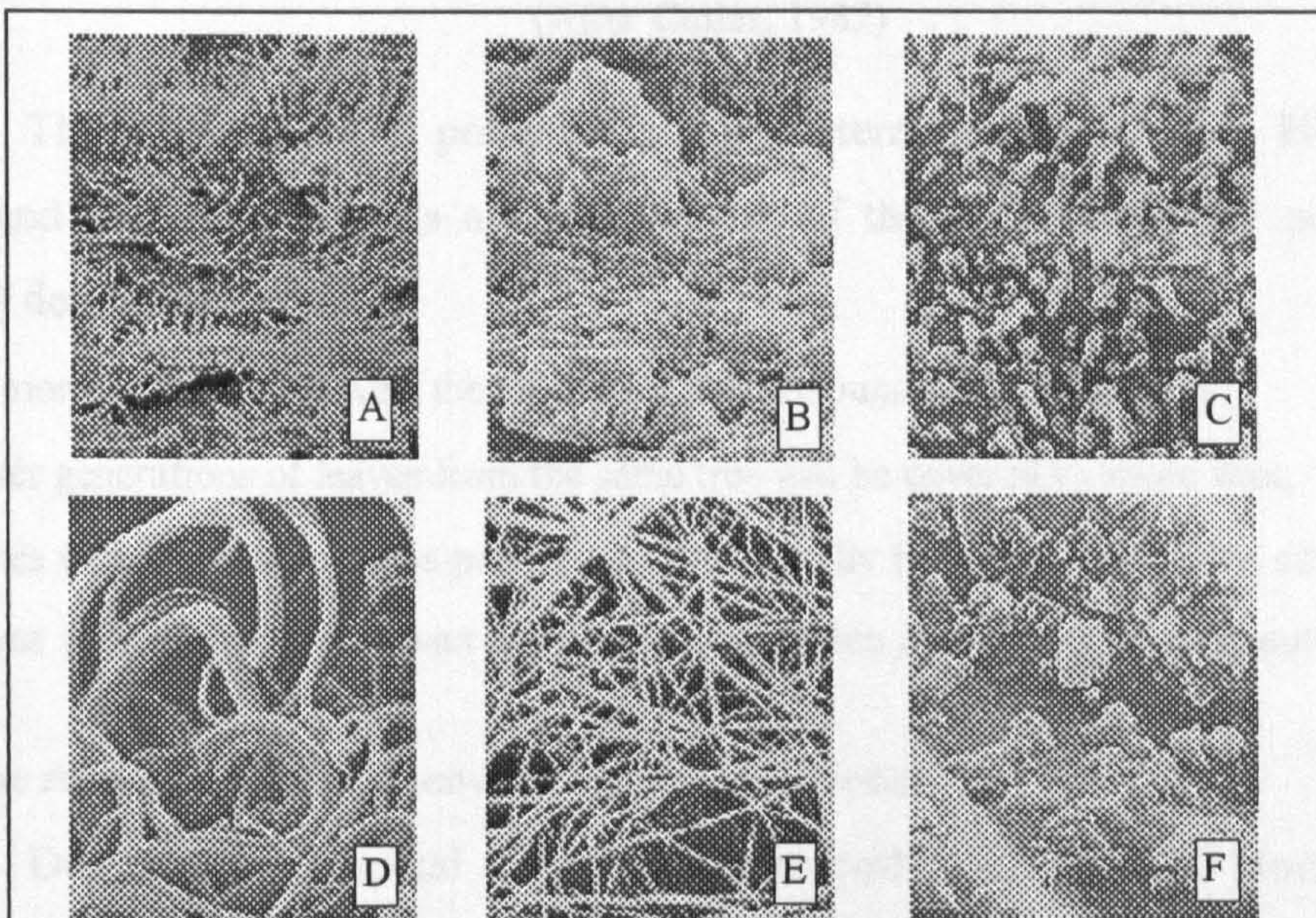


Figure 7.4.Various types of epicuticular wax. (After Cutler, 1982)
A. dendrites, D. long coiled,
B. granular, E. overlapping thin tubes,
C. thin rods, F. platelets

Each type of wax has its specific character:

- a thick wax film usually appears in fine granular wax;
- plate wax has approximately 0.5 to 1.0μm thickness;
- tubular wax is usually 2 to 3 μm thick and is found in stems, glumes and lemma.

Plant epicuticular waxes are composed from complex mixtures, which vary from one to another in numbers, relative abundance, and homologue distributions of constituent classes. Epicuticular waxes comprise commonly major components such as primary alcohol (C_{26}, C_{28}, C_{30}), hydrocarbons (C_{29}, C_{31}), secondary alcohol (C_{29}), β-diketones (C_{31}, C_{33}), and ursolic acids. Whilst intracuticular waxes consist principally of fatty acids of the short series (C_{16}, C_{18}). Common major constituents of plant epicuticular waxes can be seen in Table 7.3.

Class	Constituents
primary alcohol	hexacosanol, octacosanol, triacotanol
hydrocarbons	nonacosane, hentriacontane
secondary alcohol	nonacosan-10-ol
β-diketones	hentriacontane-14, 16-dione, tritriacontane-16, 18-dione
triterpenoid	ursolic acid

Table 7.3. Common major constituents of plant epicuticular waxes (After Cutler, 1982)

The arrangement of pores on cuticles determines wax shapes. However, the sizes and shapes of crystals are independent of the diameter of the pores. Cutler (1982) determined that:

- the more mature the leaves, the more wax will be found on their surfaces;
- newer generations of leaves from the same tree will be covered by more wax;
- leaves with thick amorphous primary cuticles usually have less wax on the surfaces, whilst leaves which have thicker wax usually have very thin amorphous primary cuticles.

C. The response of wax to environmental conditions

Desert plants respond to their climates with thick cuticles. However, thick cuticles do not always mean thick wax layers. Temperate species, which have thick cuticles, often have thin wax layers. There are some leaves that have very thick wax layers; they may be as thick or thicker than the cutin layer underneath and sometimes they can reach several millimetres in thickness, as was found in some tropical plants. These conditions can be explained by the following [Cutler, 1982]:

- dimensions and overall densities of wax increase in relation to the increase of radiant energy flux;
- dimensions and densities of waxes also increase when temperature increases;

- increase in relative humidity reduces densities of tubular waxes, which is formed on plants grown at low temperature (15°C) and which restricts the development of dendrite waxes on plants maintained at high temperature (32°C);
- as growth temperature increases, waxes tend to develop across, rather than project from, the cuticles.

D. Natural and synthetic waxes for commercial purposes as a comparison

Dictionary definitions, which state that wax is 1) a soft, sticky, yellow substance or 2) any of various solid fats or oily substances that melt easily [Oxford English Dictionary, Advanced Learners' Dictionary, 1995] are not completely true. Not all types of wax are sticky and melt easily. Moreover, most waxes are not sticky but slippery, and some types of wax have high melting points. Waxes need some additives such as ethyl cellulose to increase their stiffness and reduce their melting points [Bennett, 1944].

The chemistry of leaf waxes is various but is not significantly different from that of commercial waxes. Basically, leaf waxes and commercial waxes have similar wax constituents. They only vary in the amounts of each constituent composition [Bennett, 1944].

The shapes of leaf wax show how particles can be deposited and lodged on leaves. Deposition on leaf surfaces is mostly caused by surface textures and very rarely by stickiness or adhesiveness of the waxes, even though some types of wax may have these characteristics. Leaf waxes generally have similar constituents to commercial waxes. However, the melting points of leaf wax are usually higher. This might be caused by their natural cellulose components (which might perform as ethyl cellulose). This explains why leaf waxes do not easily melt nor become sticky in quite high temperatures.

7.2.2.4 Deposition on leaf surfaces related to wind speed and surface wetness

According to Shriner, the efficiency of impaction on dry surfaces is less than that on wet or sticky surfaces by a factor of 3 to 10 or even more, depending on wind speeds and sizes and orientation of the obstacles. Deposition velocity is increased by leaf wetness [Shriner, 1991].

The effect of moisture content on leaf surfaces seems in general to be that the water film cushions the impaction and prevents the rebound of particles. In using droplets, the droplets are caught more efficiently, presumably because they cushion their own impact. If this interpretation is correct, then the efficiency with which dry leaves trap particles may depend on the composition of the epicuticular wax. An observation showed that particles could be partially buried in the wax on impact [Grace, 1977].

7.2.2.5 Deposition of particulate matters on leaf surfaces in still air conditions

On the one hand airborne particulates are more easily deposited on furry or waxy surfaces where they will lodge until wiped away by rain. On the other hand, particles are very rarely absorbed by leaf surfaces, because:

- Leaf surfaces are covered by wax so that particulates cannot penetrate the inner layers.
- Stomata are mostly on the abaxial surface and are very rarely found on the adaxial surface. Even when the stomata are on the adaxial surface, pores on its surface are very small, of approximately 4 μm, so only very fine particulates may lodge in the inner layers [Grace, 1977].
- Stomata close regularly, so that it is more difficult for particulates to lodge in them.

7.2.2.6 Possibility of particulate matter depositions on vegetation

A leaf's inner layers have no significant effect on particle depositions. The whole process involves purely deposition without any further absorption. A thin layer of particles will lodge on the leaf surface for a period of time as there is no significant wind to re-suspend it (wind speeds lower than 2.7 m/s) [Grace, 1977] or wax on the cuticle holds it tightly.

In tropical humid countries with generally low wind speeds, when particles are deposited on the waxy cuticle, the particles lodge until the following morning when dew usually forms. It is postulated that a compound between dew and fine particles perform in a similar manner to that of an adhesive, which causes particles to stick more strongly to the leaves. In these conditions, only heavy rains can dislodge the particles. However, in some cases particles will still lodge on leaves, because:

- rains are not strong enough to dislodge them all;
- leaves overlap each other so that rains do not reach the lower leaves.

In the above cases, it needs a strong manual wipe to clean particles from the leaves. When there is no manual wiping, deposition processes will occur continuously and the layer of particles will progressively thicken.

High wind speeds will bring more particles to be deposited or impacted. When this occurs after a period of deposition, the particles fall to the ground or are blown away as resuspended particulates. When still or low wind speeds occur after a period of deposition, particles will remain on the surfaces. Before dew, rain will easily dislodge particles from leaf surfaces. After dew, heavy rain or a physical wiping action is needed to dislodge particles from leaf surfaces

When a leaf holds a maximum amount of particles, it will start to fade, as the particles block sun light and so impede photosynthesis. The leaf then falls to the ground to be replaced by a new leaf, and deposition processes will continue on the new surface [Grace, 1977 and Mathew, 1998].

7.2.2.7 Possibility of particles resuspension caused by the wind

An experiment by using lycopodium sp. (pollen) showed possibilities of particle resuspension at particular wind speeds [Grace, 1977]. The study suggested that particle resuspension will occur when the wind speeds impinging on the leaves is 2.7 m/s [Grace, 1977]. The actual threshold was between 1 and 3 m/s. However, under plant canopies, it is unlikely that any particles would be resuspended after reaching the ground. This is because the wind speeds under plant canopies are usually below the threshold required for resuspension.

7.2.3 Windows

Windows are the most likely opening types to permit both air pollution and noise intrusion. Roofs and other ventilation openings, such as doors and small openings above closed-glass windows allow less intrusion of these pollutant types. Unfortunately, because of their high positions (i.e. roof openings and small openings above closed-glass windows), they are usually difficult for occupants to operate to suit their needs. A solid wall will simply obstruct particulate pathways and thus prevent particulates entering the buildings. However, in reality, there is almost always an opening within a wall, particularly in buildings in very hot climates.

Whilst considering the use of windows for natural ventilation, the possibility of designing the window details to reduce the intrusion of particulate matter from entering the houses needs also to be considered. The design objective is to create an impaction surface for particulate matter whilst minimising the obstruction to airflow. An angled surface is the type that comes closest to meeting this objective. The surface materials of the window are also of importance for impaction and deposition processes.

- Orientation

  Windows that are oriented away from particulate matter sources will reduce their concentration within the houses. However, as particulate matter tends to remain suspended in the atmosphere for a long time and to follow the air streamlines, this reduction is insignificant. This is the major difference between particle pollutants and sound pollutants.

- Position

  As fine particulates remain suspended in the atmosphere for a long time and follow air streamlines, the position of a window on a wall, either vertically or horizontally, will not affect the particulate removal processes significantly.

- Dimension

  The smaller the dimensions of the window, the fewer particulates will enter. However, this conflicts with natural ventilation requirements, which requires large openable windows.

- Material

  Materials with rough surfaces may deposit more particulate matter. The deposited particulates then have to be carefully and regularly cleaned to avoid resuspension. This means that the materials should be easy to maintain, be easy to clean, and have high durability. An experiment carried out in a controlled chamber consisting of two compartments showed that rough surfaces, in this case wall and ceiling, accumulate much more dust than smooth surfaces. However, the resulting reduction of airborne particle concentration is insignificant [Schneider, et al, 1999].

- Style

  Designers could choose window styles that have less porosity in order to reduce pollutant entry. However, this would probably be self-defeating, as larger windows would be needed to achieve the required ventilation rate. Some options can be seen in Figure 6.7.

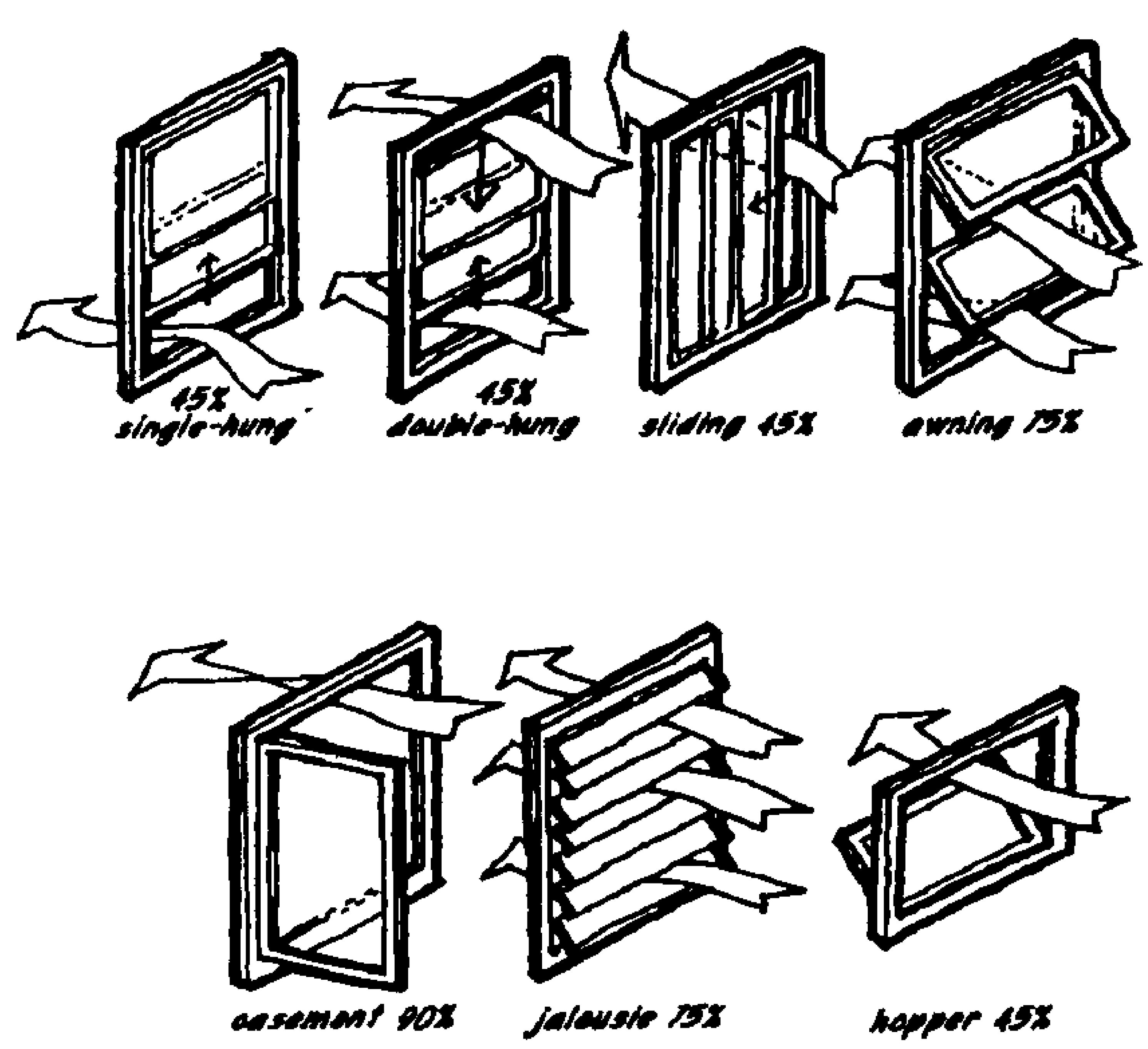


Figure 7.5. Porosity of various types of window
(After F.Moore, 1993)

Angled surfaces are likely to impact some of the particles that pass through and still permit air to flow through the windows.

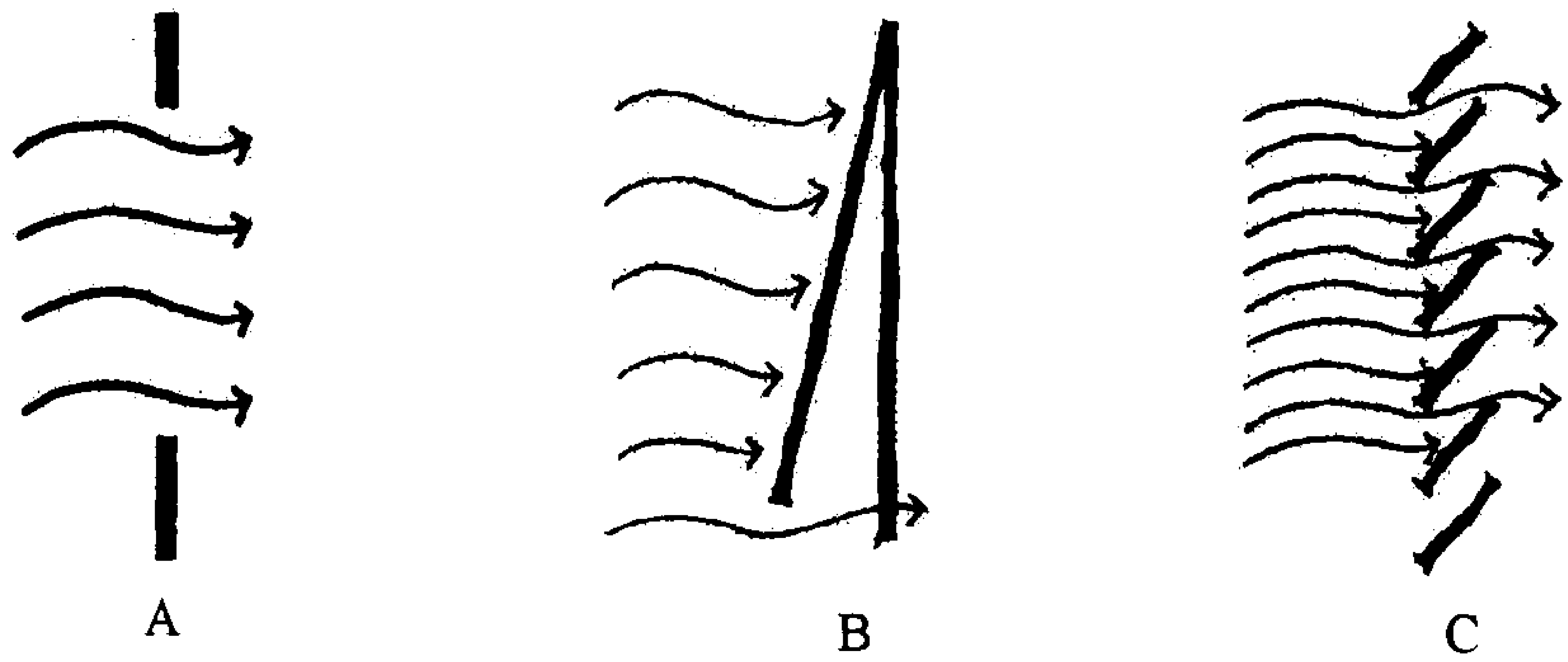


Figure 7.6. Airflow through different opening types
A. Side-hung windows
B. Top-hung windows
C. Jalousie Windows

7.3 Conclusion

Attempts to reduce PM10 by modifying its patterns of deposition by design are possible. Both dry and wet depositions are important for a country with two seasons like Indonesia. However, due to the length of the dry season compared to that of the rainy season, dry deposition appears to provide the most potential for deposition, especially in a very long dry season that usually generates much more dust and other finer particulate matters. Creating obstructions between the sources of particulate matter and the inside of the building that work by impaction seem to offer one possible solution.

By carefully studying all possible means of reducing particulate matter, there is potential to provide natural ventilation and increase particulate matter deposition at the same time. The possibilities of achieving this by vertical building elements, i.e. fences, vegetation, and walls/windows have been explored above. All these vertical elements are discussed and tested in details in Part IV.

CHAPTER 8
THE PRINCIPLES OF SOUND ATTENUATION

The principles of sound attenuation along a pathway are important when considering attempts to use vertical building elements to reduce the intrusion of street noise into living spaces. Vertical building elements can be expected to effectively reduce indoor noise levels when designed with regard to these principles.

8.1 The principles of sound attenuation

Sound that travels along a pathway experiences attenuation before it reaches the receivers. As sound waves spread out from a source, their amplitude decreases and the sound level drops. The attenuation occurs because of barrier absorption as well as the effects of any reflecting or blocking objects in the path. In a free field, distance and air absorption usually give the greatest attenuation.

8.1.1 Attenuation by distance

The reduction of sound due to distance differs between point source and line source. In the case of point source, each time the distance between source and receivers is doubled, there is a reduction of 6 dB. In the case of multiple sound sources, the rate of reduction in overall sound level will be less and will depend on a number of factors. One typical example is the case of vehicles on busy main roads: the reduction caused by distance is likely to be of the order of 3 dB each time distance is doubled [BRE/CIRIA Report, 1993].

8.1.2 Air absorption

Air absorption varies with frequency, temperature and humidity. In an enclosure, the absorption of the air is equal to 4mV, where m is the energy attenuation constant, and is dependent on humidity and frequency and V is the volume of the enclosure [Templeton and Saunders, 1987]. As shown by Table 8.1, based on an experiment carried out in a large enclosure ($100m^3$) at 20°C, the absorption by the air varied with frequency and humidity [Templeton and Saunders, 1987]. This experiment showed that sound attenuation by air absorption is higher at lower humidity, but is insignificant at low frequency [Templeton and Saunders, 1987].

Sound absorption (dB) in relation to relative humidity							
Frequency	20%	30%	40%	50%	60%	70%	80%
125	0.06	0.05	0.04	0.04	0.03	0.03	0.02
250	0.14	0.13	0.12	0.11	0.10	0.09	0.08
500	0.25	0.25	0.26	0.26	0.26	0.25	0.25
1000	0.57	0.47	0.45	0.46	0.48	0.50	0.51
2000	1.78	1.21	1.00	0.90	0.88	0.88	0.88
4000	6.21	4.09	3.10	2.60	2.27	2.08	1.95
8000	19.0	14.29	11.0	8.95	7.61	6.99	6.04

Table 8.1. Sound absorption in relation to relative humidity in a 100m² enclosure (After Templeton and Saunders, 1987)

An example of reduction by air absorption in a certain condition (21°C, RH 60%, per 100 ft (30.5m)) is shown by Table 8.2.

Frequency	Reduction per 100 ft (30.5m) at 21°C and 60% RH
125 Hz	-
250 Hz	-
500 Hz	-
1000 Hz	0.1 dB
2000 Hz	0.2 dB
4000 Hz	0.5 dB

Table 8.2. Air absorption (After Templeton and Saunders, 1987)

8.1.3 Temperature gradients

The velocity of sound is higher in warm air than in cold air. The layers of air refract sound in different ways. Sound is refracted upwards during the day and refracted downwards at night [Templeton and Saunders, 1987].

8.1.4 Wind effect

The effect of wind gradients on the propagation of sound is a complicated and not fully understood phenomenon. Associated air turbulence and temperature gradients affect wind gradients. In other cases, sound waves are affected by wind blowing along their course. Wind velocity increases with height above the ground and its gradient deflects the sound waves upwards or downwards [Templeton and Saunders, 1987].

Frequency	Approximate fluctuations per 100ft (30.5m) at a wind speed of 16 km/h (4.4 m/s)
125 Hz	0.3 dB
250 Hz	0.5 dB
500 Hz	1.3 dB
1000 Hz	2.8 dB
2000 Hz	2.3 dB
4000 Hz	2.5 dB

Table 8.3. Wind effects related to sound absorption
(After Templeton and Saunders, 1987)

Sound level is increased or decreased depending on whether the wind blows from the source of sound toward the receivers or away from the receiver. A wind direction parallel to the path of the sound will not give an appreciable effect.

8.1.5 Ground attenuation

The surface of the ground can absorb sound energy. The effect is quite local and applies within 6 m of the ground. Hard surfaces give little attenuation and smooth surfaces such as grass can give a reduction of overall noise level up to 5 dB per 100ft (very thick grass) [Templeton and Saunders, 1987]. Table 8.4 shows sound attenuation by ordinary thickness of grass.

Frequency	Reduction per 100 ft (30.5m)
125 Hz	0.5 dB
250 Hz	1.5 dB
500 Hz	3.0 dB
1000 Hz	2.5 dB
2000 Hz	1.0 dB
4000 Hz	1.0 dB

Table 8.4. Sound absorption by grass
(After Templeton and Saunders, 1987)

8.1.6 Sound shadow

Significant sound attenuation is gained by the presence of solid and massive obstructions. Screening the path of sound can create an 'acoustic shadow', if the sound has high frequency. At low frequencies, diffraction will occur at the edge of the barrier, and thus the shadow effect will be blurred. If the dimension of the barrier (in a perpendicular direction to the sound path) is less than the wavelength of the sound, the shadow effect disappears. For example, at 30 Hz the wavelength is over 10 m, any barrier less than 10 m long will be ineffective for sound of such low frequency [OH. Koenigsberger et al, 1973].

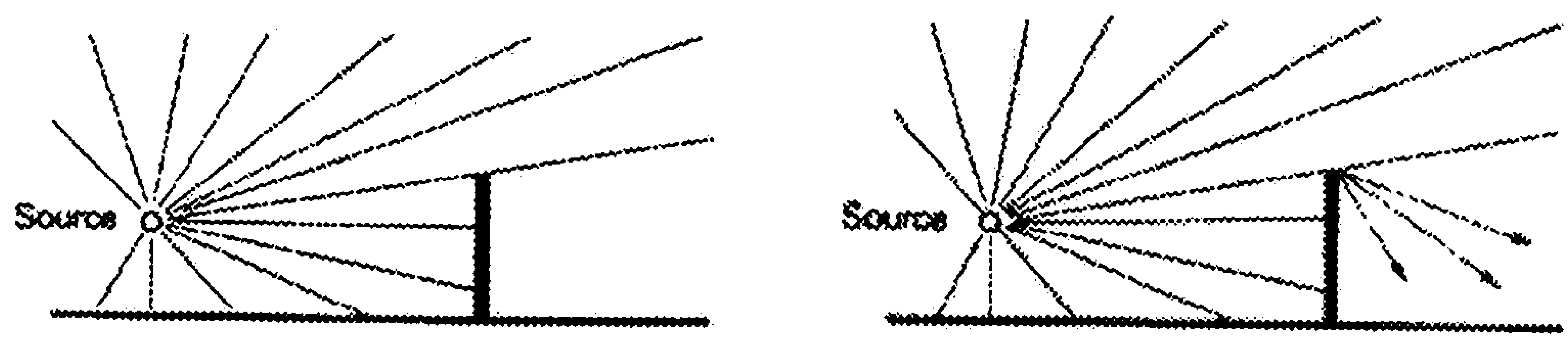


Figure 8.1. Sound shadow after a solid barrier (After OH. Koenigsberger et al, 1973)
Left: sound shadow from high frequency noise, right: diffracted sound from low frequency noise

To achieve effective sound attenuation, a given barrier will be most effective when it is as near to the source as possible. The second best position would be near the building, which is to be protected [OH. Koenigsberger et al, 1973].

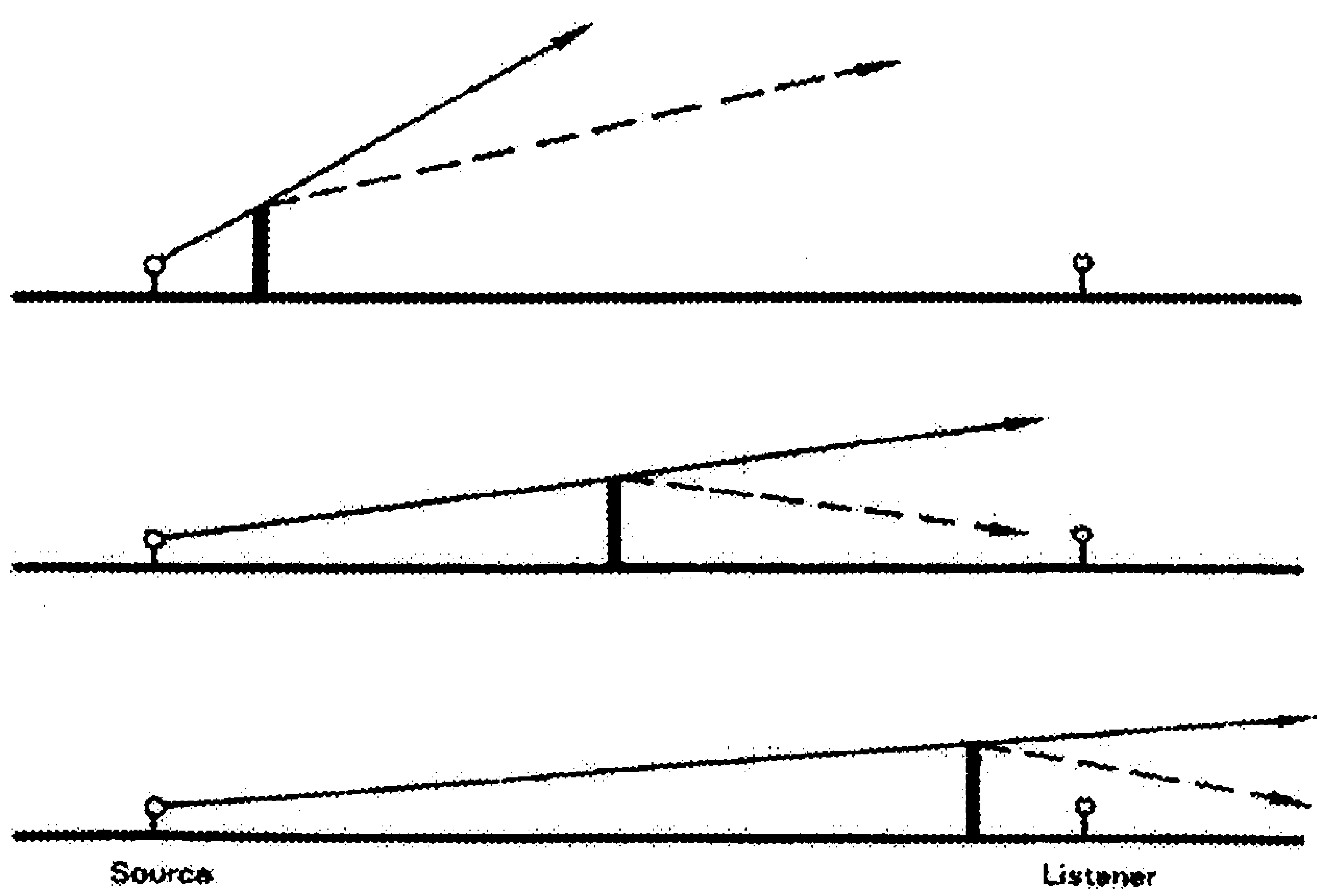


Figure 8.2. Pathways of noise due to different barrier positions
(After OH. Koenigsberger et al, 1973)

8.1.7 Building improvements for human comfort related to noise

There are some factors to be considered in providing a good room-acoustic, such as external features (distance from noise source: courtyard, screening, fence, etc.), wall (including windows and doors), roofs/ceilings, and floors. These factors encompass two other factors: design and material. Nevertheless, acoustics should be considered as a positive factor in design, equal with other factors, and not as a matter of treatment when the design is finished [JE. Moore, 1967].

- Courtyards, screens, fences, etc.

  The presence of courtyards or screens between a building and a noise source will reduce noise to some degree. The longer the yard and the bigger the screens, the more noise will be reduced. However, zoning between noisy and quiet areas is always better, so it should not be necessary for buildings to be completely sealed.

- Walls (including windows, doors and other openings)

  As vertical elements, walls receive noise (i.e. traffic noise) more readily compared to horizontal elements. Heavy walls and roof constructions are of advantage only if doors, windows, and air intakes are made sufficiently sound-retardant so as not to provide weak links for noise transmission. Doors, windows, and other openings are the weakest sound transmissive parts of buildings/houses. The fact that some windows generally have to be opened for ventilation further tends to permit ready noise access into the house.

- Roofs and ceilings

  Another weak element is the building roof, e.g. roof materials. Roof materials such as clay tiles with a timber roof frame have many small open areas (leakage) on the surfaces that will permit noise intrusion. Sometimes the joint between the roofs and the walls is also weak. In this case, ceilings must be designed to prevent noise intrusion.

- Floors

  In a single storey building, sound intrusion through floors is negligible, as there is no room either below or above the house. However, floors are the most likely medium of vibration. Weak floors can be improved by using absorbent materials or by using raised floors, but these are now rarely used for houses, such solutions are found in auditoriums or recording studios.

8.2 Possible design of vertical building elements for natural ventilation with regard to the nature of noise

As with the process of particulate matter reduction, it is mostly vertical elements that have significant effect on preventing noise from entering the living spaces of typical Indonesian houses. Possible vertical elements to reduce noise are fences, vertical elements within the front courtyards (e.g. vegetation), and walls and openings.

It is evident from information presented earlier in this Chapter that noise attenuation by natural means, such as distance, air absorption, temperature gradients, wind effect and ground attenuation is difficult to achieve. Hence, the intentional inclusion of specific features may be the most appropriate solution for achieving adequate noise reduction.

8.2.1 Fence

A fence for noise reduction purposes differs from that for particulate matter reduction. Because of the nature of sound, fences should be solid and massive in order to create effective sound barriers, hence creating perfect sound shadows. An effective barrier will create a sound shadow which will shade openings and thus prevent noise intrusion through the openings.

- Dimension

  As for particulate reduction purposes, the larger the dimension of the fence, the greater the noise reduction that will be gained. However, once again it is important to calculate appropriate dimensions for both reducing pollutants and permitting natural ventilation.

- Density

  Rough guides to appropriate densities of sound barrier are [Freeborn and Turner, 1988/1989]:

  - to provide reduction of 0 to10 dBA, the minimum density is 5 kg/m^2;
  - to provide reduction of10 dBA to15dBA, the minimum density is 10 kg/m^2;
  - to provide reduction of 15 dBA to 20dBA, the minimum density is 20 kg/m^2.

- Material

There are some building materials that are able to fulfil the minimum barrier densities as determined above. These can be seen in Table 8.5.

Material	kg/m²
asbestos cement sheet 4.8 mm	8.4
lightweight aggregate concrete blocks	7-11
concrete commonly used for floor 25 mm	55-65
gypsum plaster board 9.5 mm	6.5-10
clay tile commonly used for roof	34-40
concrete tile commonly used for roof	34-45

Table 8.5. Weights of building materials. (After H.J. Elridge, 1974)

These materials can be improved in their thickness to provide better noise reduction. Some of these materials are not commonly used for fencing. However, they may be used for fencing, either as the main materials or for finishing purposes.

- Design/style

The appearance of most cheap solid barriers is dull and unaesthetic as can be seen in Figure 8.3. Solid barriers that are aesthetically acceptable and do not detract from the appearance of the house but which can also act as barriers to pollutants are preferred.

Figure 8.3. Common physical appearance of massive barriers

8.2.2 Vegetation

Vegetation is unlikely to provide significant noise reduction. This is based on the principle that only massive vertical elements with no leakage will provide significant noise reduction. By its nature, sound is easily transferred through even very small cracks in a barrier. Hence, even though vegetation is planted very close to achieve some degree of thickness, it will not perform like a single wall. For example a tree belt of 100m may only reduce traffic noise by approximately 3 dBA. Consequently, tree planting is not a practical noise control on sites for housing [BRE and CIRIA Report, 1993]. A very thick vegetation belt is impractical in small houses with narrow front courtyards.

It was postulated that solid fences and windows would be able to offer solutions for noise pollution. Regardless of the consideration that vegetation is ineffective to reduce noise, with the measuring device available, a field trial was set to see the effects of vegetation on noise conditions in Yogyakarta. This is described in Chapter 12.

8.2.3 Windows

A window may be described as a large opening in the wall. Hence, windows are the most critical point for walls with regard to noise intrusion. Attempts to achieve sound attenuation by improving receiver conditions are not merely done by putting barriers between sources and receivers, but also by developing appropriate layout and orientation of the buildings. Firstly, these should avoid direct noise. Secondly, the openings including dimension, style, materials, etc., should be carefully designed.

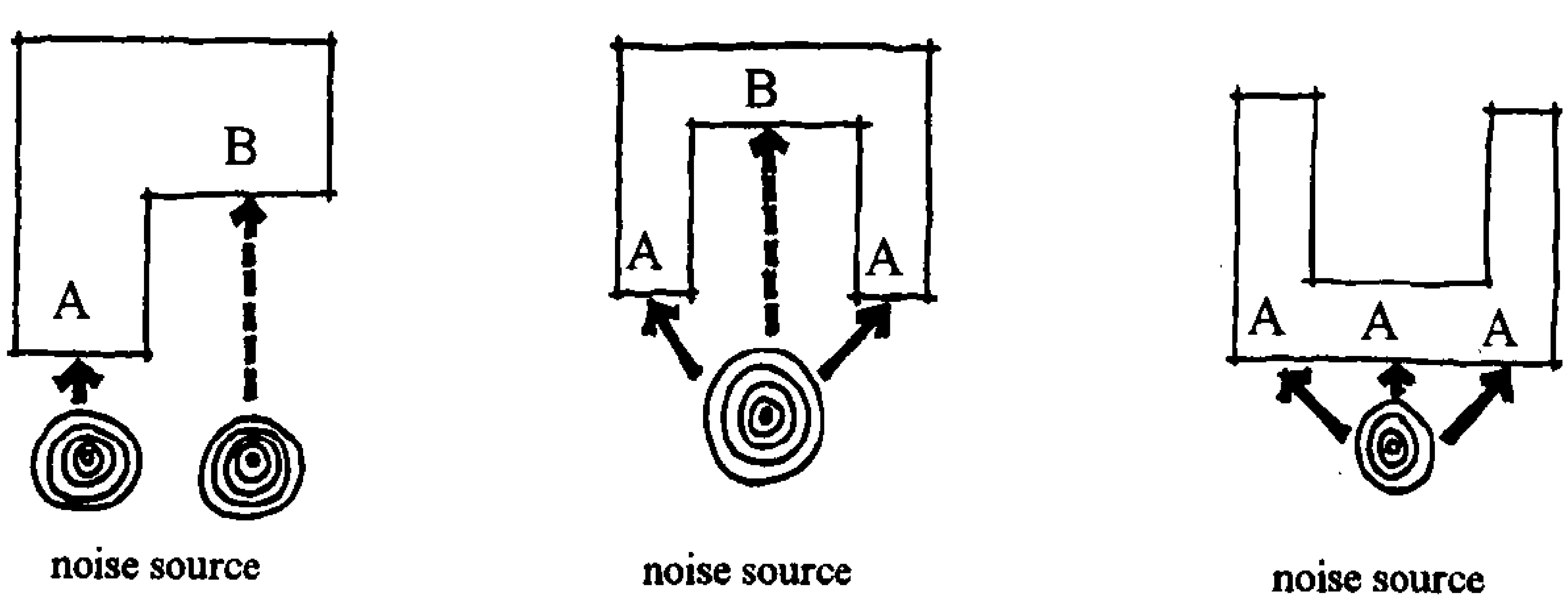


Figure 8.4. Opening positions in relation to noise sources:
B openings receive less noise than A openings

In the case when the distance between noise source (S) and point A is half of the distance between S and B, the noise received by point B is 3 dB lesser than that received by point A [BRE/CIRIA Report, 1993]. This reduction value received by point B will decrease if the distance of S-A >1/2 S-B and increase if the distance of S-A<1/2 S-B.

- Orientation

  Windows that are orientated away from noise sources will offer greater noise reduction compared to those that are orientated close to noise sources [BRE/CIRIA Report, 1993].

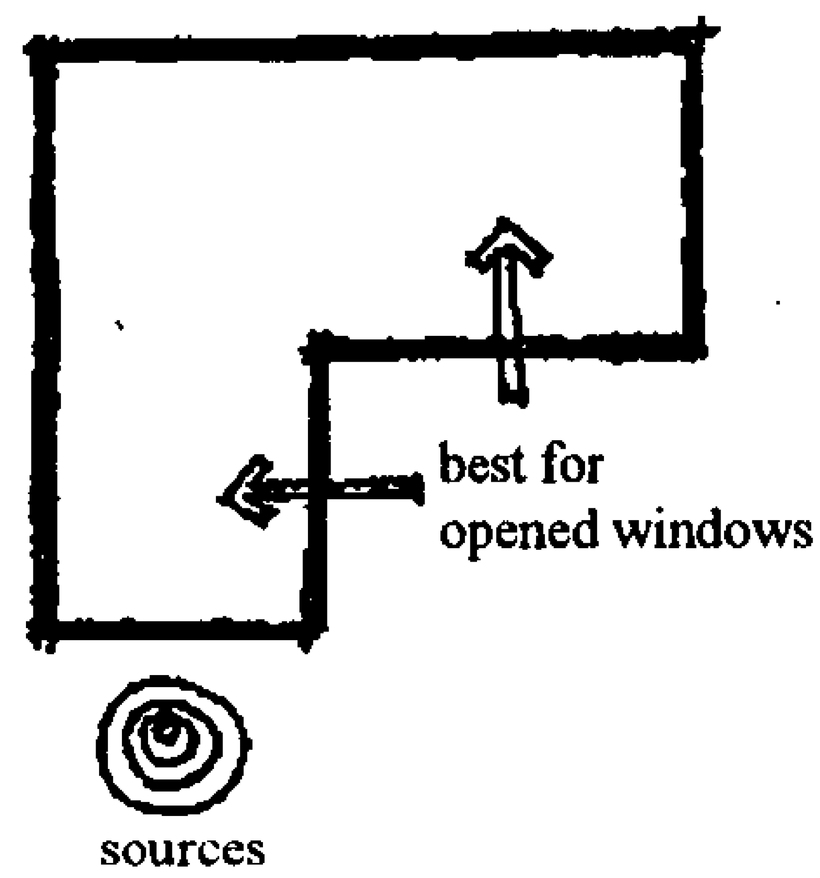


Figure 8.5. Windows that are installed away from the noise sources receive less noise

- Position

  The vertical position of windows is important for determining whether or not the windows can reduce noise. Therefore, the windows should be installed within the sound shadow of the fence barriers. Fence barriers reduce external wind speed. However, this can be improved by placing the window either slightly higher or further away from the sound barriers but still within the sound shadow. This gives a chance for the house to gain oblique wind from over the top of the fence, as long as the distance between the window and the fence is minimally six times the fence height [Koenigsberger, et al, 1973]. This can be achieved by a 1.1m fence height for house type A and a 1.3m fence height for house type B.

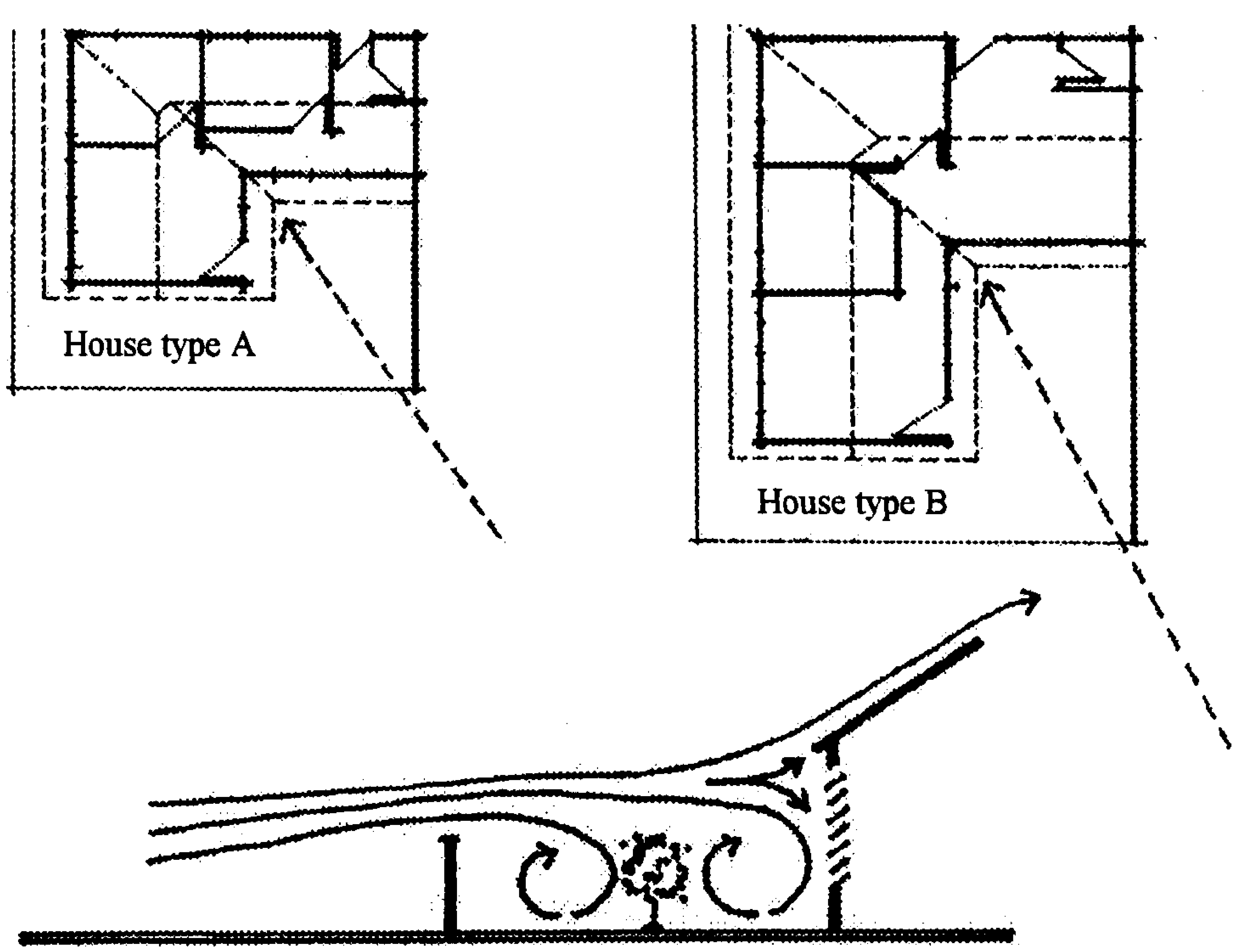


Figure 8.6. Airflow over the top of a fence
(Source: the author based on Koenigsberger, et al, 1973)

- Dimension

  As sound is easily transferred even by small cracks in the wall, there is no particular standard for window dimensions for noise reduction. Smaller windows will provide more noise attenuation compared to larger windows. However, the reduction is likely to be very small and thus insignificant. The styles and materials mostly determine the insulation value of a window.

- Material

  Materials that will reflect sound away from the window surfaces, such as solid materials, are preferred. This means that only some parts of the sound will be transmitted into the rooms. It is also important to prevent gaps between the walls, the frames and the panels. This will maximise noise reduction when the windows are closed. This may be achieved by using sealant between walls, frames, and panels.

- Style

  The best window style for noise reduction is a closed double glass window. However, this will not permit natural ventilation. Hence, the best strategy may be to distinguish windows for views from windows for natural ventilation. Thus, the reduction in noise afforded by closed windows can be maximised. This means that the horizontal position of a window is of importance in relation to the window type. Openable windows should be placed away and farther from the noise source, whilst fully closed windows may be placed closer to noise sources [Burt, et al, 1969].

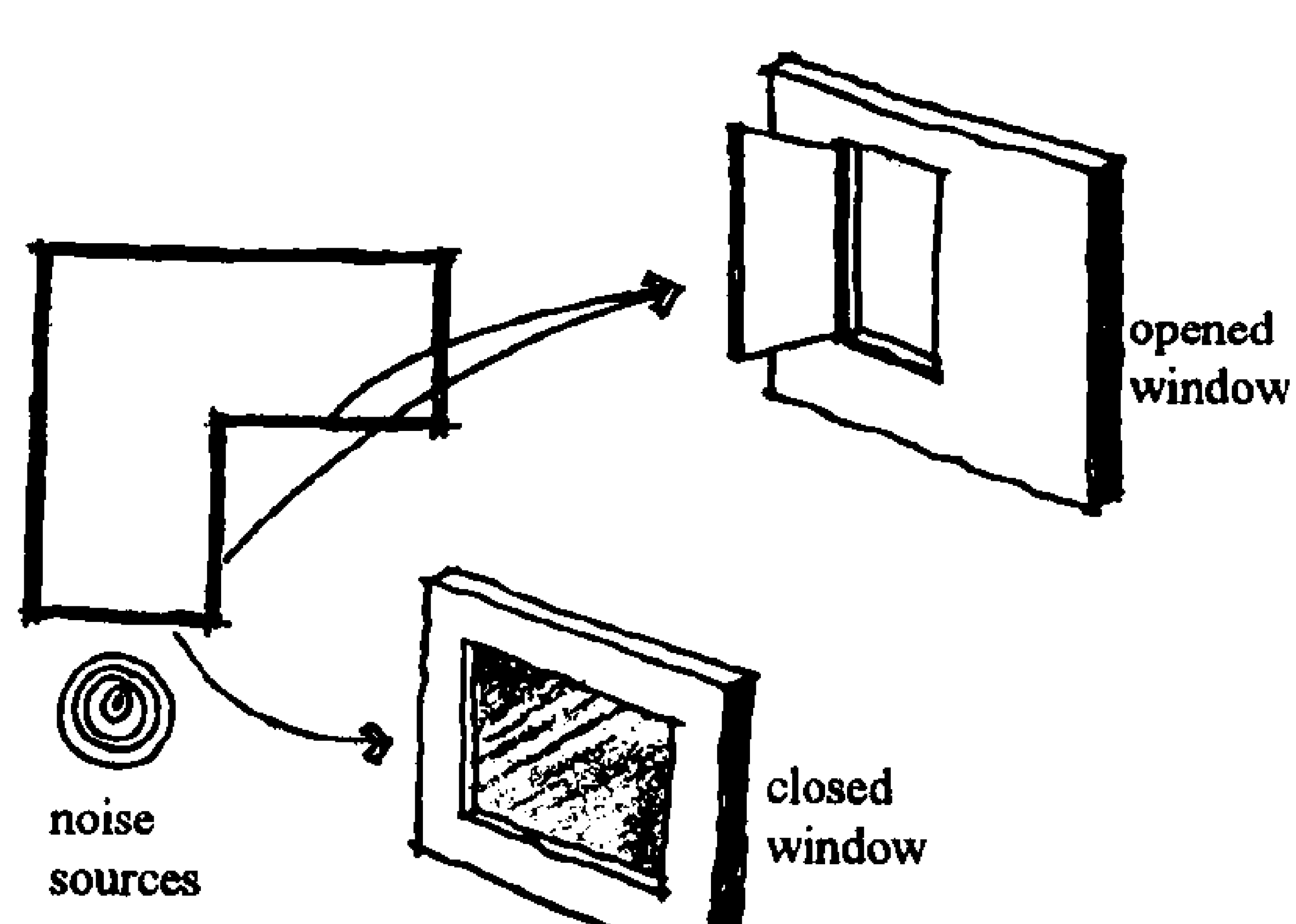


Figure 8.7. Window types and positions with regard to noise sources

The reason for choosing a particular window style is because the insulation provided by a facade depends almost exclusively on the insulation value of the windows. Table 8.6 shows approximate insulation values offered by different types of window.

Types of Window	Approximate Insulation Values
Opened single window	5-15 dB
Closed openable single window	20-25 dB
Closed glass windows, glass 3 mm	24 dB
Closed glass windows, glass 4 mm	25 dB
Closed glass windows, glass 6 mm	28 dB
Closed glass windows, glass 12 mm	33 dB
Staggered-opened double windows (100m cavity)	10-20 dB
Closed double windows (100mm cavity)	25-28 dB
Closed double windows (200mm cavity, 4 mm glass)	40 dB
Closed double windows (200mm cavity, 6 mm glass)	42 dB

Table 8.6. Type of windows and their insulation values
(After W. Burt et al, 1969)

A wide range of insulation values shows the variation that can occur as a consequence of, for example, the quality of sealant around the windows. Performance is very dependent on the quality of the windows. Even an opened window can have a wide range of insulation values as received by occupants. Table 8.6 shows that approximate insulation values of an opened window range from 5 to 15 dB [W. Burt, et al, 1969]. The maximum insulation of an opened window received by occupants in the centre of the room is approximately 15 dB and would fall to zero as the occupants approached the window. An opened window also gives a range of insulation according to the climate. According to the Environmental Protection Agency (EPA), an opened window in warm climates provides insulation of approximately 12 dB, whilst in cold climates of approximately 17 dB, with an approximate average of 15 dB [EPA, 1974, cited in Chunnif, 1977].

8.3 Conclusion

Attempts to reduce noise levels by using sound shadow are likely to lead to a solution. As noise attenuation by distance, air absorption, temperature gradient, wind effect and ground attenuation are difficult to achieve in urban low cost housing conditions, the most appropriate attenuation is achieved by the use of a barrier to create a 'sound shadow'. Indeed, not all noise frequencies will develop sound shadow beyond the barrier, for example low frequency noise tends to diffract at the barrier's edge. However, creating a sound barrier will be useful at least to reduce high frequency noise, which in some cases may be more annoying. Low frequency noise, which is diffracted at the barrier's edge, should then be treated by the use of a specific opening that may reflect or absorb the noise (opening with angle surfaces, i.e. louvre/jalousie openings).

By carefully studying all possible processes of noise attenuation, there are prospects for this research to meet the requirements for both natural ventilation and noise reduction. As mentioned, the possibilities mostly come from vertical building elements, i.e. fences, vegetation, and walls/windows. All these vertical elements are to be discussed and tested in details in Part IV.

PART IV

DESIGN PROPOSITIONS

CHAPTER 9

DESIGN PROPOSITIONS

Based on some possibilities of reducing pollution levels by natural processes of removal or of attenuation by utilising vertical elements, some design propositions are formulated in this Chapter, including design propositions for general housing designs.

9.1 Housing designs

9.1.1 The general principles of housing design

The general principle of housing design within a polluted city centre is, as much as possible, to avoid pollution. When the space is very limited and thus it is impossible to create a distance between source and receiver, it is then the receiver conditions that need to be designed to prevent pollutant intrusions. For naturally ventilated houses, this might be done by orienting the openings away from pollution sources but still permitting the openings to face prevailing wind direction and creating a housing or room layout that will permit private rooms to be placed away from pollution sources. Such strategies to meet these principles are explored and discuss below.

9.1.2 Design propositions for housing

9.1.2.1 Houses

Room arrangements and building layouts should be composed which provide the opportunity to separate private and public zones and to separate rooms with high or low ventilation demands. This means that public rooms or rooms that need high ventilation are located on the outer sides of the house.

L shape or U shape building layouts are preferred as they provide more possibilities for placing windows away from noise sources. However, it seems that an L shape is more suitable for small houses with a limited floor area of 21 m^2 to 36 m^2. With these areas the width of the house is approximately only 6m. If the U shape is used to design building with 6 m width, each room within the building will only have a limited width of approximately 2m which is unsuitable to accommodate any activity within the house, as can be seen in Figure 9.1a. If one of the wings is maximised to 3m, the other wing and the middle open area will only have 2m and 1m width, which is also too narrow to accommodate any activity and to give good window positions to receive the prevailing wind, as can be seen in Figure 9.1b. Therefore, an L-shape is preferred due to its simplicity and the opportunity to maximise the room width and the open area, as can be seen in Figure 9.3.

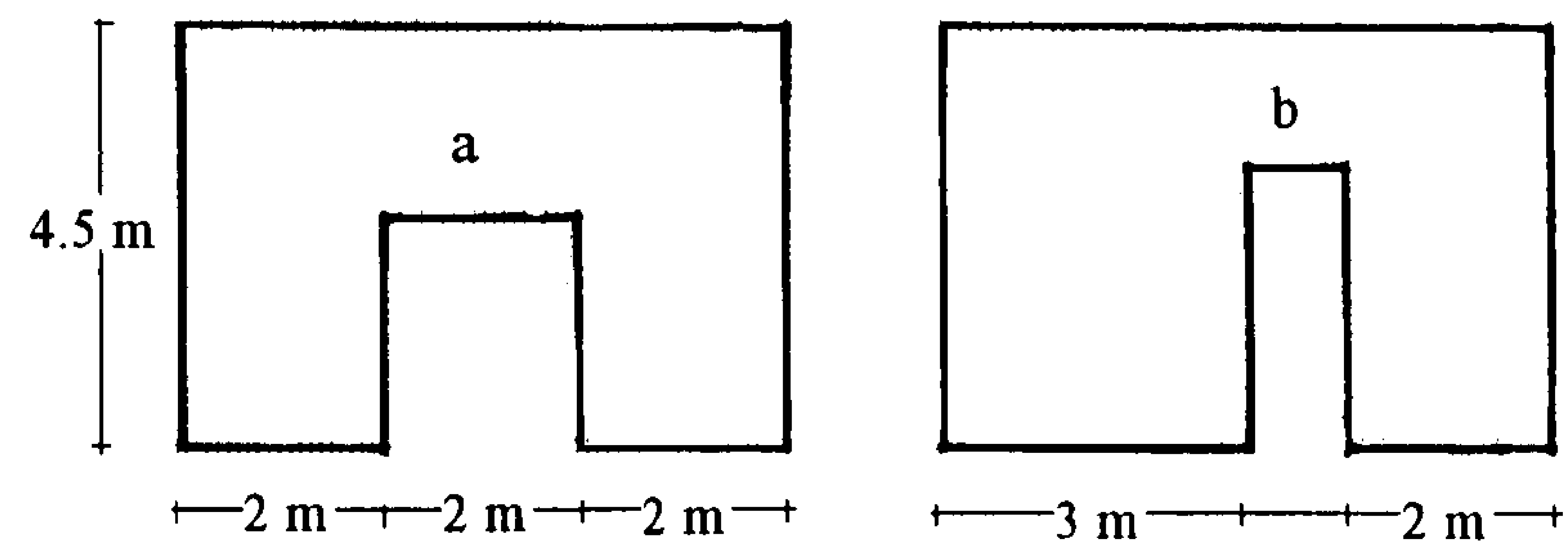


Figure 9.1. The disadvantages of using U-shape building layout

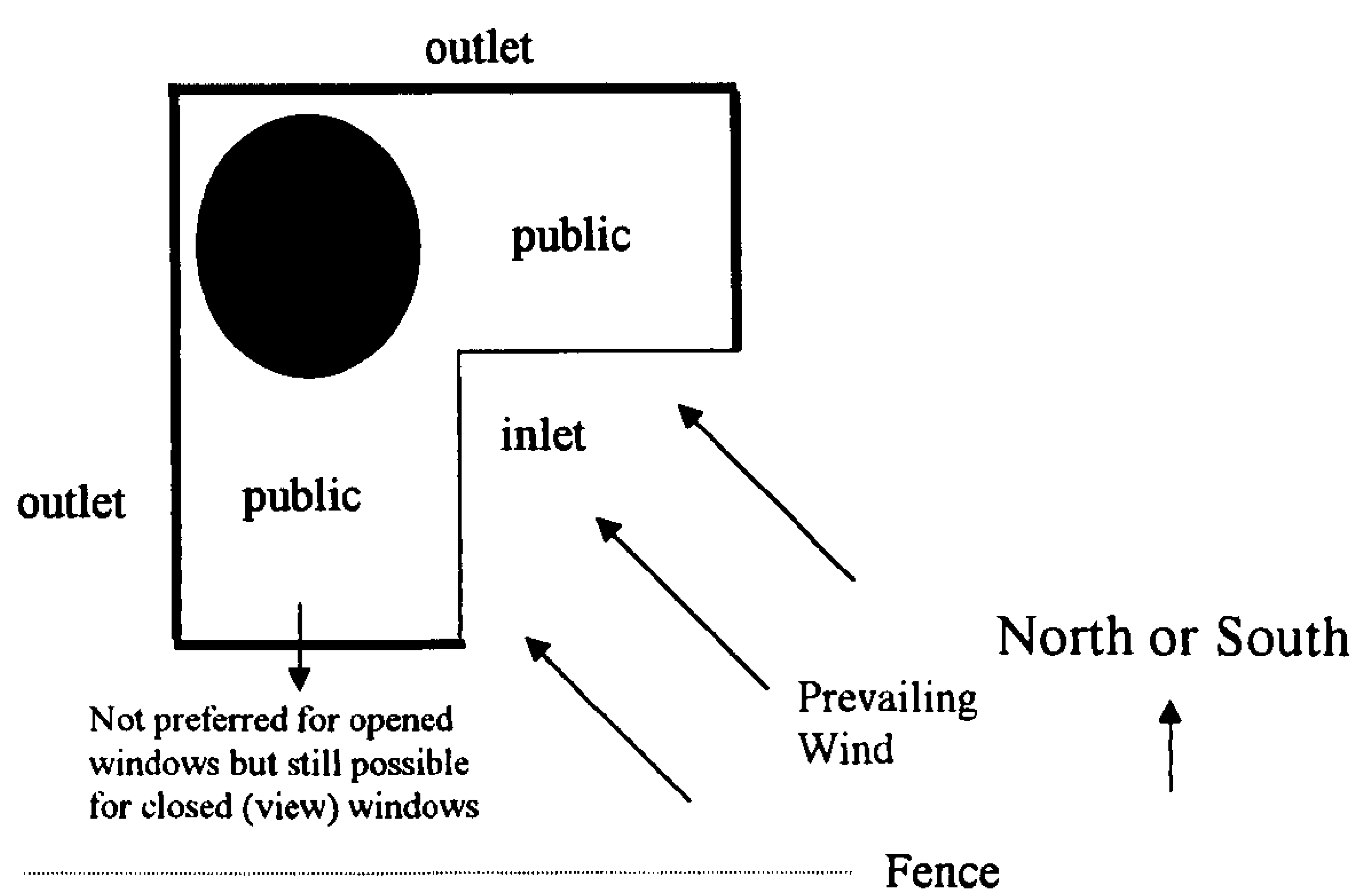


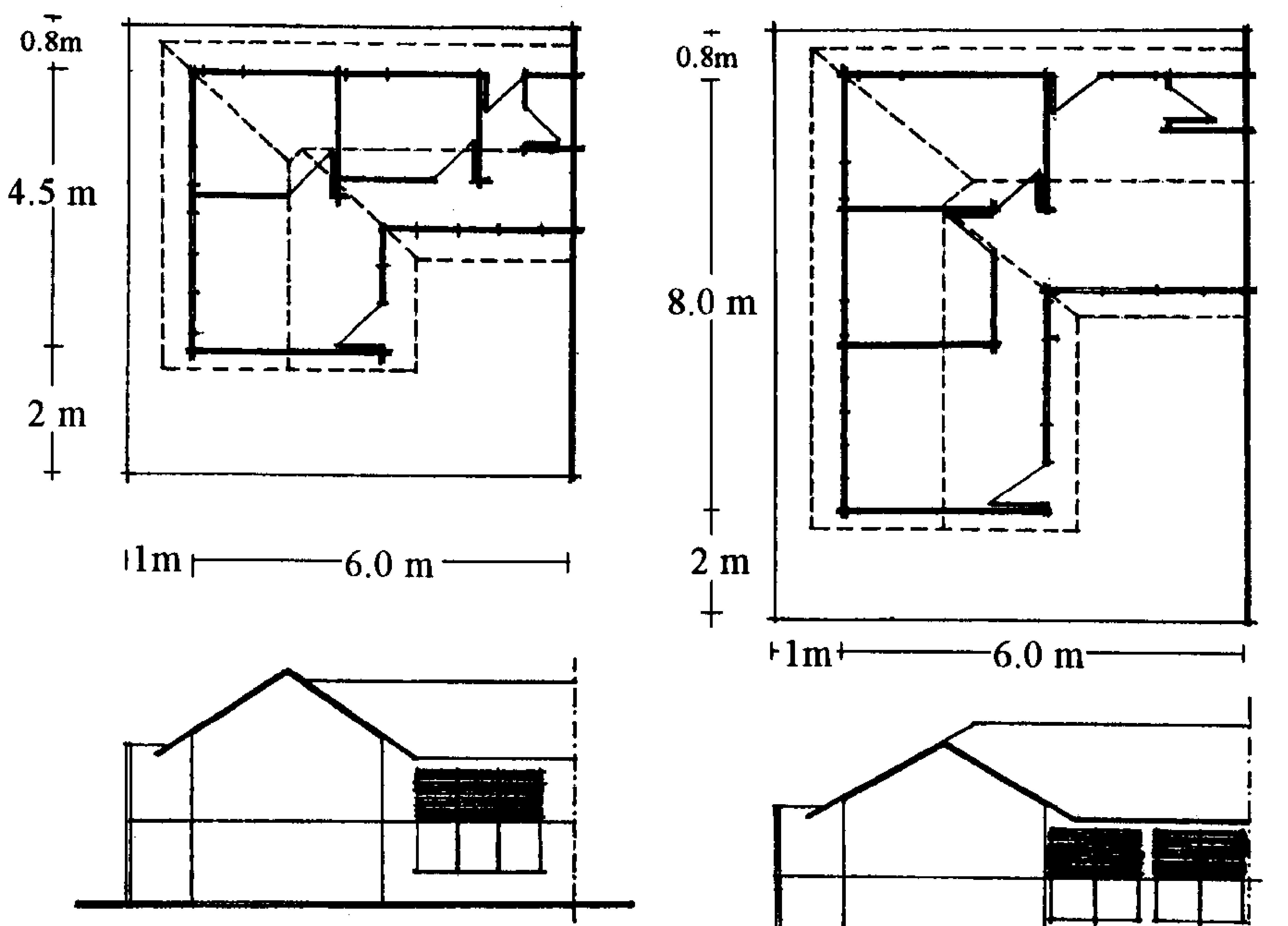
Figure 9.2. The advantages of using L-shape building layout

The L-shape allows public areas to act as buffers to protect the private area from noise and to supply airflow to the private area.

9.1.2.2 Windows

Both inlet and outlet windows should be placed away from the noise source. Louvre/jalousie windows are proposed due to the earlier hypotheses (set out in Chapters 7 and 8) that windows of this type have greater ability to pass air, deposit particles, reflect noise and reflect direct sunlight. Shading devices are required to protect window material from rain, which falls throughout the year in Indonesia. As an addition, a window screen needs to be installed to protect the occupants from insects especially at night time.

Housing design proposals that incorporate the above features are shown in Figure 9.3.



House type A (21 m²)

House type B (36 m²)

Figure 9.3. Design propositions of general housing appearance

9.2 Design of vertical building elements

9.2.1 Fences

As attempts to reduce particulate matter by improving the sources and the mediums are difficult to apply in Indonesia, methods of reducing the pollution experienced by receivers through their own situation or actions would be more effective.

The first consideration in improving receiver conditions is to explore the elements of the receiver, which comprise the vertical and horizontal elements of the house. As the outermost vertical element, a fence could improve the housing conditions by obstructing pollutant pathways before they enter the house. The idea of using fences is practical, since most Indonesian houses are surrounded by fences.

However, the Indonesian fences could be improved to enable them to function more effective as pollutant barriers as well as security and privacy barriers.

9.2.1.1 Fences to reduce particulate matter

Chapter 7 explained that impaction and both dry and wet depositions are important particulate removal processes, particularly in Yogyakarta conditions.

There are some important factors to be considered in using fences as barriers for particulate matter reduction, such as dimensions, porosity and material surfaces. These are the factors that will cause impaction, deflection or deposition of particulate matter.

A particulate barrier will obstruct particulate pathways from entering housing boundaries in two ways: impaction and/or deposition. The impaction processes then will be followed by three outcomes: impacted and fallen to the ground, impacted and deposited, or impacted and deflected. The first outcome happens with large particulates that are still affected by gravity. The second mostly occurs when impaction surfaces provide particular conditions that encourage the particles to be deposited (e.g. sticky, hairy, etc.). The third outcome occurs when the wind, which brings the particles, blows hard and particulates bounce off the impaction surfaces. Any of these three outcomes is possible in Yogyakarta. Wind speeds in Yogyakarta are mostly slow, but when impaction surfaces are sufficient for bouncing, deflection after impaction is likely to occur. However, as fine particulates mostly move by Brownian motion, the process of particulate removal when impaction surfaces bounce the particulates is only effective for coarse particles, which then cause the particles to fall to the ground. Therefore, the most effective process for fine particulate removal is when impaction surfaces provide particular conditions that encourage the particles to be deposited.

As indicated earlier in Chapter 7, the most important consideration in using fences for particulate barriers and natural ventilation is dimension and materials, particularly the materials of surface finishing. Surface materials that will capture more particulates are preferred. An investigation carried out in the Netherlands showed that vegetation and other very rough surfaces could enhance particulate deposition

[Ruijgrok, et al, 1997]. This means that surface materials should cover the following factors:

- surface finishes that will encourage particles deposition (e.g. furry, sticky, etc.);
- high surface areas compared to that given by ordinary flat surface areas (e.g. overlapping surfaces (vegetation), holes in surfaces, etc.);
- ease of cleaning and maintenance, especially natural cleaning by rain.

Vegetation or some artificial barriers that are designed to behave like vegetation seem capable of fulfilling all the above factors.

9.2.1.2 Fences to reduce noise

When using noise barriers, both acoustical and non-acoustical aspects need to be considered. Location, dimension, and transmissive and reflective (insulating)/absortive characteristics determine the acoustic performance of a noise barrier. Non-acoustical considerations are visual effects (layout and elevation), safety, maintenance, drainage, etc [OECD, 1995].

Erecting noise barriers between a street and areas adjacent to the street can attenuate traffic noise. A noise barrier essentially interferes with the propagation of the sound waves from the street to the receivers. The sound waves travel linearly over the top of the barriers, creating a 'shadow zone' behind the barriers where noise levels are lowered. The use of solid and massive barriers can effectively reduce noise levels by 10 dBA to 25 dBA depending on their density. Lighter barriers will only reduce noise by 5 dBA [OECD, 1995]. The heights and locations of noise barriers relative to streets are also important acoustical considerations. The existing noise conditions, i.e. primary data of field conditions, are important in finding the right dimension and location of a barrier.

Traffic noise levels can be evaluated by two different ways: measurements and predictions [OECD, 1995]. In the measurement methods, to make direct measurements of noise, acoustical instruments such as sound level meters are used. Prediction methods are based on acoustical theories of sound emission and propagation, which are used to calculate noise levels by simulating real or predicted situations by means of mathematical or physical models.

Measurement methods are relevant when applied to existing situations, whereas prediction methods can be used for both existing and planned situations. Prediction methods are very useful and some of them have been applied in a wide range of noise situations [OECD, 1995]. However, the small numbers of different available scenarios limit all prediction methods which currently exist. Where adequate resources are provided, measurements are also made to test the accuracy of predicted levels. In this research, both field measurement and prediction methods were used to provide data.

Figure 9.4 shows a method of predicting the level of acoustic pollution. Firstly, a set of input data is determined consisting of the location of a particular street, the morphology of the chosen street, traffic data including numbers and types of vehicle, traffic signals, and other traffic characteristics of the chosen street and the standard of noise levels at this street type. Secondly, this set of data is then calculated according to an algorithm for propagation as the result of reflection and attenuation and as the result of diffraction and absorption. The level of acoustic pollution derived from the calculation is then checked against the standard of noise levels in this street type [OECD, 1995].

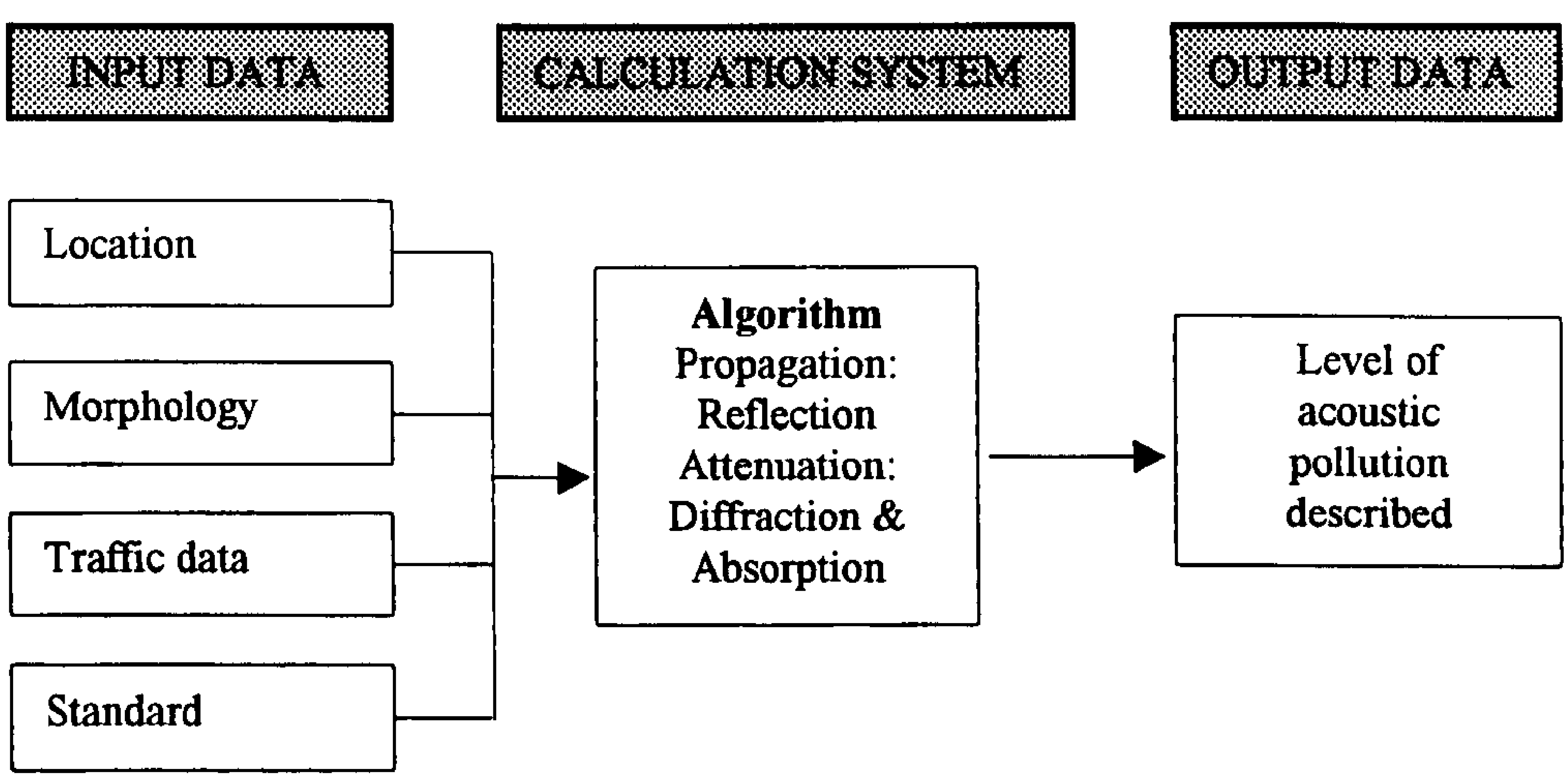


Figure 9.4. Chart of noise calculation process
(After OECD, 1995)

9.2.1.3 Design propositions of fences

Based on the above discussion and the discussion about the use of fencing as particulate matter and noise barriers (Chapters 7 and 8), which also permit natural ventilation (Chapter 6), the design propositions for fences are as follows:

- Dimension: as long as the house front length with height of approximately 1 m to 1.5 m. This is to permit airflow over the fence through to the window, which is normally 1.7m to 2.0m above the ground. Fence height below that of the house will also, incidentally, give a good appearance for the house.
- Position: at the near edge of the kerb (at the outer edge of the front courtyard). This is a common fencing position in Indonesian housing. As it is closer to the receiver (house), this position gives an opportunity to maximise its function as a noise barrier by creating an appropriate 'sound shadow'.
- Materials: solid and massive materials to create a 'sound shadow' for noise reduction, such as red brick, grey brick or prefabricated concrete. For particulate matter reduction process, finishing material that may provide more surfaces for particulate deposition is also proposed. This can be done by planting vegetation over or in front of the solid fence.

9.2.2 Vegetation

Indonesia is a tropical country with a huge variety of fast-growing vegetation. The Indonesian government advises families to cultivate their gardens, particularly planting varieties that benefit everyday life, such as plants for food and medical purposes. This gardening habit also brings many benefits to the whole building design, since, as described earlier in Chapter 7, vegetation can also reduce pollution.

9.2.2.1 Design propositions of vegetation

It is always wise to explore local resources in solving problems. The use of local vegetation will save time and cost, even though it may be difficult to find vegetation which is able to reduce pollutants to the extent required.

As a tropical country with high rainfall, vegetation in Indonesia is mostly tall (trees), the rest being shrubs and bushes. As mentioned above, low-growing vegetation is best suited for reducing particulate matter as well as for permitting airflow for natural ventilation, therefore the use of low-growing vegetation is proposed. Another possibility is to use climbing vegetation, which can be planted over a frame. The selection of shrubs or climbing vegetation is to be according to the following criteria:

- local species;
- durability;
- ease of growth, maintenance and regeneration;
- leaf characteristics (sticky, furry or shiny surfaces);
- aesthetic appeal.

9.2.3 Windows and other openings

Windows are the vertical elements of a house closest to its occupants. After the fence and the vegetation have filtered out a proportion of the pollutants, it is expected that windows will prevent still more of the pollutants from entering the house. Hence, pollutants are to be reduced in three stages: by fences , by vegetation (in the case of particulate matter) and finally by windows or other opening apertures.

9.2.3.1 Windows for natural ventilation and as pollutant barriers

The size and performance of windows are of great significance to occupants, particularly those in tropical humid climates who expect windows to have certain properties of supplying satisfactory ventilation rates. A window that is to open is more complicated compared to a fixed closed window, hence it is more expensive. With opened windows, a predictable insulation performance is also more difficult to achieve than it is with closed windows or without window [Collin and Collins, 1977].

The ventilation function of a window is the most difficult to design for. Sufficient openable window area should be included in the design process to accomplish the required air changes per hour (ach). There are recommendations for the number of air changes in a room of a certain purpose which should be supplied in a certain period. For rooms in tropical humid climates which accommodate intensive work, minimum of 30 air changes per hour is suggested [F.Moore, 1993].

Even though there are standards or guidelines for a certain amount of air to be supplied for maintaining health and indoor comfort, it is difficult to ensure that sufficient ventilation is ever achieved. This is because the operation of the openings is in the hands of the occupants. Some occupants in a building may feel that the indoor environment is cool and comfortable, which encourages them to close the windows. Meanwhile the rest of the occupants feel that the indoor temperature is still too high, so they prefer the windows to be opened. This problem can be solved by installing permanent ventilation either by mechanical ventilation or more simply by windows that are kept open all the time, such as louvre (jalousie) windows.

As mentioned earlier, in order to use windows for both natural ventilation and pollutant barriers, it is necessary to select window designs that enable the obstruction of pollutants which still permit airflow. Fixed opened windows such as louvre (jalousie) windows are capable of permitting natural ventilation and obstructing pollutants (by impacting or depositing particulate pollutants and reflecting or absorbing noise).

9.2.3.2 Windows to reduce particulate matter

Sections 6.1.1 and 7.2.3 describe how the orientation, position, dimension, material, style or type and accessories of a window are of importance in gaining both natural ventilation and obstruction of pollutants.

Chapter 7 discussed the possibility of using windows with angled openings that might obstruct pollutant pathways. However, there are many types of window with angled surfaces such as top hung and bottom hung windows, which may obstruct pollutants pathways but which are poor in supplying airflow for natural ventilation, particularly at low wind speeds. Side hung windows which are not fully open may obstruct pollutant pathways, but these will supply poor airflow. Therefore, angled surfaces that provide more areas for air to flow through such as louvre (jalousie) windows are suggested. It will be proved by the ventilation flow rate calculation in Chapter 10 that this type of window is capable of supplying the suggested ventilation rates for tropical buildings of 30 air changes per hour. As fixed louvre windows will cause airflow to move upward, this type of window is better placed slightly lower than casement windows, except when double jalousie windows are used. However, the use of double jalousie windows is impractical for inducing indoor airflow in the low wind speeds common to Indonesia.

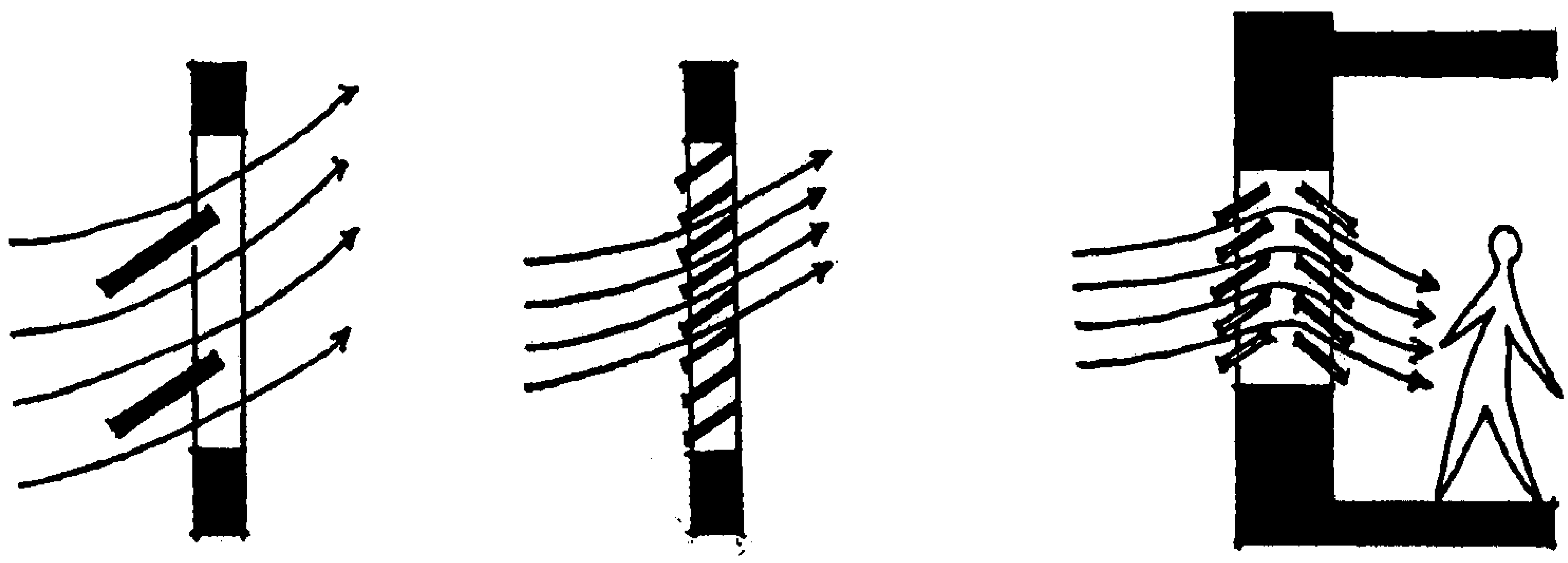


Figure 9.5. Air flow through hopper, jalousie and double jalousie windows
(Source: Lechner, 1991)

A window, and thus its materials, consists of two parts: body and surface. Body materials are normally chosen for durability, low cost and ease of maintenance and operation. Surface materials are chosen for their ability to trap particulate matter and for their durability against rains and solar radiation. Body materials that expand easily or materials between the frames and the openable areas that expand differently will cause difficulties in operation.

A common body material for windows in Indonesia that also fulfils factors of durability, low cost, ease of maintenance and operation is timber. However, this material may need a surface finish to improve its durability against rain and solar radiation and for particulate trapping, which can be achieved by providing a rougher surface [Schneider, et al, 1999]. Paint and varnishes that increase surface roughness and durability are available.

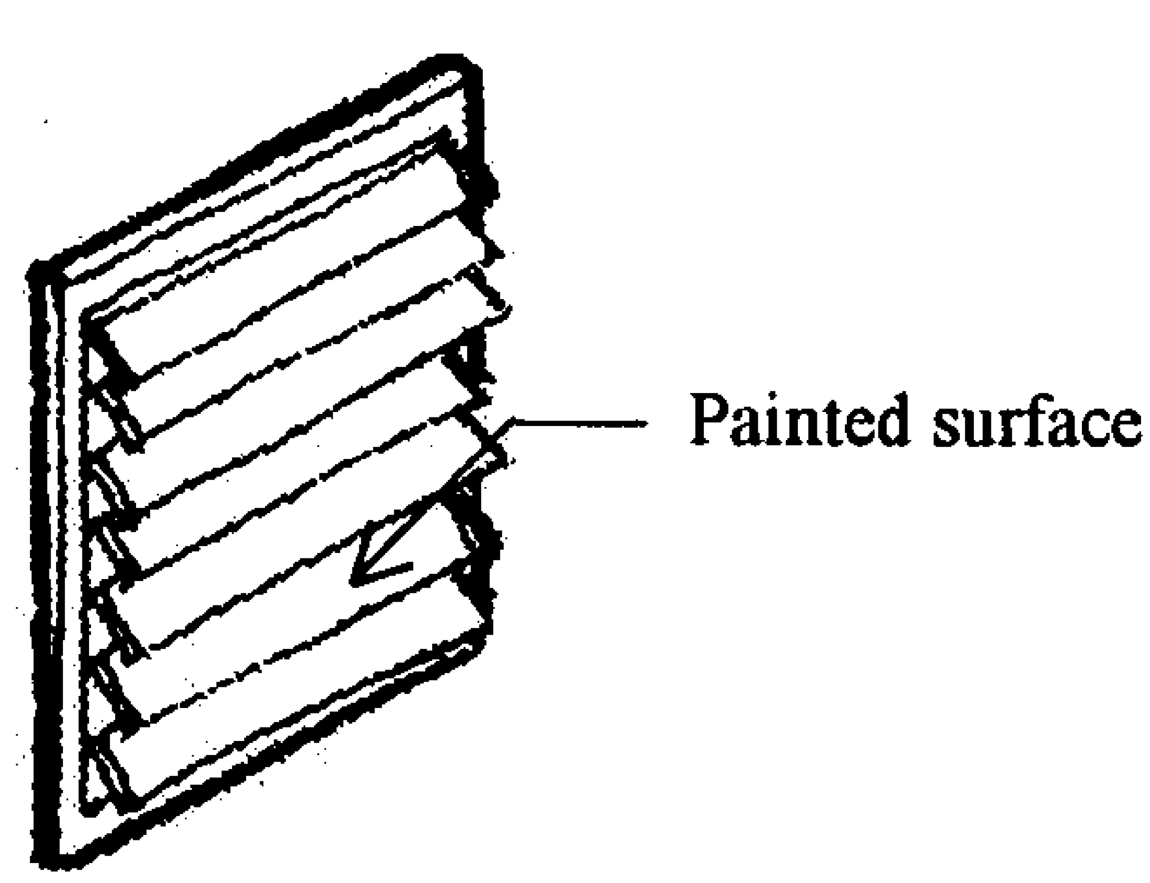


Figure 9.6. A louvre window with painted outer surface

The detailed design of a louvre comprises two significant factors: louvre degree and louvre shape. For particulate impaction, the greater the angle of the louvre the better. However, as can be seen in Table 9.1, increasing the angle also reduces airflow. The best angle is 90° from the horizon, but this will completely block the airflow. In the limit, a 90° angle is similar to a closed window. The reference angle for the ventilation flow rate calculation (to be discussed in Chapter Ten) is 45°, which permits airflow of 75% from the total window areas [F. Moore, 1993]. This means that to achieve a similar air change as indicated by the ventilation flow rate calculation, the window area needs to be increased to reach similar values of air changes to those supplied by an angle of 45 °. For example, by increasing the angle from 45° to 50°, the window's ability to pass air will decrease to 63% of that of the fully opened windows. This is only 84% of that given by a louvre with an angle of 45°, so that the areas need to be increased by about 19%. With similar calculations, percentages of air supplied by other angles are as follows:

Angle of louvre	Air flows compared to fully opened windows	Air flows compared to louvre windows with angle of 45°	Increase in area to achieve same ventilation rate to those given by angle of 45°
45°	75%	100%	0%
50°	63%	84%	19%
55°	52%	69%	45%
60°	43%	57%	75%

Table 9.1. Air flows supplied by different angles of louvre
(Source: F. Moore 1993)

Considering the limitation of wall areas in house type A and B of Indonesian low cost housing, the window areas can only be increased by up to 30%, which means that the maximum angle is approximately 52°. However, it should be noted that increasing the window dimension thus means increasing particulate matter intrusion. Since particulate removal does not only depend on the angle of the impaction surface, there is probably no advantage in increasing the angle of the louvre surfaces and the window dimension. Therefore, angle of 45° is chosen to provide a compromise between the requirements of particulate impaction and those of airflow.

9.2.3.3 Windows to reduce noise

Principles for reducing noise by using windows relate to the behaviour of sound, as sound may reflected, absorbed and transmitted. The windows will then as far as possible reflect noise off building surfaces, absorb noise to a limited degree and transfer as little noise as possible into the room. The use of angled windows is to provide a reflective surface for the approaching noise. The more area of angled surfaces there are, the more noise will be reflected and thus less noise will be transferred. A combination of reflecting and absorbing surfaces can be used to obtain the best result. Absorbent lining in the inner surface of the louvre will absorb noise that would otherwise be reflected toward the rooms [O.H. Koenigsberger, et al, 1973].

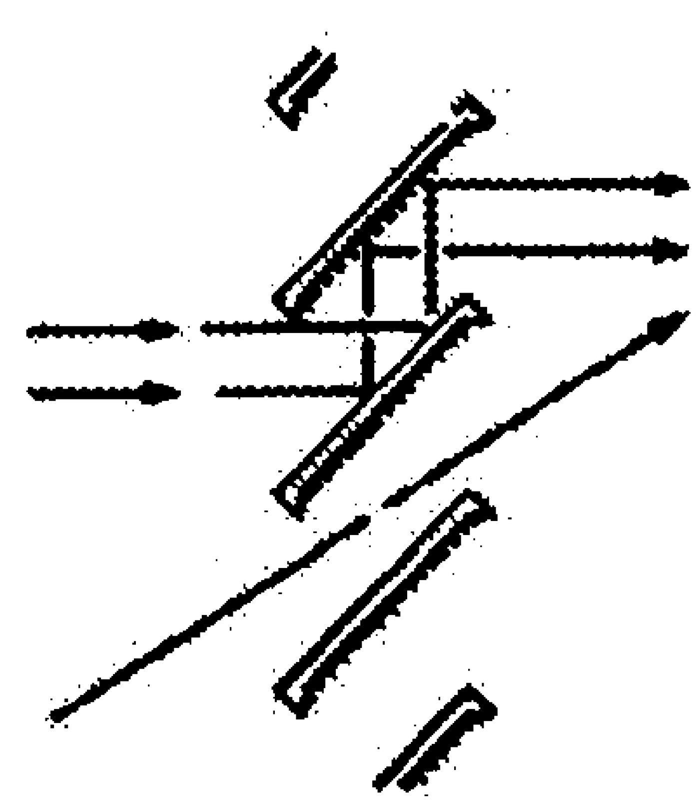


Figure 9.7. Louvre windows with absorbent lining in the inner surfaces
(After O.H. Koenigsberger, et al, 1973)

Figure 9.7 shows that noise is reflected twice. Koenigsberger shows that if one of the surfaces absorbs noise with approximately 0.75 absorptivity, a reduction of some 6 dB will be achieved. If both surfaces absorb noise, the total reduction will be some 12 dB [O.H. Koenigsberger, et al, 1973].

The most important step in reducing noise by using windows is to place the windows within the sound shadow of the barrier. A window that is higher than the barrier may still provide good noise insulation if it is placed within the sound shadow. Hence, the noise that approaches the louvre surface is noise that is refracted from the top of the barrier, which is less than the direct noise before it is refracted.

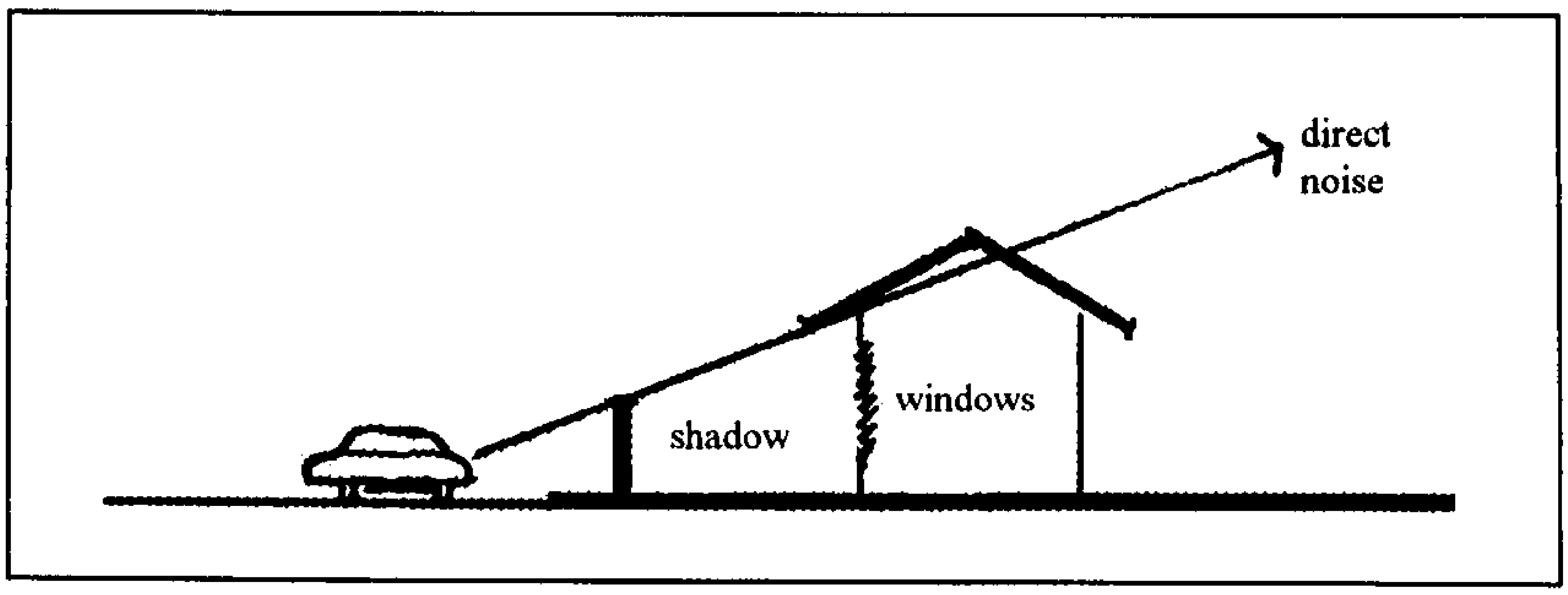


Figure 9.8. Window heights within the sound shadow
(After O.H. Koenigsberger, et al, 1973)

As with principles for using angled surfaces to reduce particulate matter, the greater the angle of the louvre, the more noise will be reflected away from the building. The more complex the shape of the louvre, the less the noise that will be transmitted into the rooms. However, once again we need to consider free flows for natural ventilation, which is difficult with particular louvre shapes [O.H. Koenigsberger, et al, 1973], as shown by Figures 9.9 and 9.10.

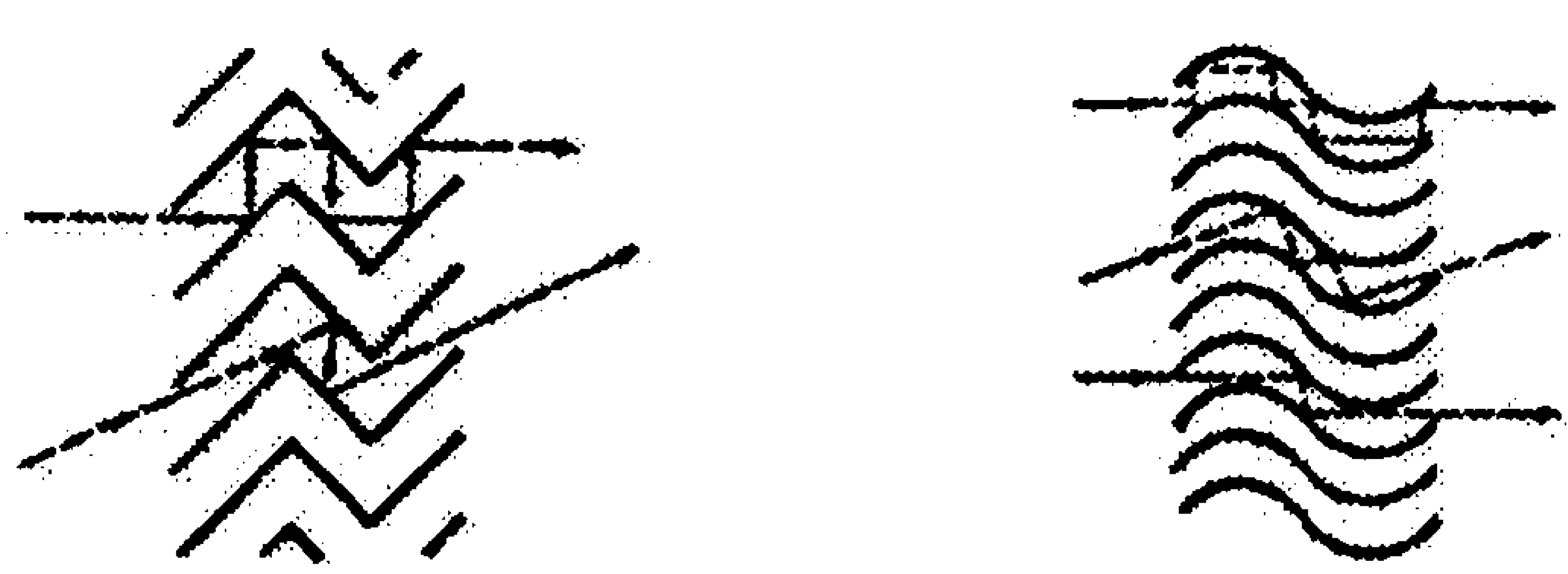


Figure 9.9 and 9.10. Specific shapes of louvres
(After O.H. Koenigsberger, et al, 1973)

9.2.3.4 Design propositions for windows

Based on the above discussion on using windows for reducing the intrusion of particulate matter and noise, whilst also permitting natural ventilation, the design propositions for windows are:

- Dimension: of approximately 0.6 m to 0.8 m above the ground to suit the occupant levels, with a height of approximately 1 m to 1.5 m to gain airflow from the top of the fence. The width is approximately 0.5 m to 0.7 m for ease of operation, particularly for fully opened windows.

- Style: the proposed styles for inlets are louvre windows and for outlets are either louvre or casement windows.
- Position: inlet windows are proposed to be installed in the wall that either faces away the pollution source or furthest from it, whilst the outlets are proposed to be placed opposite the inlets in order to create cross ventilation and induce greater indoor velocity.
- Materials: a commonly used low cost material such as timber is proposed for constructing the windows. To increase the durability and the ability to trap particulate matter, the timber window might be finished with a special paint or varnish that may create a rougher surface.

CHAPTER 10
VENTILATION FLOW RATE CALCULATIONS

A simple computational model (Brevent), which was developed by the Building Research Establishment (BRE), UK, was used to calculate the required ventilation rates or air changes per hour (ach) within the proposed housing design.

10.1 Ventilation flow rate calculations approach

Once the new design has been proposed, the first important property to be examined within the new design is the indoor thermal comfort. Perception of indoor thermal comfort can vary from one person to another. As mentioned in Chapters 3 and 6, environmental factors that affect person feelings about thermal comfort are air temperatures, radiant temperatures/surface temperatures, air movements, and humidity [Fanger, 1973 and McMullan, 1992]. As temperature and humidity can not be controlled except by air conditioning, there are two aspect that affect the indoor thermal comfort of naturally ventilated houses i.e. the amount of air changes to be supplied per hour in to the room and the indoor air velocity. Air change per hour (ach) is a value without any particular unit and always relates to the volume of the room to where the value of air changes per hour should be supplied. For example if a room with a volume of 150 m^3 requires 30 air changes per hour to maintain indoor thermal comfort, the air to be supplied is 150 m^3 x 30 = 4500 m^3/h (1.25 m^3/s).

A computational model is chosen to examine the air changes per hour within the proposed design. Building a real house with a detailed design exactly as has been proposed would provide more realistic results. However, since this requires a very high cost and a long time for construction, a computational model is useful for predicting the indoor thermal levels of a room or a house. Brevent was chosen for this examination. From this prediction, it then can be seen whether the proposed design is capable of providing the required air changes per hour for indoor thermal comfort. From here, the study then examines the ability of the proposed design to reduce pollution.

10.2 Brevent software description

The Brevent software was first commercially launched in 1992. It is a model for predicting ventilation rates in dwellings. It is based on a set of equations that describe infiltration through building fabric, and flow through discrete elements such as openings (e.g. trickle ventilators and air bricks, etc.), windows, extract fans, combustion appliances (flues), and passive stack ventilation devices (vertical ducts). This is a single-zone model but becomes two-zone if a ventilated subfloor space is included.

10.2.1 Principles

Brevent is a mass balance model that iterates on static internal pressures in order to find the flow rates for any given weather conditions. Pressures outside the dwelling are calculated from weather data and the pressure coefficients are experimentally determined by assuming constant wind speeds. Leakage paths are approximated by distributing the total leakage (multiply the designed air changes per hour by the volume of the dwelling) around the walls, floors and ceilings of the dwelling on an area weighted basis. Then, by choosing an initial floor level internal pressure (P_I), the flow rates into the dwellings via user-defined routes can be calculated. Flows into the dwellings are defined as positive and out from the dwellings as negative. Detailed formulae for Brevent calculations can be seen in Appendix 3.

10.2.2 Data for Brevent calculation

Users must specify the required weather conditions (i.e. wind speeds, wind directions, and temperatures) and dwelling dimensions. Element dimensions and flow coefficients are needed for each discrete flow.

10.2.3 Output: total ventilation flow rates

The total ventilation flow rate for dwellings is the sum of the moduli of all flows into and out of the dwellings divided by two, because flow in equals flow out. The ventilation rate is measured in air changes per hour, i.e. the ventilation flow rate divided by the volume of the dwellings.

As windows and walls can have flow in both directions, these components must be treated separately and their moduli added to give the total ventilation figures.

10.2.4 Reasons for using Brevent

Brevent is a simple single-zone ventilation model. This means that air is either inside or outside and all internal partitions are ignored. A single-zone model is appropriate if the information required relates only to the total air changes rate for buildings or the flow through a particular component. In these cases the internal partitions can be ignored, and a single zone is a fair representation of reality.

Brevent software seems adequate to calculate airflow rate in single story houses. Low cost housing in Indonesia is very simple. There are usually two or three rooms. For houses with an L shape, the first two rooms are usually located in the outer layer, so that there it is only one room located in the inner layer (Figure 10.1 below.). The proposed housing design, which would be calculated using Brevent, has three or four rooms. However, only the outer rooms are important for this calculation. The result of airflow rates in the outer rooms can be used as basic calculations for the inner rooms if required later. This shows the limitations of a Brevent simulation, which can only calculate the air supplied to a single house, consisting of one layer. However, as the houses are usually very simple, further calculations for the inner rooms may be unnecessary, especially when the houses are designed in an L-shape (Figure 10.1).

Multi-zone software has more ability to calculate flows of air from room to room and estimate concentration of pollutants in rooms. However, as estimation of pollutant concentrations will be calculated by CFD, a single zone model such as Brevent is sufficient for the calculation of airflow rates.

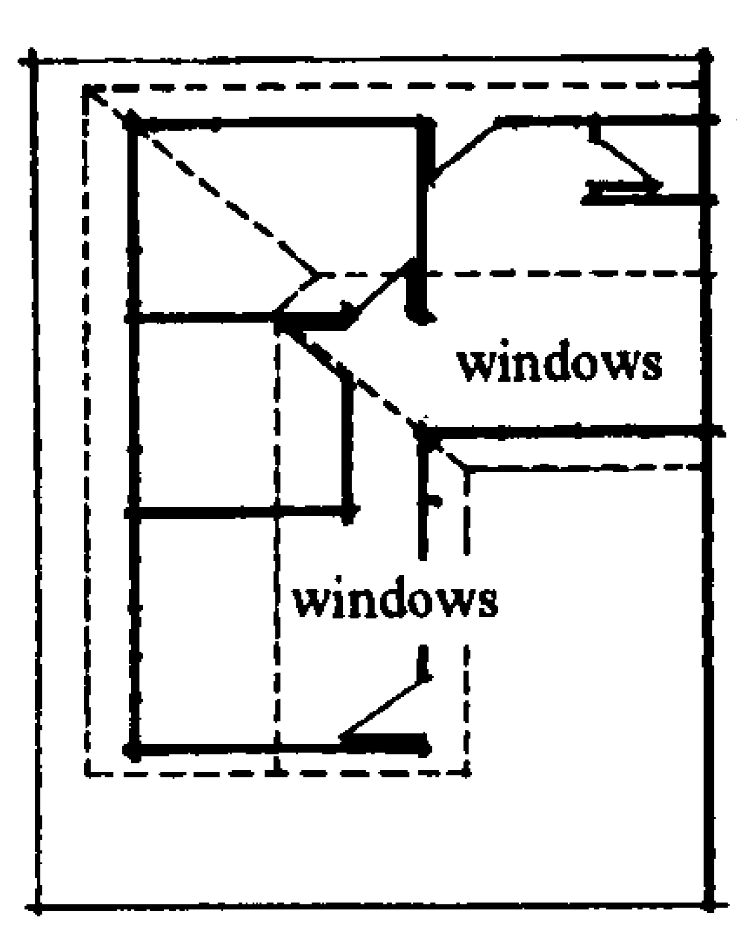


Figure 10.1. Design propositions for general room layouts (Plan of house type B)

10.2.5 Applications of Brevent

Brevent has already been used on a number of different projects at the Building Research Station (now BRE), UK and has been validated [BRE, 1992]. These have included investigating the performance of Passive Stack Ventilation (PSV) systems, the ventilation of a sub-floor void, the development of the UK Building regulations for ventilation in houses, and work on the developing CEN standard for ventilation calculations across Europe [BRE, 1992]. It can also be used to enable people to understand the effect of changes to the ventilation of a building, for example by changing the position of a window or adding another ventilation device.

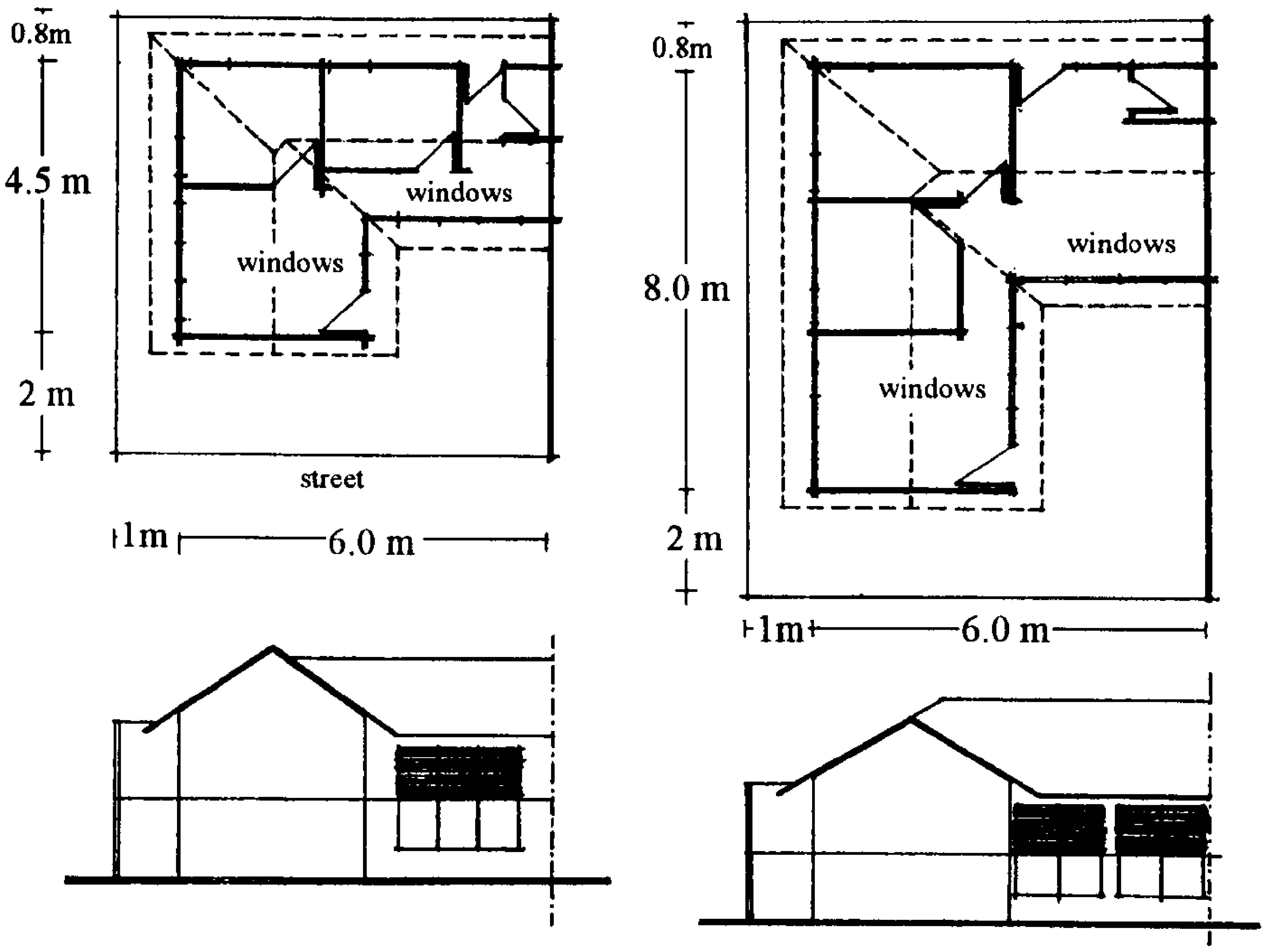
10.3 The Brevent calculation

10.3.1 Preparation for the Brevent calculation

A set of manual calculations based on Fuller Moore's formulae [F. Moore, 1993], refer to Appendix 2, was prepared to guide the computational calculation. This manual calculation narrows the options for inputs, hence saving time and providing more precise results. The principle of the manual calculation is to determine the microenvironment around buildings and to calculate the approximate openings required to supply the number of air changes per hour (ach). The air changes per hour to be calculated is based on a suggestion for warm humid climate of a minimum of 30 ach, which is proposed for comfort cooling [F. Moore, 1993].

The steps of manual calculation are as follows:

The first step is to sketch general ideas of the new suggested housing design based on comfort factors, which are taken from Chapter 9. The housing dimensions are as follows:



House type A House type B

Figure 10.2. Housing dimensions for ventilation flow rate calculations

Data for the manual calculation can be seen in the following tables.

1. Weather conditions in Yogyakarta:

MONTHS / SPECIFICATIONS		OCT 94	NOV 94	DEC 94	JAN 95	FEB 95	MAR 95	APR 95	MAY 95	JUN 95	JUL 95	AUG 95	SEP 95	Average
Temperature °C	max	33.0	33.9	30.7	30.7	30.7	30.8	31.9	32.3	31.6	31.0	30.3	32.5	31.6
(Daily average)	min	23.6	24.7	24.1	23.7	23.4	24.1	24.2	24.4	23.9	22.9	22.0	23.1	23.7
Humidity %		77	79	85	88	88	87	84	83	86	83	80	78	83.2
Wind m/s	Average	2	1.5	1.5	1	1.5	1.5	1.5	1	1.5	1.5	1.5	1.5	1.5
	Most of angle	210	120	210	210	210	210	210	120	120	120	180	180	-
Rainfall mm		1.1	3.2	9.0	19.7	21.8	10.6	7.7	0.9	5.2	0.7	0	0.005	-

Table 10.1. The weather of Yogyakarta in 1994/1995
(Source: *Dinas Navigasi Udara, Adisucipto*, Yogyakarta, 1995)

Data in Table 10.1 was not used in the Brevent, but only to give an idea of the external temperature ranges in Yogyakarta. In this calculation, the average daily temperatures during a specific month was used. The reference month was June [F. Moore, 1993], when the average daily temperature ranges between 24°C and 32°C, i.e. a diurnal range of 8°C.

1. Temperatures within some houses

House number / Temperature °C	1	2	3	4	5	6	7	8	9	10
Early morning temperature (7-8am)	20	23	21	21	24	20	21	22	23	19
Morning to noon temperature (9- 12pm)	27	26	30	29	32	30	28	31	32	29
Afternoon temperature (1-5pm)	30	24	32	25	32	29	28	32	27	25
Evening temperature (7-9pm)	24	22	24	21	27	19	23	25	20	25
Activities	N	N	C	L	MS	L	S	MS	CT	C

Table 10.2. Primary data on indoor temperatures, measured in the first week of Oct 1996.

Keys: C = craft; N = no particular activities
CT = catering; MS = meal shop
L = manual laundry; S = shop

Data presented in Table 10.2 is from field measurement taken over the first week of Oct 1996. Many indoor activities within low cost housing in Yogyakarta are commercial activities, which are usually carried out in daytime (9.00 to 17.00). Hence, morning to noon and afternoon are the most important periods to be considered in the calculations, as early morning temperatures are usually low enough not to cause uncomfortable conditions. Data in Table 10.2 was not used in the Brevent. The data provided in this table is only to give information on the approximate range of indoor temperatures which are experienced in low cost housing in Yogyakarta. Outdoor temperatures are mostly similar and fairly stable all over Yogyakarta, but indoor temperatures vary with specific activities.

2. Fuller Moore's data for the manual calculations (refer to Appendix 2):

Wind Incidence Angle (°)	Windspeed ratios
0-40	0.35
50	0.30
60	0.25
70	0.20
80	0.14
90	0.08

Table 10.3. Inlet to site 10 metre wind speed ratios

Terrain type	24 h ventilation (humid)	Night-only ventilation (arid)
oceanfront	1.30	0.98
airports or flatland	1.00	0.75
rural	0.85	0.64
suburban or industrial	0.67	0.50
centre of large city	0.47	0.35

Table 10.4. Terrain correction factors

Window type (based on Figure 6.7)	Effective open area
single hung	45 %
double hung	45 %
sliding	45 %
awning	75 %
casement	90 %
jalousie	75 %
hopper	45 %

Table 10.5. Effective open area of windows

Based on the above factors, details of the manual calculation are as follows:

No.	Specification	Formula	House type A	House type B
1	building conditioned floor area		189 ft²	324 ft²
2	average ceiling height		8 ft	8 ft
3	house volume	step 1 x step 2	1,512 ft³	2,592 ft³
4	design air change rate/hour (rec.30)		30 ach	30 ach
5	required air flow rate (cfm)	(step 3 x step 4) : 60	756 cfm	1,296 cfm
6	design month (recommended: June)		June	June
7	name of nearest city		Surakarta	Surakarta
8a	wind speed	on June	3.4 mph	3.4 mph
8b	wind direction		SE	SE
9	wind angle to wall with largest window		30° and 60°	30° and 60°
10	inlet-to-site 10 m windspeed ratio	table 10.3	average = 0.30	average = 0.30
11a	terrain correction factor	table 10.4	0.67	0.67
11b	neighbouring buildings	Neighbourhood = 0.77 no surrounding = 1.0	0.77	0.77
11c	correction factor	second floor window = 1.15 otherwise = 1.0	1.0	1.0
12	windspeed correction factor	step11a x step11b x step11c	0.52	0.52
13	site windspeed (ft/min)	step 8a x step 12 x 88	155.6 ft/min	155.6 ft/min
14	window inlet airspeed	step 13 x step 10	46.7 ft/min	46.7 ft/min
15	net aperture inlet area	step 5 : step 14	16 ft²	28 ft²
16	total effective inlet+outlet area (screened)	3.33 x step 15	53 ft²	93 ft²
17	total effective area as % of floor area	(step 16 : step 1) x 100	29 %	29 %
18	effective openings of window type	table 10.5	Jalousie & casement	Jalousie & casement
19	calculate total effective area of each window : frame opening area (ft²) x effective opening factor x number of opening = (about equal or exceed step 16) **type 21 :** jalousie : 9 ft² x 0.75 x 5 = 33.75 ft² casement : 9 ft² x 0.90 x 3 = 24.3 ft² total : 58 ft²	**type 36 :** jalousie : 9 ft² x 0.75 x 6 = 40.5 ft² casement : 9 ft² x 0.90 x 7 = 56.7 ft² total : 97 ft²		

Table 10.6. Manual calculation for using natural ventilation based on Fuller Moore's formulae

The results of the manual calculation were used to give an idea for or to narrow the inputs of the Brevent calculation, especially regarding the approximate numbers of windows and window dimensions. More details on Fuller Moore's basic calculation method can be found in Appendix 2.

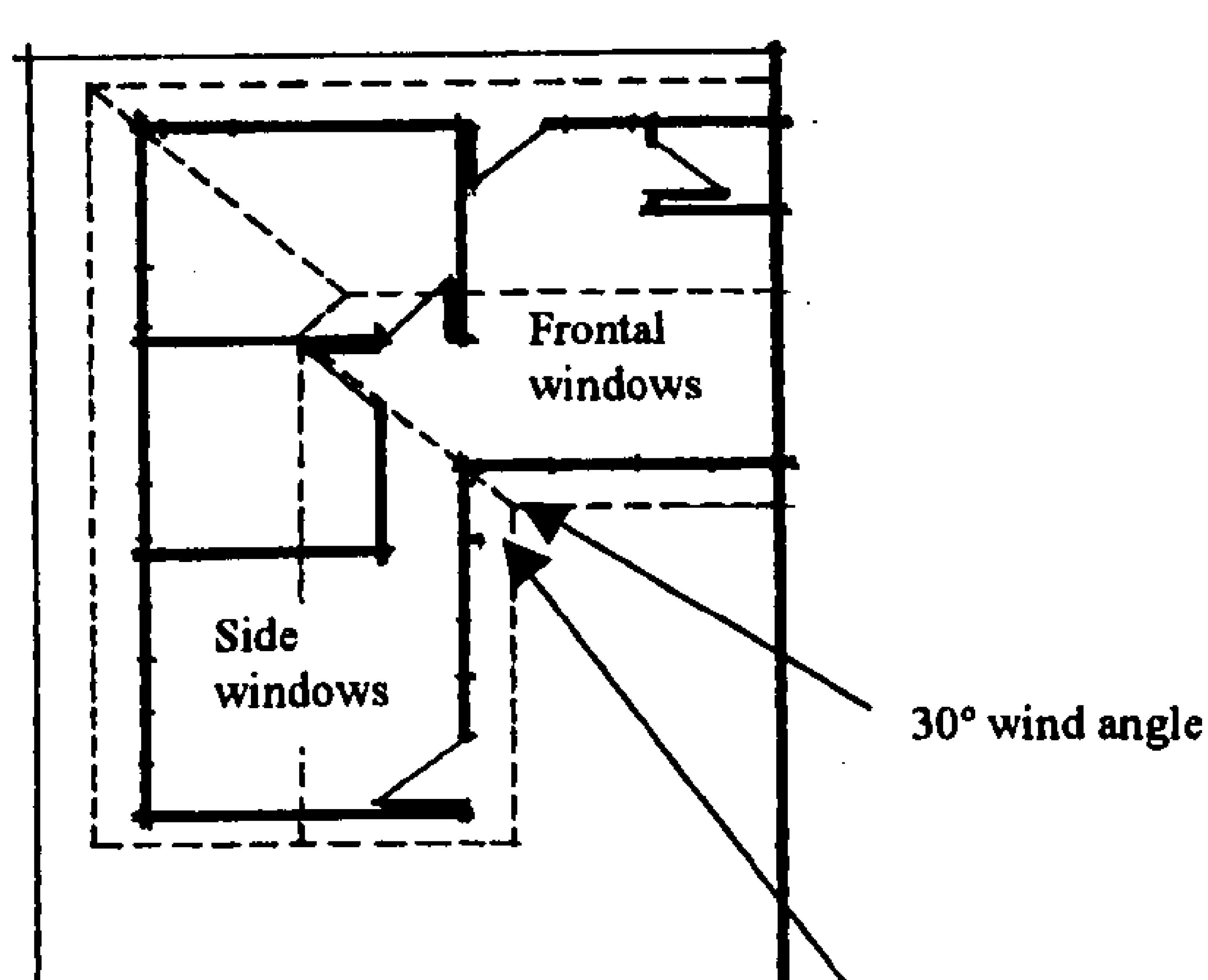


Figure 10.3. Wind direction can be either obliquely of 30° or obliquely of 60° depending on the position of the windows

10.1.1 The Brevent calculation

The results of the numbers of window and their dimensions from Fuller Moore's calculations are listed together with other factors that are required for Brevent inputs, as can be seen in Table 10.7. More detailed descriptions of Brevent specifications can be found in Appendix 3.

SPECIFICATION		VALUE	DESCRIPTION
House type		Semi detached	-
Length of front face	Type 21	6 m	Simplification of the L-shape
	Type 36	6 m	
Length of side face	Type 21	4.5 m	Simplification of the L-shape
	Type 36	8 m	
Envelope height		2.4 m	Height of walls from ground
Dwelling height	Type 21	3.9 m	Height from ground to roof top
	Type 36	4.15 m	
Orientation of the front face		0°	Primary data
Lowest internal temperature		24° C	Primary data
Highest internal temperature		32° C	Primary data
Internal temperature step		2° C	Brevent specifications
Lowest external temperature		24° C	Secondary data
Highest external temperature		32° C	Secondary data
External temperature step		2° C	Brevent specifications
Lowest windspeed		0 m/s	Secondary data
Highest windspeed		2 m/s	Secondary data
Windspeed step		0.5 m/s	Brevent specifications
Starting wind angle		30°	Secondary data (refer to Figure 10.3)
Final Wind angle		60°	Secondary data (refer to Figure 10.3)
Wind angle step		30°	Brevent specifications
Anemometer height		10 m	Secondary data
Wind profile exponent		0.33	Choose from the following: Open flat country: 0.17 Country with scattered wind breaks: 0.2 Urban: 0.25 City: 0.33
Pressure difference		50 Pa	Quoted as a normal value
Leakage exponent		0.6	Quoted as a common value
Leaky value		20 ach	Value for a leaky house (Brevent specifications)
Housing density	Type 21	0.33	Primary data
	Type 36	0.35	Primary data
Window areas	Type 21	Minimum 58 ft² = 5.4 m²	Approximately 8 windows, about 0.7 m² each (the number and dimensions are to be changed during the Brevent experiment)
	Type 36	Minimum 97 ft² = 9 m²	Approximately 13 windows about 0.7 m² each (the number and dimensions are to be changed during the Brevent experiment)

Table 10.7. Brevent inputs

Opening types	Specification
Jalousie windows	Width = 0.65 m Height = 1.6 m Height above ground = approx. 0.6 m Effective open areas = 75%
Casement windows	Width = 0.65 m Height = 1.3 m Height above ground = approx. 0.90 m Effective open areas = 90%
Doors	Width = 0.75 m Height = 1.8 m Height above ground = 0 m Effective open areas = 90%
Door upper openings	Width = 0.75 m Height = 0.15 m to 0.2 m Height above ground = 1.8 m Effective open areas = 75%

Table 10.8. Opening dimensions for the Brevent inputs

Some of the dimensions for the above opening were changed to provide sufficient data for further analysis.

10.2 The Brevent results

The above inputs gave 250 runs and thus 250 outputs for each house type. Several alternatives were simulated starting with different numbers, dimensions and types of window in each surface, and continuing with roof openings. All these experiments needed to consider one important factor: the average air changes per hour needs to be approximately 30 [F. Moore 1993].

Thirty options were run for both house types. However, only some of them fulfilled the required ventilation rates. There were two options for window designs:

- both inlet and outlet are jalousie windows;
- jalousie windows in the windward side (input windows) and casement windows in the leeward side (output windows).

The thirty options from the experiments showed that when both windows were jalousie the ventilation rates were approximately 2-3 ach lower compared to when there were jalousie windows on the windward side and casement windows on the leeward side.

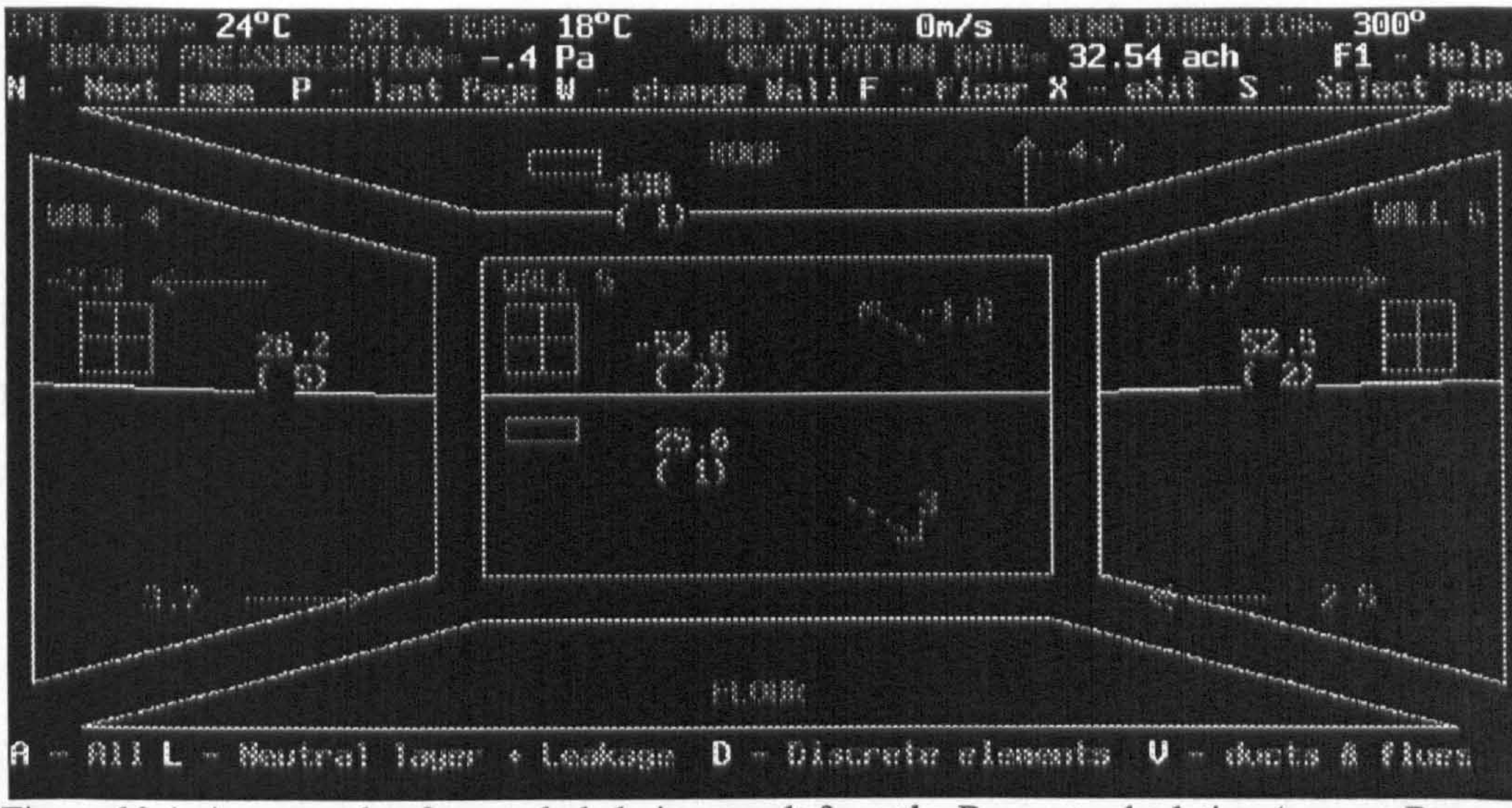


Figure 10.4. An example of an exploded view result from the Brevent calculation (source: Brevent)

Keys:

At the top of the screen, the basic weather data for the particular run loop is given, followed by the predicted indoor pressure at ground level (relative to outside) and the total dwelling ventilation rate. The green values show airflow in each surface (m³/h) followed by number of the discrete elements (windows or openings). The yellow horizontal line shows the neutral layer, completed with red values of flows below and above the neutral layer on each surface (m³/h). Positive values show flows into the dwelling and negative values show flows out of the dwelling.

With roof openings installed in the leeward side (outlets), the experiments on roof openings showed that roof openings could improve ventilation rates by up to 3 ach depending on the number of the roof openings. One roof opening could increase ventilation rates by approximately 1 ach. The overall experiment also showed that:

- Temperature differences were the most significant factor generating air motion within the houses when external wind speed was 0 m/s.
- The greater the temperature differences between indoor and outdoor, the better the ventilation rates (ach) within the houses.
- Wind directions either with an angle of 30° or 60° (refer to Figure 10.3) to the windows gave relatively similar ventilation rates for given low external wind speeds (i.e. 0 m/s to 1 m/s).
- For external wind speeds of more than 1.5 m/s, a wind direction of 60° provided a slightly greater ventilation rate compared to one of 30°. The difference varied. The higher the wind speeds the greater the ventilation rates provided by a wind direction of 60°. In some cases the difference might reach 4 ach.
- There were two critical periods within the house when the ventilation rates could be very low. Firstly when there was no temperature difference between indoor and outdoor (when the external wind speed is 0m/s, there would be zero ventilation rate). Secondly when the external wind speed was 0m/s. However, since the period when there is no temperature difference between indoor and outdoor can only last a very short time (with zero ventilation, the indoor air would get hotter and thus created a temperature

difference), it is the second condition that is of more interest. An external wind speed of 0 m/s is most likely in a very high density housing area, especially with a barrier in front of the house.

From 30 options, there were only 20 which could provide ventilation rates close to the requirement of 30 ach. The 20 options used jalousie windows as inlets and casement windows as outlets. These 20 options (11 options for house type A and 9 for house type B) with their minimum ventilation rates when the external wind speed v = 0 m/s with temperature differences above zero ($\Delta t \neq 0$) are presented below.

EXP NO.	DETAILED OPENINGS IN HOUSE TYPE A	minimum ACH ($v = 0$ m/s, $\Delta t \neq 0$)
1	8 windows, without roof opening	24
2	8 windows, 1 roof opening (approximately 20cmx50cm)	25
3	8 windows, 2 roof openings	26
4	8 windows, 3 roof openings	26
5	8 windows, opened back door	30
6	8 windows, opened back door, 1 roof opening	31
7	9 windows, without roof opening	28
8	9 windows, 3 roof openings	30
9	9 windows, opened back door, 3 roof openings	35
10	9 windows, 4 roof openings	36
11	10 windows, without roof opening	30

Table 10.9. Experimental results for house type A

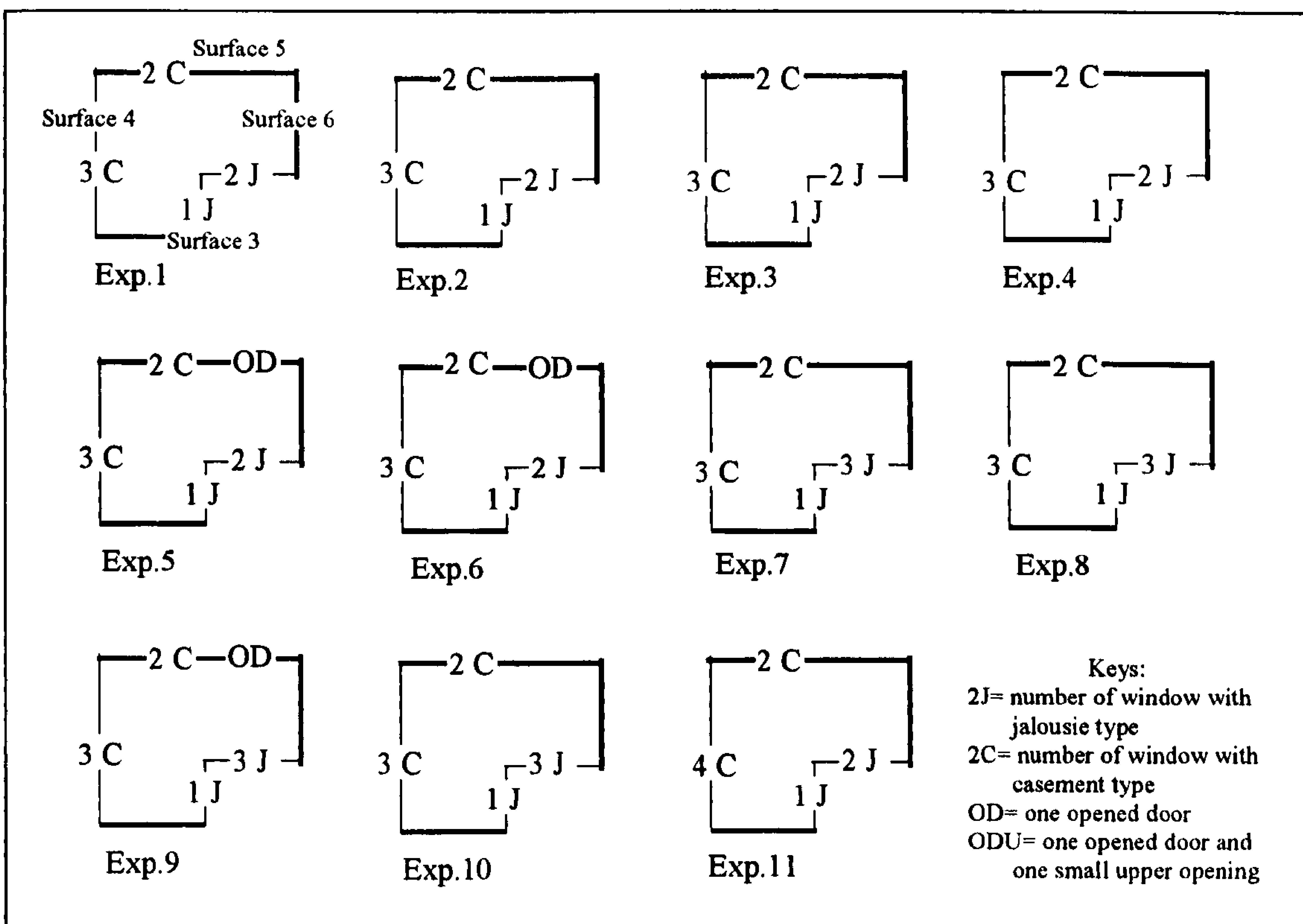


Figure 10.5. Detailed sketches of house type A for experiments in Table 10.9.

EXP NO.	DETAILED OPENINGS IN HOUSE TYPE B	minimum ACH (v = 0 m/s, Δt ≠ 0)
12	11 windows, opened back door, 4 roof openings	25
13	11 windows, opened back door, 6 roof openings	25
14	12 windows, opened back door, 4 roof openings	27
15	13 windows, opened back door, 4 roof openings	28
16	13 windows, opened back door, 6 roof openings	29
17	14 windows, opened back door, 4 roof openings	30
18	14 windows, opened back door, 5 roof openings	31
19	14 windows, opened back door + small upper opening, 4 roof openings	30
20	14 windows, opened back door + small upper opening, 3 roof openings	30

Table 10.10. Experimental results for house type B

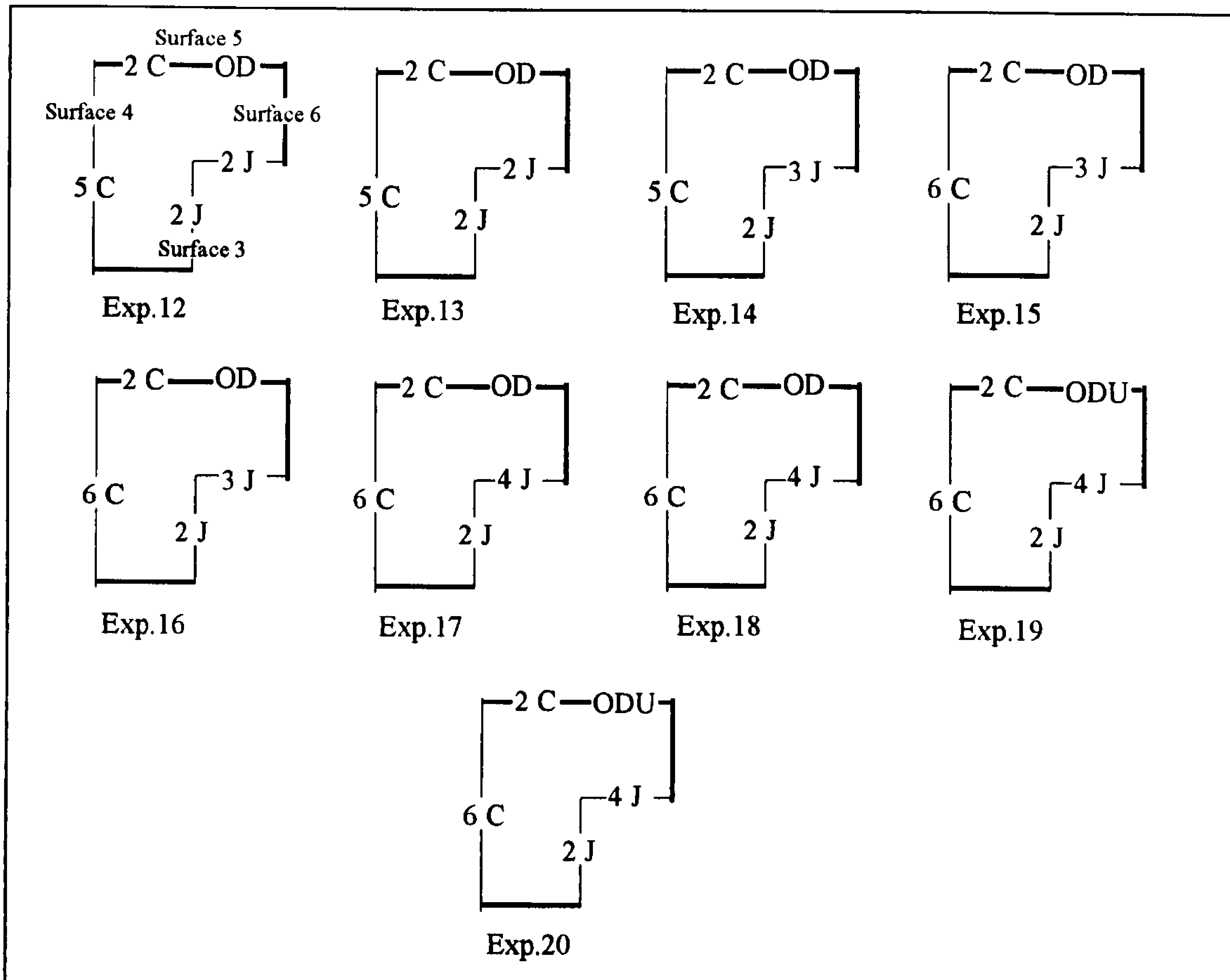


Figure 10.6. Detailed sketches of house type B for experiments in Table 10.10.

Keys:

2 J	= number of window with jalousie type
2 C	= number of window with casement type
OD	= one opened door
ODU	= one opened door and one small upper opening

10.3 Analysis

From the above design options (11 options for house type A and 9 options for house type B), it can be seen that most of the designs for the Brevent experiments were capable of supplying approximately 30 ach. A selection was made from these designs to find the most practical designs for both house types A and B. The selection was based on minimum 30 ach (to be strict) in condition when v = 0 m/s with temperature differences above zero ($\Delta t \neq 0$) and limitation of wall areas and roof areas. Fewer number of windows in the walls and fewer number of roof openings are preferred (it is only possible to design a maximum of 3 roof openings on the back of the roofs). Another reason is that the more windows and roof openings there are, the higher the cost, which is not a good solution for low cost housing. Some of the designs suggest opening the back door, which will not cause much pollutant intrusion because of the long distance from pollutant sources and the presence of obstructions. Moreover, it is customary in Indonesia to keep the back door open. Thus, options 5, 6, 8, 11, 16, 17, 18, 19 and 20 with the window dimensions as determined by Table 10.8 are those which fulfil the above criteria.

The type of roof opening selected for this experiment is a louvre opening that will automatically protect the interior from rain (Figure 10.7). The calculation for a roof opening is based upon its dimension and porosity.

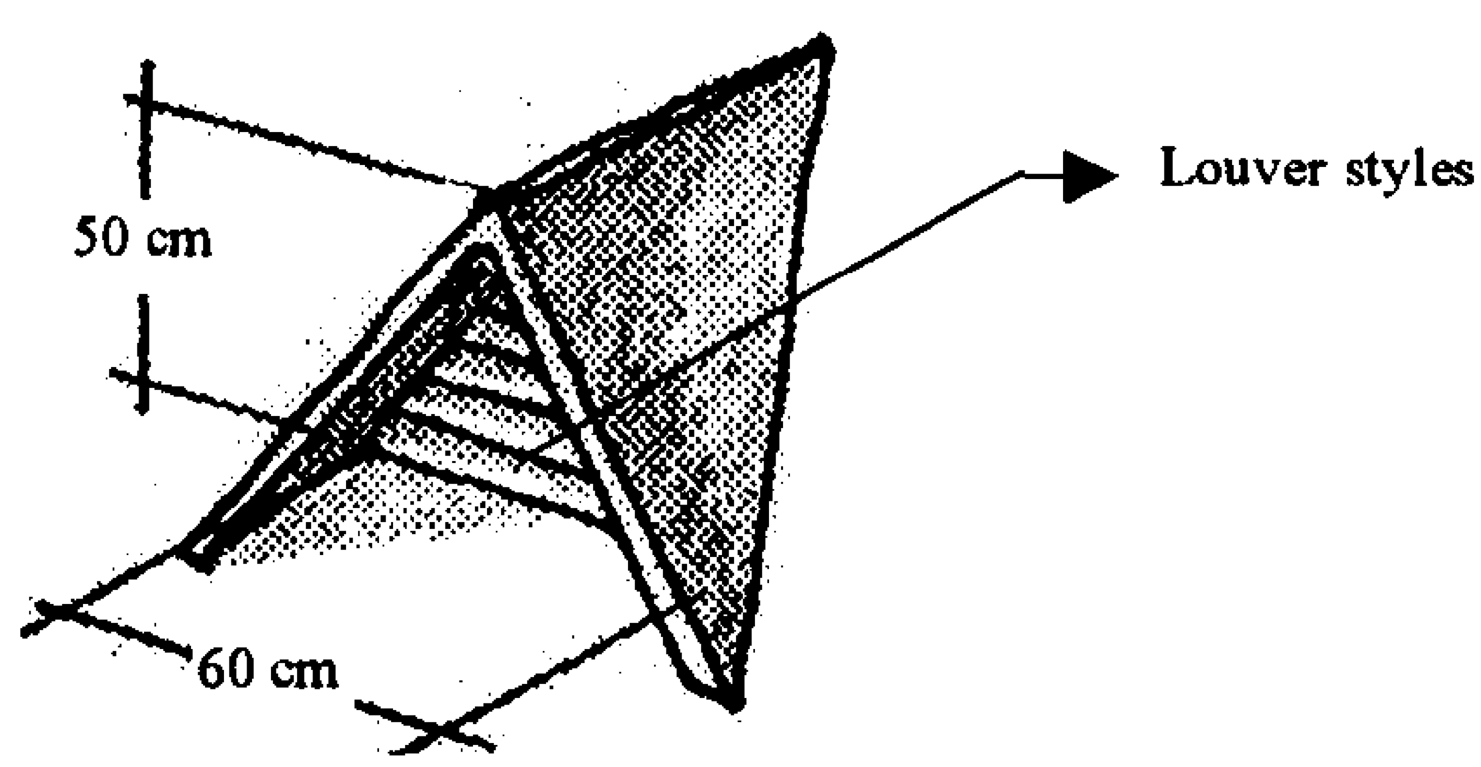


Figure 10.7. The roof type for Brevent experiment

A house can experience temperature differences throughout the day caused by changes of activities within the house. Therefore, in the absence of wind, it is mostly the activities within the house that generate ventilation. As there are activities within the house, heat is gained both from occupants and appliances. These will increase indoor temperatures to be higher than the outdoor temperatures. The temperature differences will generate ventilation within the house. There is a formula which can be used to calculate the heat generated within a house experienced a series of temperature differences. The formula is as follows [McMullan, 1992]:

$$P_v = \frac{C_v N V \Delta t}{3600}$$

Where: P_v = heat generated =heat energy/time (W)
C_v = volumetric specific heat capacity of air
= specific heat capacity x density (J/m³K)
N = air infiltration rate for the room
(the number of complete air changes per hour)
V = volume of the room (m³)
Δt = difference between the inside and outside air temperature (°C)

Note: The notation P is used here to represent this rate of heat energy, but some other sources, such as CIBSE, use notation Q instead of P.

In a simple way, the heat generated within a room can also be calculated by using a psychometric chart (refer to Appendix 6), as follows:

1. Calculate ventilation rate = (ach x room volume): 3600

   The room volume of the 36m² house type B (used in exp. 20) is 86.49 m³.
2. Calculate the mass flow rates. First of all, this requires ventilation flow rate from step 1, external temperature (°C), and external humidity (%RH). By using psychometric chart the specific volume of the air (m³/kg) can be determined. Then calculate the mass flow rates by dividing the ventilation flow rate by the specific volume found from the psychometric chart.
3. Calculate the difference in enthalpy (heat content) between the entering and leaving air. By using psychometric chart, the enthalpy of the outdoor air can be determined. The enthalpy of the indoor air can also be determined by assuming that moisture content within the house is similar to that of the outdoor air. The difference in enthalpy then can be calculated by subtracting the enthalpy of indoor air from that of the outdoor air.
4. Calculate the heat carried away from building by multiplying the mass flow rate obtained in step 2 with the difference in enthalpy (obtained in step 4).

Examples of the above calculation method are shown below. This calculation applies for houses as specified for the Brevent inputs (based on experiment 20). As mentioned before, each set of data (each experiment) gave 250 runs and thus provided 250 outputs. Experiment 20, which is chosen for heat calculation, also gave

250 outputs and only the first 18 outputs are calculated. These 18 outputs are adequate to indicate the heat experienced by the house.

One value of air changes per hour in experiment 20 is calculated in detail as follows (refer to run no. 5 in Table 10.11):

1. Indoor temperature = 32 °C, outdoor temperature = 24°C, outdoor humidity = 75% (averaged from a series of field measurements, refer to field experiments in Chapter 12), Ach = 61, room volume = 86.49 m³, and thus the ventilation rate = 1.46 m³/s
2. The psychometric chart shows that the specific volume of the given specification in step 1 is 0.86 m³/kg. So the mass flow rate = 1.698 kg/s
3. By assuming that the indoor air has similar moisture content to that of the outdoor air, at the given temperature and humidity, the psychometric chart shows that the enthalpy of the outdoor air = 68 kJ/kg and the enthalpy of the indoor air = 60 kJ/kg. Thus the difference in enthalpy is 8 kJ/kg
4. The heat carried away from the building = 1.698 kg/s x 8 kJ/kg = 13.58 kJ/s (13.58 kW)

By using the same calculation method, the heat generated within house in exp. 20 shows is as follows:

No. of run	Internal temperature (°C)	External temperature (°C)	Wind speed (m/s)	ach	m³/s	Specific volume (m³/kg)	Difference in enthalpy (kJ/kg)	Heat carried away (kW)
1	24	24	0	0	0	0.86	0	0
2	26	24	0	31	0.74	0.86	2	1.72
3	28	24	0	43	1.04	0.86	4	4.84
4	30	24	0	53	1.27	0.86	6	8.86
5	32	24	0	61	1.46	0.86	8	13.58
6	24	26	0	31	0.74	0.869	2	-1.70
7	26	26	0	0	0	0.869	0	0
8	28	26	0	31	0.74	0.869	2	1.70
9	30	26	0	43	1.04	0.869	4	4.78
10	32	26	0	52	1.25	0.869	6	8.63
11	24	28	0	43	1.04	0.879	4	-4.73
12	26	28	0	31	0.74	0.879	2	-1.68
13	28	28	0	0	0	0.879	0	0
14	30	28	0	30	0.72	0.879	2	1.64
15	32	28	0	43	1.04	0.879	4	4.73
16	24	30	0	53	1.27	0.887	6	-8.59
17	26	30	0	43	1.04	0.887	4	-4.69
18	28	30	0	30	0.72	0.887	2	-1.62

Table 10.11. The heat generated within house in exp. 20.

If the heat values (P_v = 8.86 kW (run no. 4)) from the above calculations are graphed, the curve lines will be as follows:

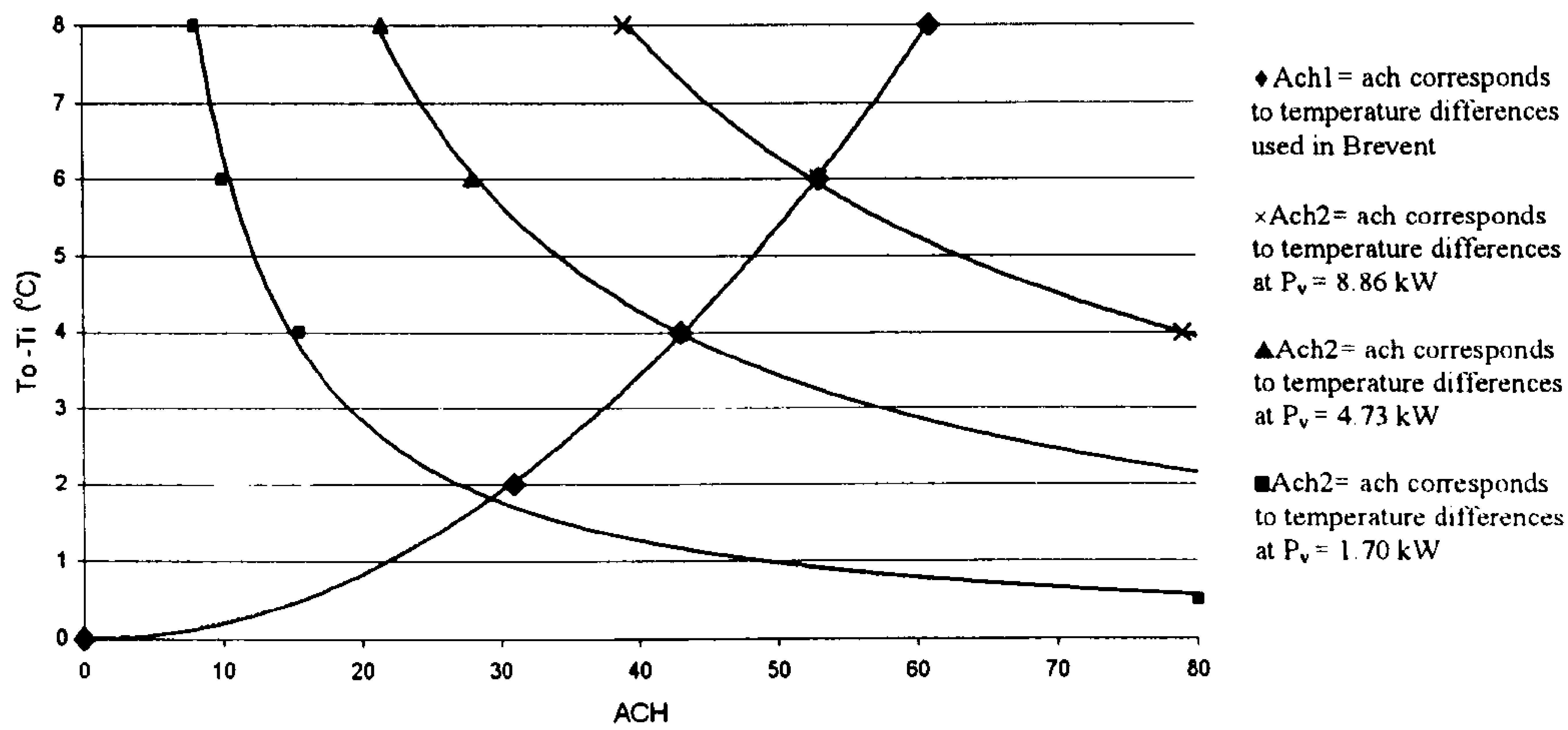


Figure 10.8. Ach corresponds to temperature differences in particular P_v values.

Figure 10.8 describes how the ventilation rates of a house always correspond to the difference between indoor and outdoor temperatures. The greater the temperature differences, the greater the ventilation rates will be (curve ACH 1). However, for a given rate of heat gain within the house, the greater the ventilation rate, the lower will be the temperature difference between indoor and outdoor, as shown by curve of ACH 2 (P_v=8.86 kW), ACH 3 (P_v=4.73 kW) and ACH 4 (P_v=1.70 kW). Therefore, these three curves move up or down depending on the particular value of P_v but the shape of the curves will remain fairly similar, as in the constant P_v values and the decrease of temperature differences, the ventilation rates decrease. This means that in the absence of wind, temperature difference is one of the essential factors which induce air motion around the house, hence which supply ventilation within the house. The point where the curves intersect indicates the temperature difference and air change rate that can be expected at a given rate of heat gain.

10.4 Conclusion

From both manual and Brevent calculations, there were several options for opening designs to supply approximately 30 ach in naturally ventilated houses. Unfortunately, only a few of these are practical options for these simple houses. The most practical options are no.5 for house type A and no.20 for house type B. Both options are preferred due to their capability to supply a minimum of 30 ach (when external velocity v = 0 m/s and temperature differences $\Delta t \neq 0$) through a small number of windows and roof openings.

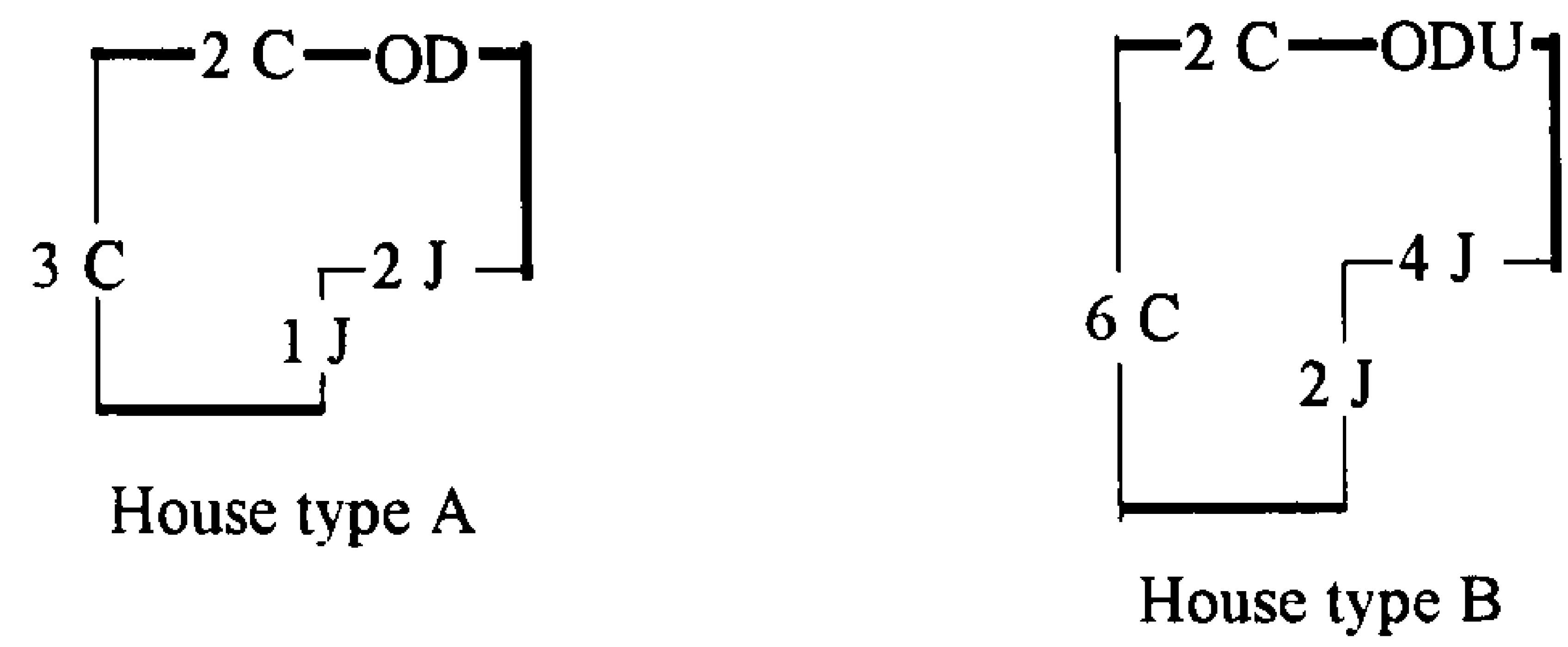


Figure 10.9. Brevent Result: the best opening designs for house type A and type B

Keys:		
	2 J	= number of windows with jalousie type
	2 C	= number of windows with casement type
	OD	= one opened door
	ODU	= one opened door and one small upper opening

As can be seen in Figure 10.9, there are two window types to be used, i.e. jalousie and casement windows. The use of a casement as the output window, particularly in the back of the house, is preferred as it can provide greater ventilation rates than when all the windows are jalousie. The use of casement windows will not significantly affect pollution reduction as they are installed at the leeward side of the house.

These two options are not strict. They can be modified depending on the type of the house. For example, for houses that have wider front courtyards, the style and position of the windows can be modified to suit the required air changes per hour. These best options can be used as guidance for a house with a larger floor area. For example a house with a floor area of 45 m² or 56 m² will need more windows and openings to achieve approximately 30 ach when the external wind speed is 0 m/s. Jalousie windows are proposed for installation close to pollutants (front walls and side walls with prevailing wind) and casement windows are proposed for installation farther from the pollutants (side walls with non-prevailing wind and back walls).

CHAPTER 11

THE ABILITY OF THE PROPOSED FENCE DESIGNS TO REDUCE PARTICULATE MATTER AND NOISE

Fencing design both for reducing particulate matter and noise and permitting natural ventilation has already been proposed in Chapter 9. Below, the capability of the proposed design to reduce these types of pollution is examined. To provide predictions for particulate matter dispersion, the performance of the fence has been examined using computational simulation. To confirm the CFD results to the real conditions, field trials were carried out. The prediction of noise attenuation offered by the proposed fence designs was calculated manually. As financial resources and permission from the owners to build a new fence in front of their house were limited, the capability of a fence to reduce noise in real conditions could not be determined.

11.1 Examining particulate matter dispersion by fences

11.1.1 The computational model approach

The proposed fence design for reducing particulate matter has been described in Chapter 9. However, the proposed design with regard to particulate matter has not yet been determined in details. The proposed design was mostly related to the use of fences that have high surface areas compared to the area provided by an ordinary flat surface in order to induce more impaction and deposition. The proposed fence dimension, as described in Chapter 9, is only related to natural ventilation purposes, noise reduction purposes and for creating a good facade for the house. It is proposed that the position of the fence be sited in the common fencing position in Indonesian housing, which is closer to the receiver (house) than to the pollution source (street). This position should maximise the effect of 'sound shadow' for noise reduction, regardless of the effect of particulate matter reduction.

From the above discussion, it seems clear that it is important to examine the ability of fence to reduce particulate matter, regardless of their surface characteristics. This investigation needs a tool able to examine different porosities of fence, from the most porous fence to a completely solid fence, as suggested for a sound barrier. Short growing vegetation is commonly found along Indonesian streets. The porosity of this vegetation is typically between the range of 15% (with sparse leaves) to 33% (dense foliage). Since the use of vegetation to reduce particulate matter is also proposed, this range of porosity is also important to be examined.

The tool should also be able to examine different dimensions and positions of the fence. The fencing position refers to the distance from the house and thus the width of the front courtyard. The different width of the front courtyard is important for providing adequate data confirming a variation of the real front courtyard of the proposed L-shape housing design. In this housing layout, there is a front wall closer to the fence (approximately 2m to 2.5m away) and walls further from the fence (approximately 4.5m to 5m away).

All the above examinations can be carried out at once by doing a set of field experiments over a certain period. The data resulting from this experiment will be adequate for the researcher to do a comprehensive and accurate analysis related to particulate impaction and deposition process due to specific obstructions. However, a set of field experiments which covers all the above factors (surface conditions, porosity, dimension and position in certain microclimatic conditions) would require resources beyond those available for the present study. To substitute for field experiments, the use of a computational model was considered. The computational model would be able to study various fencing conditions with less time and cost. However, using such a model has limitations. In the case of the computational model, the model would only be able to represent the physical conditions of the fence, i.e. dimension, porosity and length of the front courtyard, excluding the surface conditions whether smooth or rough. Even in dealing with the physical conditions, the model still has a limitation. The smaller and the more detailed the scale of the model, the more accurate the result gained in relation to the detailed fence conditions. However, a small scaled model would need quite a long time to construct [Shaw, 1992] and is considered to be beyond the scope of the present work. To see the capability of different fence conditions, in relation to their neighbouring conditions (i.e. house, street, neighbouring walls and other blocking elements, such as tall vegetation with dense foliage) in a certain temperature, humidity, wind speed and wind direction, a large scaled computational model is sufficient. However, there is still one critical factor that a computer model such computational fluid dynamic (CFD) cannot represent, i.e. the actual weather conditions, which in reality could change abruptly. The real weather conditions were predicted to have a strong relation with particulate matter impaction and deposition processes in reality. To provide a reasonable prediction, the CFD needed average weather conditions which could be obtained from real weather conditions. Another weather condition that cannot be represented by CFD is rain, which unfortunately will significantly help the process of particulate removal from the atmosphere [EPA 1982].

Apart from all the weaknesses, a computational model was still considered useful in predicting particulate matter dispersion in specific circumstances. The prediction then to be referred as the minimum reduction of particulate concentration offered by specific building elements in the dry season, as one study has shown that in the presence of rain, the concentration of particulate matter in the air is less than in the dry season [Monn, et all, 1997]. The prediction provided by CFD, which in this case represents a flat fence surface, was also regarded as a minimum, based on a study which shows that the presence of a rough surface would reduce slightly more particulate matter [Schneider, et al, 1999].

Earlier CFD work have indicated that the result of a computational simulation and an experiment in a controlled environment is generally similar [Lu, et al, 1996]. Ideally, however, the result obtained by CFD will always be checked by a similar experiment carried out in a controlled chamber, where all of the variables such as temperature, humidity, wind speed and wind direction can be accurately controlled [Lu, et al, 1996]. However, it was not possible with the resources available to include such work in a controlled chamber in this study. The CFD simulation was instead compared to data obtained from a field experiment which was carried out over a limited period.

11.1.2 The Computational Fluid Dynamic (CFD) model

Computational Fluid Dynamic (CFD) can be described as the use of computers to produce information about the ways in which fluids flow in given situation [Shaw, 1992]. The CFD requires physical dimensions, microclimatic data and neighbouring conditions to obtain precise results.

According to CFD, the property of the air is represented as fluids. Fluid can exist in either of two stable phases: liquid or gas [Shivamoggi, 1998 and Davis 1996]. Within this CFD experiment, the particulate matter suspended in the air is termed with the air as gas fluids. For simulating the particle flows within the air, a numerical technique is required [Shivamoggi, 1998 and Davis 1996]. Firstly, to build this numerical technique, the type of the fluid is determined; the next stage is to determine the flow property of the fluids which consist of fluid velocity, normal shear stress or pressure, viscosity and density. In this experiment, temperature and humidity determine the density of the air. This was then followed by specifying the flow in terms of the relevant boundary and initial conditions. By using this property, the governing equation of the flow can be developed, starting with a small part of the fluid [Shaw, 1992]. The equation of this small part leads to equations of other parts, which then build a continuing equation to predict the total flows [Shaw, 1992], the particle locations and orientations (dispersions) [Shivamoggi, 1998 and Davis 1996].

Once the specifications of the flow problem are known, the next stage is to build a model in which the flow of the particles occurs. In this study, the particles flow through a field consists of street, the chosen building and the neighbouring features (e.g. other buildings, fence, trees, etc.) This field was then to be divided into smaller cells known as mesh. There are many aspects to study regarding this mesh, which will not be discussed in this thesis. The significant purpose of building a mesh of the given dimension is to enable the user to specify points within each cell in which the property of the fluid that we want to predict can be determined, such as the density (concentration) and velocity. The more detailed the mesh, the greater the accuracy of the prediction that can be made [Shaw, 1992]. In the case where fluid flows over a solid surface, it is slowed down by the solid surface. This is due to fluids being viscous. Once the fluid has moved past a solid surface, the effects of the surface can still be seen and this region is known as a 'wake' [Shaw, 1992].

In the presence of obstructions the progress of the pollutants is slowed down. The process can be explained by the loss of some wind energy when it approaches an obstruction. If the wind slows down enough, this will effectively 'hold' the pollutant in place and thus less particulate matter concentration will be received beyond the obstruction.

In this CFD experiment, the physics of particulate matter were represented by three equations:

1. Conservation of mass which is related to the density of the air
2. Conservation of momentum which is related to the air speed or velocity
3. Conservation of species which is related to how the air distributes the pollutant.

It is equation 3 that significantly represented the physics of particulate matter in this CFD simulation. The equation is sometimes called a scalar transport equation, the scalar being the pollutant itself (scalars have magnitude only, unlike properties such as velocity which are vectors as they possess magnitude and direction). So, the CFD involved with the 'transport' of a scalar or pollutant. The term 'transport' means how the pollutant can physically move or exist at a certain point. The 3 ways of transport concerned in this simulation are: sources, convection and diffusion. All of these influences are contained within the pollutant transport equation. The equation used for the CFD experiment is given in detail in Appendix 4.

An example, which describes more clearly the physics of particulate matter represented in such CFD simulation, is a chimney releasing a pollutant into the atmosphere. For the CFD modelling of this, there will firstly be a source of the pollutant at the exit of the chimney. Secondly, convection of the pollutant will take place. This means the physical movement of the pollutant by the moving wind. Thirdly, diffusion will also influence the distribution of the pollutant. Diffusion occurs when there are gradients of pollutant concentration and the pollutant will disperse itself from regions of higher to lower concentration. These processes may be complicated by the existence of turbulence but there are additional transport equations for the turbulence which attempt to take these effects into account.

11.1.3 Data required for running the CFD model

Data which is essential to predict the distribution and dispersion of particulate matter, is microclimatic conditions, particularly temperature, humidity, wind speed and wind directions. Temperature and humidity will give the specific density of the air in the manner of particulate matter movements. Wind speed, and specifically wind direction, will mostly affect the travel speed and the direction of particles.

Further data required are the housing or building dimensions, which comprise barrier height, barrier density, width of the courtyards and the position and dimension of the openings. Another important set of data is the neighbouring conditions, which will also affect particulate matter dispersion, particularly the presence of large obstructions such as tall trees or neighbouring walls. In this study, a set of average weather data taken from real weather data was used. The wind direction was to be varied between parallel and oblique to the street to conform to the observed weather conditions in Yogyakarta. The detailed data, which was required for the CFD inputs, is listed as follows:

Weather data :	
As the CFD is unable to cover the abrupt changes of weather as occur in reality, one set of weather conditions in Yogyakarta, which was obtained from a field measurement, was used throughout the CFD experiment. Fortunately, the daily temperature, relative humidity and wind speed in Yogyakarta are within a very narrow range. Therefore, the use of a constant set of weather data would not distort the prediction of the CFD.	Set of weather data that was mostly used: Temperature: 28.1 °C Humidity: 80.75% Wind speed:1.16 m/s Wind direction: West (parallel) and North West (oblique)
Housing data and its dimension :	
Barrier types:	First porous fence (porosity 0.15) Solid fence (porosity 0) Frame fence (porosity 0.90) Second porous fence (porosity 0.33)
Barrier heights:	1.3 m, 1.7 m, and 2 m
Length of front courtyard:	2.5 m and 4.5 m
Room dimension:	Two rooms, each 2.25 m x 3.75 m
Window dimension:	Four windows, each 0.6 m x 1 m (First option: 0.6 m above the ground, second option: 1 m above the ground)
Neighbouring conditions :	As can be seen in figure 11.1, 11.2 and 11.3

Table 11.1. The CFD input

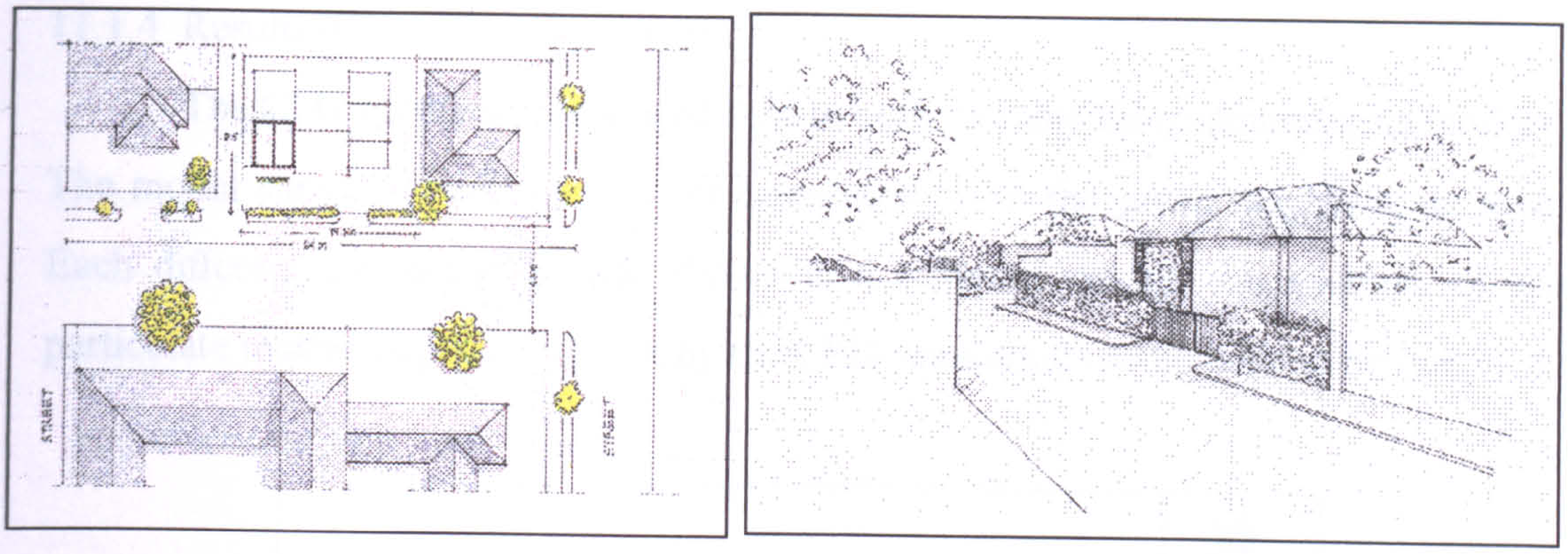


Figure 11.1 and 11.2 Neighbouring plan and perspective of the chosen house

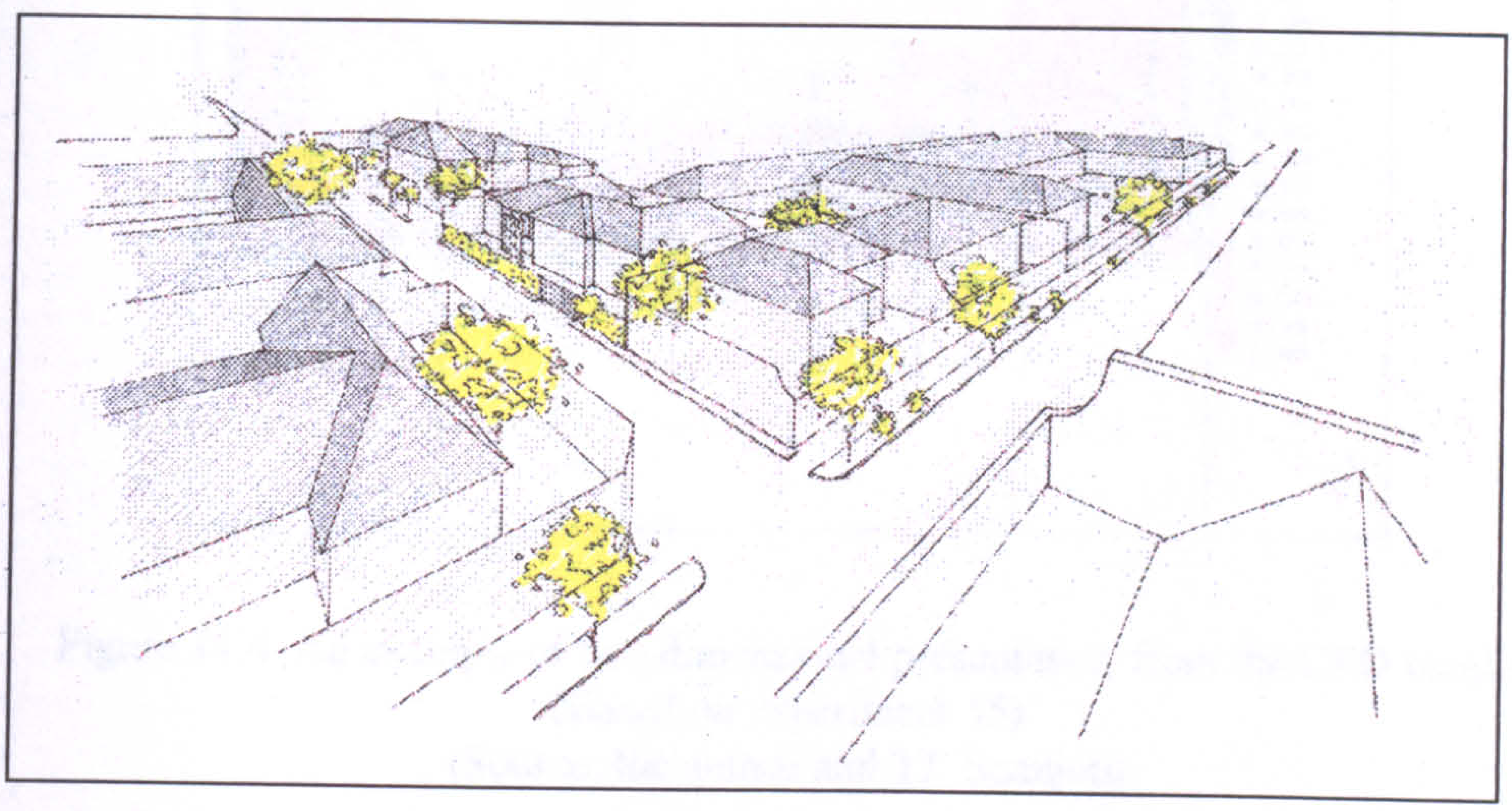


Figure 11.3 Perspective of the neighbourhood

11.1.4 Results of the CFD Experiment

The CFD simulation produced data in both two and three-dimensional models. The model showed particulate matter concentration in the given neighbouring area. Each different concentration was shown in a different colour. An example of the particulate matter dispersion drawn by the CFD simulation can be seen in Figure 11.4.

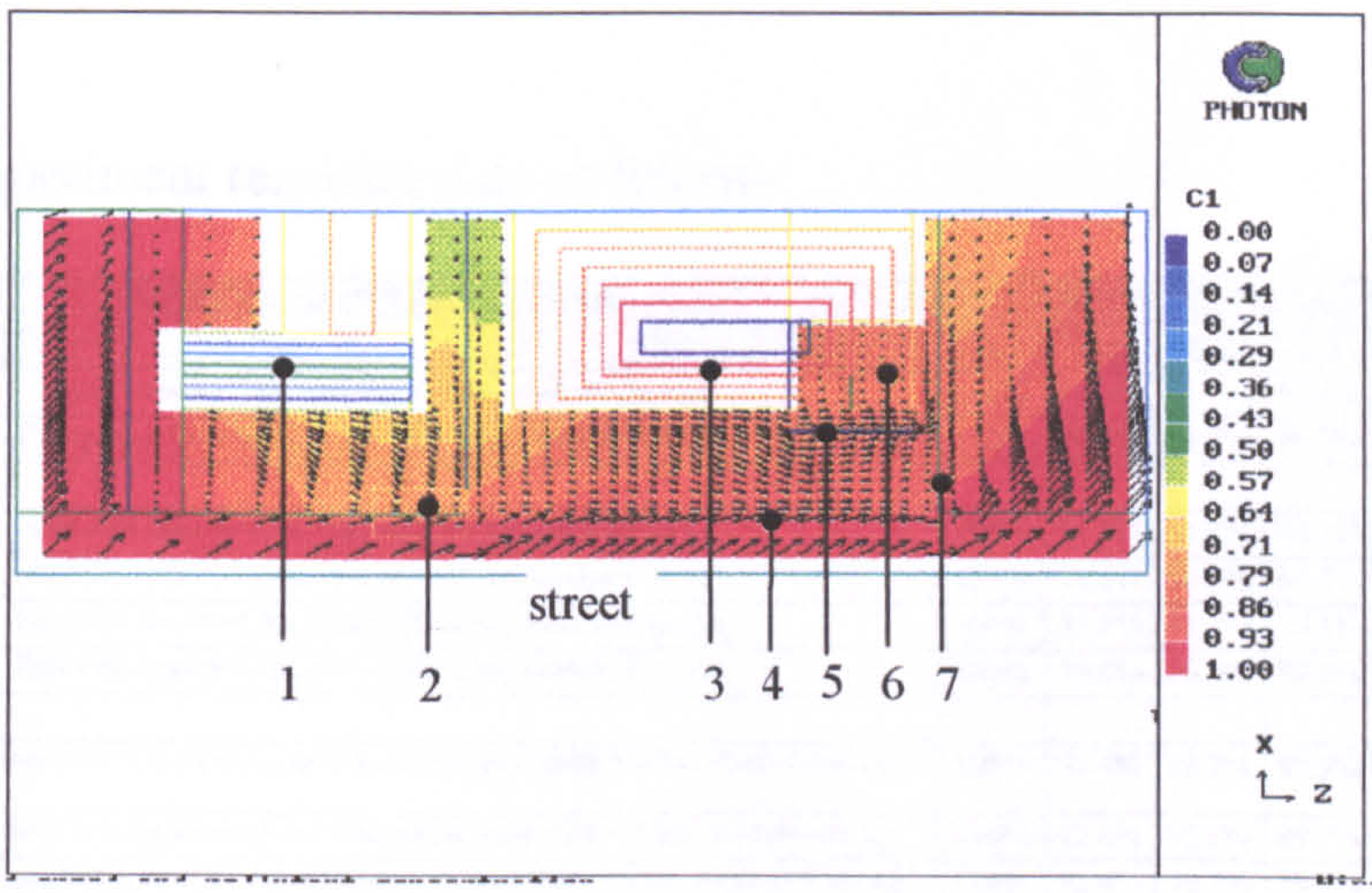


Figure 11.4. An example of two-dimensional presentation from the CFD results
(Based on experiment 15)
(Source: the author and TJ. Scanlon)

Figure 11.4 describes the dispersion of the particulate matter in a given situation as defined in this experiment. Detailed notations are as follows:

1 = a neighbouring house.

2 = an obstruction as a representation of a large neighbouring tree

3 = the reference house

4 = the first fencing

5 = the second porous fence in front of the windows

6 = the room within the house where the concentrations after certain window types were measured

7 = a high neighbouring wall

In this experiment (see Figure 11.4), the wind was set to move either parallel to the fence (i.e. the street) or at an oblique angle carrying the particulate matter with it. As can be seen in this figure, the wind slowed down when approaching a short obstruction (1m-2 m), but gathered, accelerated and deflected toward rooms with openings when approaching a high obstruction. The different colours show the distribution of particulate matter concentrations.

The CFD experiment resulting data as follows:

Exp. No	SCREEN SPECIFICATIONS	CONCENTRATION AT POINTS						
		A	B1	B2	C1	C2	D1	D2
1	Frame fence h=1.3m, yard width=4.5m, window=1m a.g.,	100%	94.8%	95.5%	90.4%	90.7%	90.3%	90.5%
2	First porous fence h=1.3, yard width=4.5m, window=1m a.g.,	100%	94.7%	95.8%	90.5%	91.6%	90.4%	91.6%
3	First solid fence h=1.3m, yard width=2.5m, window=1m a.g.	100%	91.3%	91.7%	90.1%	89.7%	90.0%	89.9%
4	First solid fence h=1.7m, yard width=2.5m, window=1m a.g.	100%	90.6%	90.8%	89.6%	89.4%	89.5%	89.3%
5	First solid fence h=1.3m, yard width=2.5m, window=0.6m a.g.	100%	91.3%	91.7%	90.1%	89.7%	90.0%	89.9%
6	First solid fence h=1.7m, yard width=2.5m, window=0.6m a.g.	100%	90.6%	90.8%	89.6%	89.4%	89.5%	89.3%
7	First porous fence h=1.3, second porous fence h=2m, yard width = 4.5m, window=1m a.g	100%	93.4%	93.7%	89.9%	89.8%	89.8%	89.7%
8	First porous fence h=1.7, second porous fence h=2m, yard width = 4.5m, window=1m a.g	100%	92.8%	92.8%	89.7%	89.4%	89.6%	89.3%
9	First porous fence h=1.3, second porous fence h=2m, yard width = 4.5m, window=0.6m a.g	100%	93.4%	93.7%	89.9%	89.8%	89.8%	89.7%
10	First porous fence h=1.7, second porous fence h=2m, yard width = 4.5m, window=0.6m a.g	100%	92.8%	92.8%	89.7%	89.4%	89.6%	89.3%
11	First porous fence h=1.3, second porous fence h=2m, yard width = 2.5m,	100%	91.1%	91.5%	89.9%	89.9%	89.9%	89.7%
12	First porous fence h=1.7, second porous fence h=2m, yard width = 2.5m,	100%	90.3%	90.5%	89.5%	89.2%	89.4%	89.1%
13	Frame fence h=1.3m, yard width=4.5m, wind=North West	100%	94.3%	95.1%	92.8%	92.9%	92.3%	92.8%
14	First porous fence h=1.3, second porous fence h=2m, yard width = 4.5m, wind= North west	100%	94.4%	95.7%	92.8%	93.1%	92.5%	93.8%
15	First solid fence h=1.3m, second porous fence h=2m, yard width =4.5m, wind=North West	100%	87.6%	89.9%	83.6%	84.1%	83.6%	84.5%

Table 11.2. Results of the CFD experiment
(Source: the author and TJ. Scanlon)

Keys: all winds on the above experiment come from West (W), unless indicated Northwest (NW).
h = height of barriers in m
ag= height of windows above the ground in m

Detailed position of each point as indicated in Table 11.2 can be seen in Figures 11.5 and 11.6.

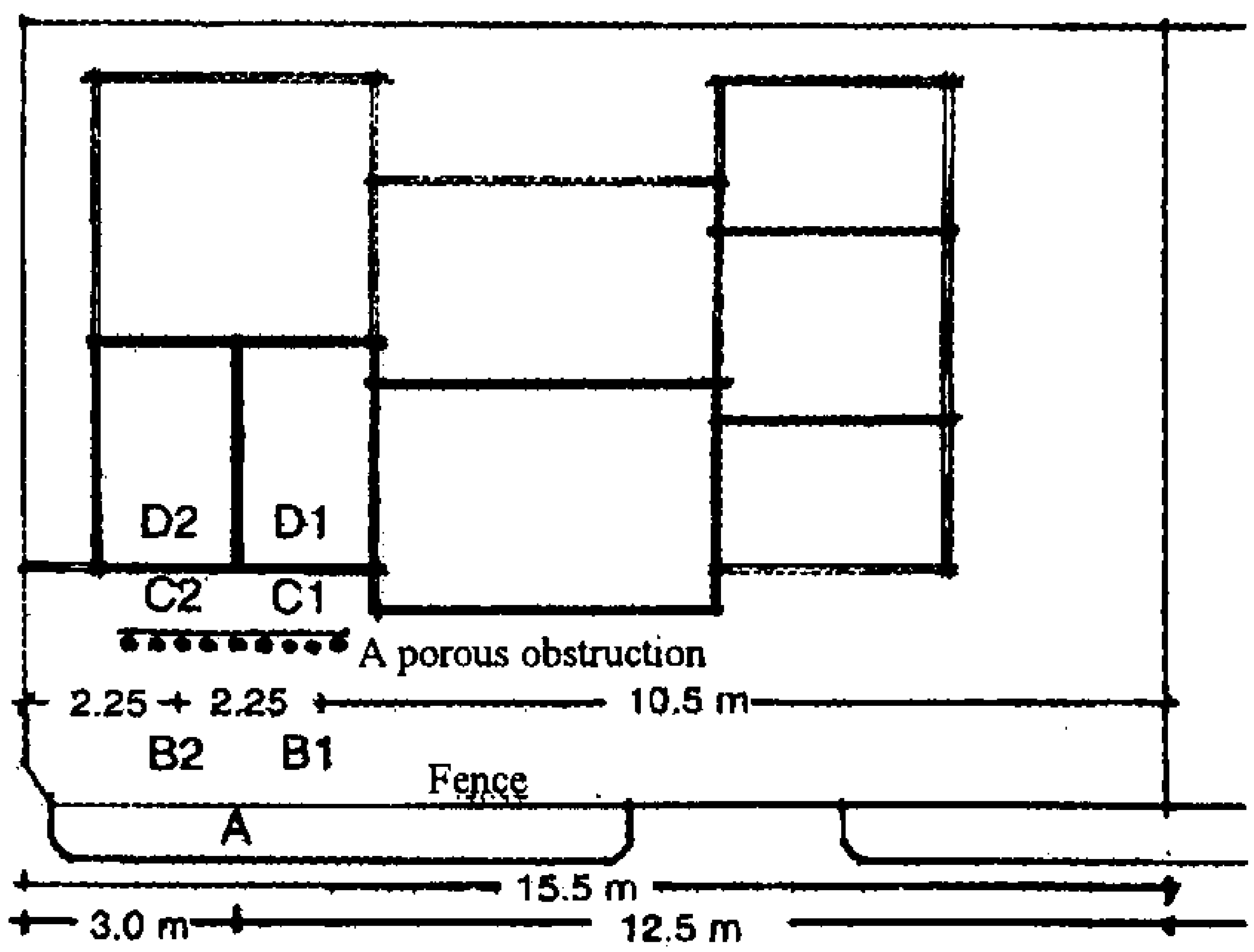


Figure 11.5. Plan of position of each point to be measured in the CFD experiment

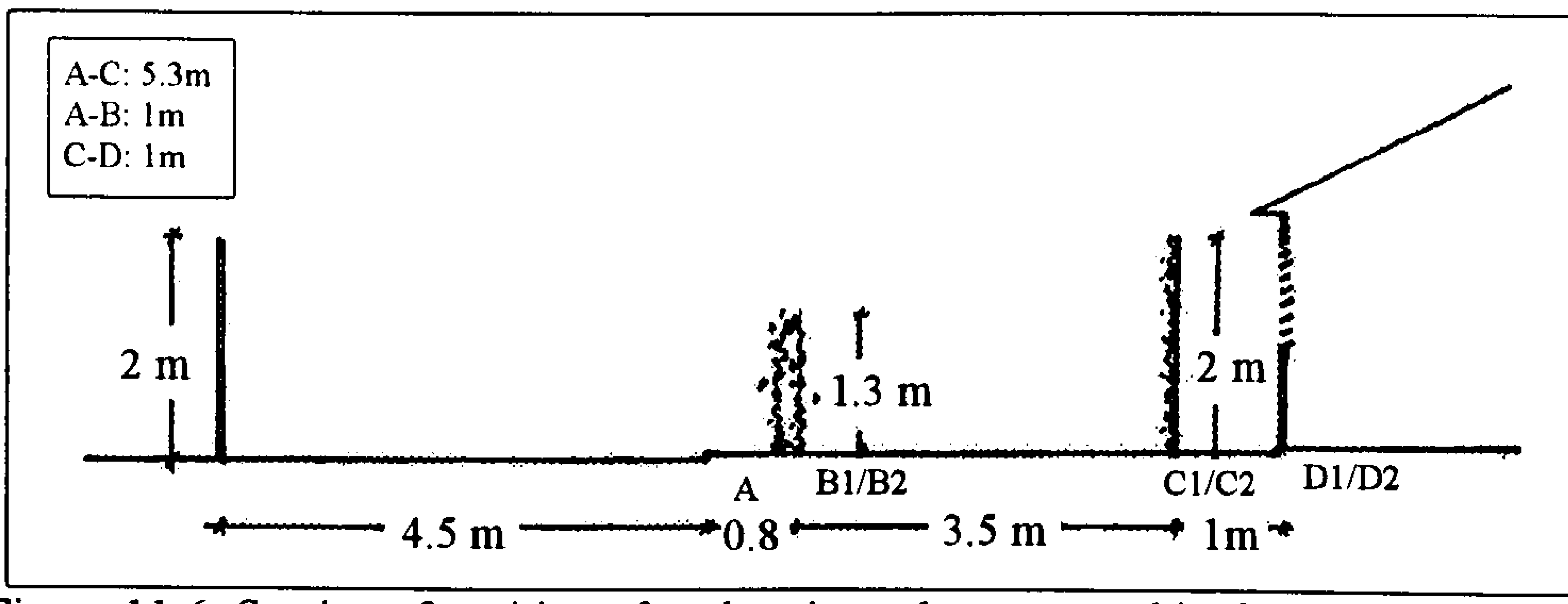


Figure 11.6. Section of position of each point to be measured in the CFD experiment
Keys: distance between A and C was to be changed between 5.3 m and 3.3 m, depending on the lengths of the front courtyard, as stated in the inputs.

From experiments 1 to 10, the CFD simulation shows that the height of the window above the ground has insignificant effects on particulate dispersion from the outdoor air into the indoor air. Therefore, experiments 11 to 15 did not consider this factor.

11.1.5 Result and discussion of the CFD simulations

As air temperature and humidity do not vary much throughout the year, the most significant factors that could affect particulate dispersion are wind speed and wind direction. But whilst the overall wind speed can be categorised as low without any significant changes throughout the year, the various reductions in particulate concentration are greatly affected by the changes in wind direction.

To make the analysis easier, the results of the CFD simulation in Table 11.2 are represented with the percentage pollutant concentration reductions in Table 11.3. CFD results related to window performance (i.e. changes in pollutant concentration between points C and D) are omitted here and will be discussed in Chapter 13.

Exp. No.	Specifications	Percentage of reduction at point (%)				
		A	B1	B2	C1	C2
1	Frame fence h=1.3m, yard width=4.5m, window=1m a.g.,	0	5.2	4.5	9.6	9.3
2	First porous fence h=1.3, yard width=4.5m, window=1m a.g.,	0	5.3	4.2	9.5	8.4
3	First solid fence h=1.3m, yard width=2.5m, window=1m a.g.	0	8.7	8.3	9.9	9.9
4	First solid fence h=1.7m, yard width=2.5m, window=1m a.g.	0	9.4	9.2	10.4	10.6
5	First solid fence h=1.3m, yard width=2.5m, window=0.6m a.g.	0	8.7	8.3	9.9	9.9
6	First solid fence h=1.7m, yard width=2.5m, window=0.6m a.g.	0	9.4	9.2	10.4	10.6
7	First porous fence h=1.3, second porous fence h=2m, yard width= 4.5m, window=1m a.g	0	6.6	6.3	10.1	10.2
8	First porous fence h=1.7, second porous fence h=2m, yard width= 4.5m, window=1m a.g	0	7.2	7.2	10.3	10.6
9	First porous fence h=1.3, second porous fence h=2m, yard width= 4.5m, window=0.6m a.g	0	6.6	6.3	10.1	10.2
10	First porous fence h=1.7, second porous fence h=2m, yard width= 4.5m, window=0.6m a.g	0	7.2	7.2	10.3	10.6
11	First porous fence h=1.3, second porous fence h=2m, yard width= 2.5m,	0	8.9	8.5	10.1	10.1
12	First porous fence h=1.7, second porous fence h=2m, yard width= 2.5m,	0	9.7	9.5	10.5	10.8
13	Frame fence h=1.3m, yard width=4.5m, wind=North West	0	5.7	4.9	7.2	7.1
14	First porous fence h=1.3, second porous fence h=2m, yard width= 4.5m, wind= North west	0	5.6	4.3	7.2	6.9
15	First solid fence h=1.3m, second porous fence h=2m, yard width=4.5m, wind=North West	0	12.4	10.1	16.4	15.9

Table 11.3. Detailed reduction offered by each obstruction type as determined by CFD experiments (Source: the author and TJ. Scanlon)

Keys:

All wind on the above experiment come from West (W), unless indicated North West (NW)

h = height of the barriers
a.g = height of windows above the ground
A = concentration adjacent to the street
B1 = concentration beyond first porous fence
B2 = concentration beyond first porous fence
C1 = concentration beyond second porous fence
C2 = concentration beyond second porous fence

From Table 11.3, some conclusions were drawn and are discussed as follows:

A. Fence porosity, front courtyard and wind direction

1. Porous barriers (15 % porosity) with narrow front courtyards reduced particle concentrations slightly more than the same barriers with wider front courtyards. This can be seen by comparing the average result of experiments 7 to 10 to the average result of experiments 11 and 12 in Table 11.4. If we relate this to the real conditions, rooms in the house which are closer to the fence would receive less intrusion of particulate matter from the adjacent street than rooms further from the fence.

Exp No.	Specifications	Percentage of reduction at point (%)				
		A	B1	B2	C1	C2
7	First porous fence h=1.3, second porous fence h=2m, yard width= 4.5m, window=1m a.g	0	6.6	6.3	10.1	10.2
8	First porous fence h=1.7, second porous fence h=2m, yard width= 4.5m, window=1m a.g	0	7.2	7.2	10.3	10.6
9	First porous fence h=1.3, second porous fence h=2m, yard width= 4.5m, window=0.6m a.g	0	6.6	6.3	10.1	10.2
10	First porous fence h=1.7, second porous fence h=2m, yard width= 4.5m, window=0.6m a.g	0	7.2	7.2	10.3	10.6
11	First porous fence h=1.3, second porous fence h=2m, yard width= 2.5m,	0	8.9	8.5	10.1	10.1
12	First porous fence h=1.7, second porous fence h=2m, yard width= 2.5m,	0	9.7	9.5	10.5	10.8

Table 11.4. CFD results on the effect of length of front courtyards

2. Porous barriers (15 % porosity) reduced particulate matter carried by parallel wind (0°/West) slightly more than those carried by oblique wind (Northwest), as can be seen in Table 11.5.

Exp. No.	Specifications	Percentage of reduction at point (%)				
		A	B1	B2	C1	C2
7	First porous fence h=1.3, second porous fence h=2m, yard width= 4.5m, window=1m a.g	0	6.6	6.3	10.1	10.2
8	First porous fence h=1.7, second porous fence h=2m, yard width= 4.5m, window=1m a.g	0	7.2	7.2	10.3	10.6
9	First porous fence h=1.3, second porous fence h=2m, yard width= 4.5m, window=0.6m a.g	0	6.6	6.3	10.1	10.2
10	First porous fence h=1.7, second porous fence h=2m, yard width= 4.5m, window=0.6m a.g	0	7.2	7.2	10.3	10.6
14	First porous fence h=1.3, second porous fence h=2m, yard width= 4.5m, wind= North west	0	5.6	4.3	7.2	6.9

Table 11.5. CFD results on the effect of wind direction on shrub barriers

3. Solid barriers (0 % porosity) reduced particulate matter carried by oblique wind (Northwest) slightly more than those carried by parallel wind (0°/West), as can be seen in Table 11.6. In the CFD simulation, this can be explained by the fact that oblique winds would deflect up the house, hence particulate concentrations within the front courtyard and those that entered the house would be less.

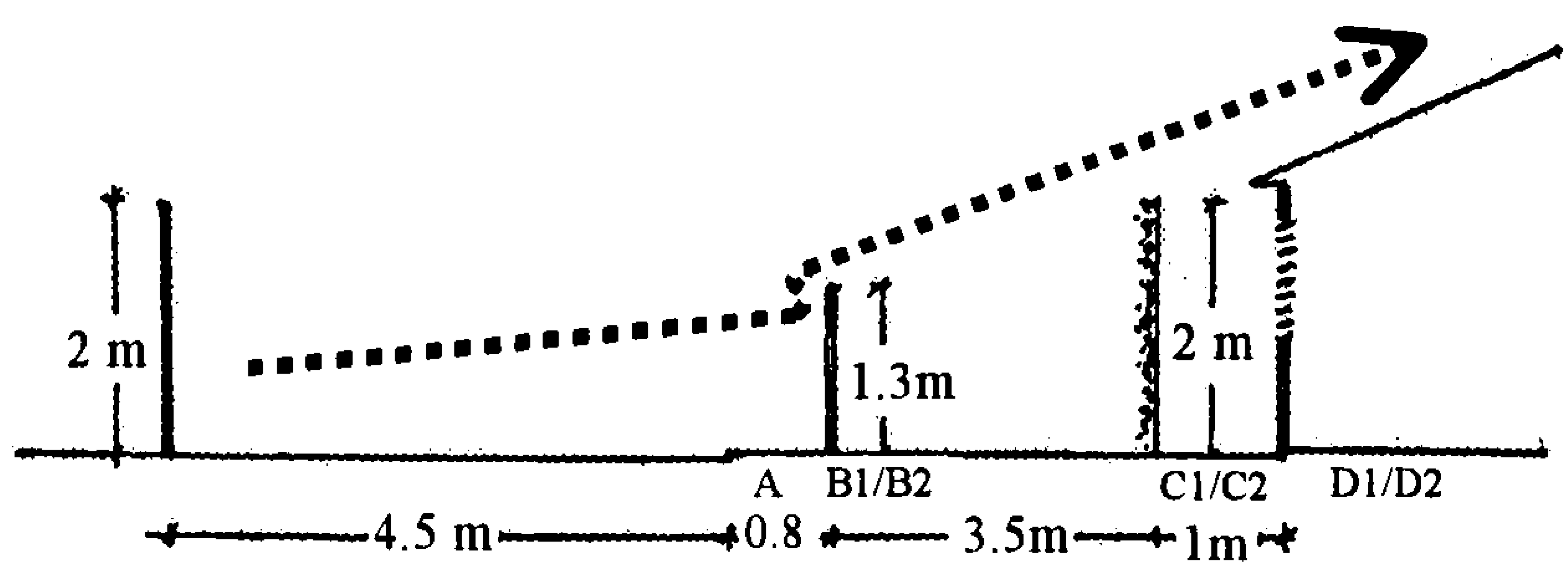


Figure 11.7. How wind is deflected by fence barriers
(source the author and TJ. Scanlon, 1999)

Exp. No.	Specifications	Percentage of reduction at point (%)				
		A	B1	B2	C1	C2
3	First solid fence h=1.3m, yard width=2.5m, window=1m a.g.	0	8.7	8.3	9.9	9.9
4	First solid fence h=1.7m, yard width=2.5m, window=1m a.g.	0	9.4	9.2	10.4	10.6
5	First solid fence h=1.3m, yard width=2.5m, window=0.6m a.g.	0	8.7	8.3	9.9	9.9
6	First solid fence h=1.7m, yard width=2.5m, window=0.6m a.g.	0	9.4	9.2	10.4	10.6
15	First solid fence h=1.3m, second porous fence h=2m, yard width=4.5m, wind=North West	0	12.4	10.1	16.4	15.9

Table 11.6. CFD results to on effect of wind direction on solid barriers

From the overall CFD experiments, solid barriers (0 % porosity) show a greater capability for reducing particulate concentrations than porous barriers. According to the CFD simulation, the loss of wind energy is greater when the wind approaches a solid barrier rather than a porous barrier. This slows down the wind sufficiently for the particles to be either deposited on the obstruction surfaces or to fall to the ground.

4. A less porous fence (representing more porous vegetation, such as climbing plants) has an insignificant effect in reducing particles. The reduction varied from approximately 1% to 5% after the reduction offered by the first fence. Less porous vegetation is expected to reduce more particles.

B. General indications

5. The CFD modelling demonstrated that solid barriers (0% porosity) worked better to reduce particulate than porous barriers (i.e. 15% porosity and 33% porosity). However, it is likely that a combination of solid and porous barriers will reduce more particulates, as it is indicated that solid barriers work better in oblique winds, whilst porous barriers work better in parallel winds (0°/parallel to the barriers).

11.1.6 Field experiments into how well fences reduce particulate matter

As mentioned above, a set of field experiments was developed to confirm the effect of fence barriers in reducing particulate matter concentration, which, in the earlier stage, has been examined by the CFD simulations. This experiment was mostly carried out to explore the levels of reduction offered by two types of fence barrier (i.e. solid and porous fences) in different types of street. This experiment was also carried out to see the effects of changes of microclimate conditions to particulate impaction and deposition processes. However, it was still not possible to cover the effect of rain on particulate removal processes. The field experiment could only measure the rain levels in millimetres (mm) as a common unit for measuring the rain levels in any particular place. Unfortunately, no relationship could be found between the amount of rainfall measured and the reduction in particulate matter concentration. Studies by the Environmental Protection Agency (EPA) have shown that there is a relationship between raindrops and particulate sizes in their removal processes. Falling raindrops remove larger particles by impaction and smaller particles by diffusion [EPA, 1982]. Therefore, it was postulated that the most significant property of rain in relation to particulate removal from the air is the diameter of the raindrops and the period of the rain. For example, two days, which have same particulate concentration with same rain levels and other microclimatic conditions, will have different particle concentration when measured after the rain. This can be either caused by the difference in the raindrop diameter or by the difference in the rain period between the two days. To provide data related to the raindrop diameter, rain period and rain level, a very long study and preparation to build an adequate model is required.

Apart from the above weaknesses, the field experiment was still considered useful in order to see how the proposed fence would function to reduce particulate matter. The experiment was carried out in March 1998 for a two week period. March sees the end of the rainy season which normally comes between October and April. Temperature increases in March, sometimes up to 35° C. During these transitional periods, rain and dry spells occur simultaneously. Thus, the experiment conforms to the diversities of the actual weather conditions in Yogyakarta.

Three houses in three locations within Yogyakarta City centre were used for this experiment. Each house represents a different type of street. The first house has a small street in front of it, used only by the owners, but it is also used as a short cut, especially when there are traffic jams in nearby streets. The second house has a one-way secondary street in front of it, used for many vehicle types including buses and passenger vans. The third house has a main street in front of it which is used for various types of vehicle including buses and trucks. All the three houses are single storey low cost houses.

Besides these three houses, there was a reference enclosure set adjacent to the original houses in each measurement. The reference enclosure had timber jalousie windows with dimensions determined by the ventilation flow rate calculations (Chapter 10).

The equipment used for this sampling were "standard low volume air samplers" (LVS), flow controlled units combined with cascade impactors with one cut size of 10μm, owned by the Bureau of Environmental Health (*Balai Teknik Kesehatan Lingkungan/BTKL*). The sampling was carried out by this bureau under the supervision of the Department of Health, Province of Yogyakarta, based on time and measurement points specified by the author. These devices were already in use for particulate matter measurement purposes within Yogyakarta and other neighbouring cities, including setting the regional standard of total suspended particulate matter within Yogyakarta City. Specifications for the devices can be seen in Appendix 5. Four identical devices were used together for 24 hours to measure PM10 concentration in four points at the same time. Details of the reference enclosure and LVS position in each location can be seen in Figures 11.8 and 11.9.

Figure 11.8. The reference enclosure

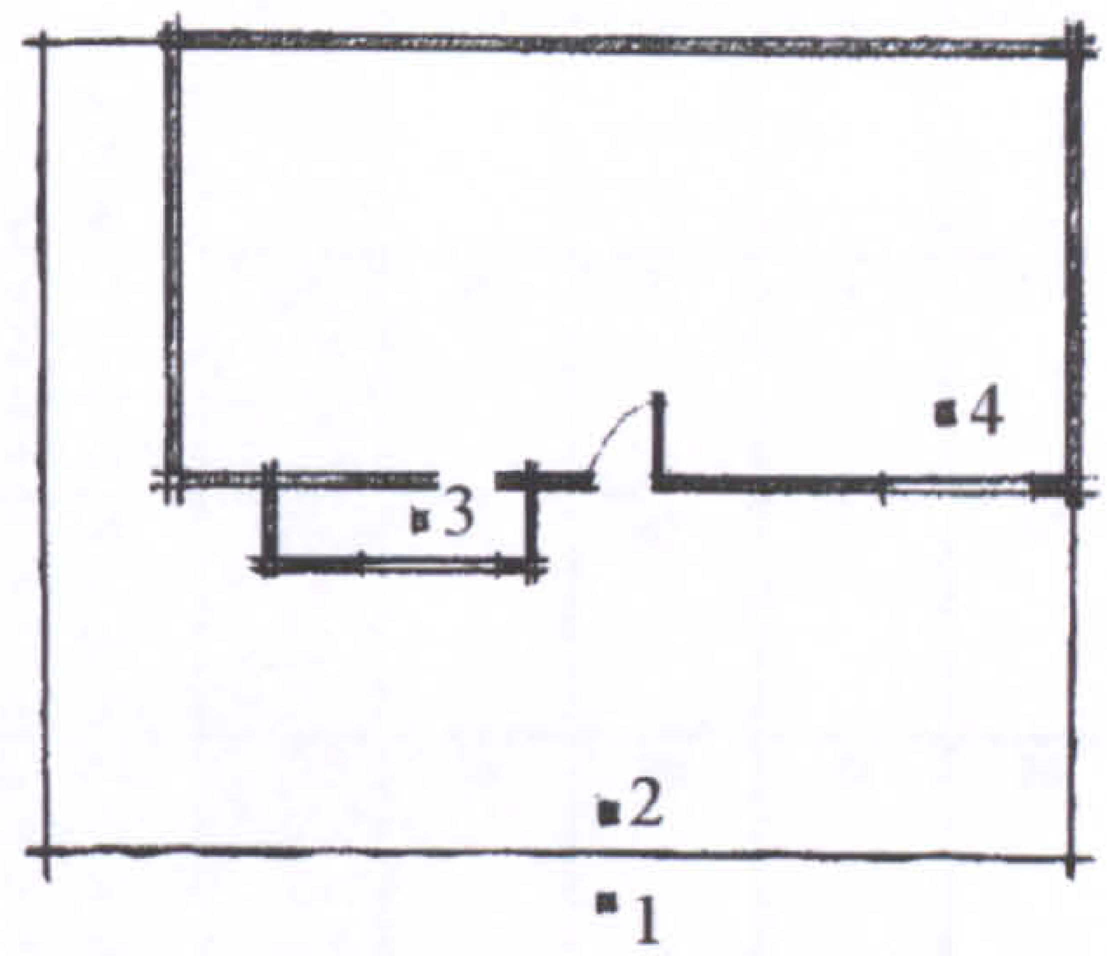


Figure 11.9. Plan of LVS position

Position 1 was set adjacent to street traffic to measure particulate concentration in the street. Position 2 was set beyond the fence, whether original or modified (see Table 11.7), to measure whether there was any reduction in particulate concentrations after the installation of the fence. Positions 3 and 4 were set within the reference enclosure and original houses in order to measure particulate concentration after the installation of different types of window. The reference enclosure had jalousie windows, whilst the original houses had different types of window: side-hung, top-hung, and moveable glass jalousie respectively depending on the number of the house, as can be seen in Table 11.7. Within this Chapter, only the performance of the fence will be discussed. The performance of the windows is to be discussed in Chapter 13.

Experiment Results and Discussion

The results of this experiment are presented in the following table.

Location	Fence/Street types/ Window types	Microclimatic Conditions (averaging from 24 hours)	Concentration at points ($\mu g/m^3$)	Reduction ($\mu g/m^3$) at points					
				1-2	1-3	1-4	2-3	2-4	3-4
First house first day	original fences (steel frames) poor asphalt street side single hung wind.	- temp. 29.7°C, RH 74.25% - heavy rain in the afternoon 30 mm - wind speed 1.00 m/s (parallel to the fence)	1= 128 2 =122 3 = 97 4 = 87	6	31	41	25	35	10
second day	original+ brick fences poor asphalt street side single hung wind.	-temp. 28.4°C, RH 82.17% - no rain - wind speed 0.84 m/s (parallel to the fence)	1= 158 2 =109 3 = 93 4 = 75	49	68	83	16	34	18
Second house first day	original fences (vegetation) hot mix street top single hung wind.	- temp. 29.4°C, RH 71.50% - rainy afternoon 22.5 mm - wind speed 0.75 m/s (parallel to the fence)	1 = 84 2 = 63 3 = 57 4 = 60	21	27	24	6	3	-3
second day	original+ brick fences hot mix street top single hung wind.	- temp. 30.8°C, RH 70.91% - no rain -wind speed 0.75 m/s (parallel to the fence)	1 = 89 2 = 62 3 = 53 4 = 51	27	36	38	9	11	2
Third house first day	original fences (brick/steel frames) hot mix street glass jalousie wind.	- temp. 29.9°C, RH 71.25% - no rain - wind speed 0.85 m/s (parallel to the fence)	1= 123 2 = 93 3 = 92 4 = 76	30	31	47	1	17	16
second day	original+brick fences hot mix street glass jalousie wind.	- -temp. 28.3°C, RH 81.75% - rainy afternoon 17 mm - wind speed 0.78 m/s (parallel to the fence)	1 = 111 2 = 79 3 = 36 4 = 55	32	75	56	43	24	-19

Table 11.7. First field experiment result
(Source: *BTKL*, March 1998)

Location	Fence/Street types/ Window types	Microclimatic Conditions (averaging from 24 hours)	Concentration at points ($\mu g/m^3$)	Reduction (%) at points					
				1-2	1-3	1-4	2-3	2-4	3-4
First house first day	original fences (steel frames) poor asphalt street side single hung wind.	- temp. 29.7°C, RH 74.25% - heavy rain in the afternoon 30 mm - wind speed 1.00 m/s (parallel to the fence)	1= 128 2 =122 3 = 97 4 = 87	4.7	24.2	32.0	22.9	32.1	10.8
second day	original+ brick fences poor asphalt street side single hung wind.	-temp. 28.4°C, RH 82.17% - no rain - wind speed 0.84 m/s (parallel to the fence)	1= 158 2 =109 3 = 93 4 = 75	31.0	43.0	52.5	13.1	27.9	18.6
Second house first day	original fences (vegetation) hot mix street top single hung wind.	- temp. 29.4°C, RH 71.50% - rainy afternoon 22.5 mm - wind speed 0.75 m/s (parallel to the fence)	1 = 84 2 = 63 3 = 57 4 = 60	25	32.1	28.6	9.5	4.8	-5.3
second day	original+ brick fences hot mix street top single hung wind.	- temp. 30.8°C, RH 70.91% - no rain -wind speed 0.75 m/s (parallel to the fence)	1 = 89 2 = 62 3 = 53 4 = 51	30	40.4	42.7	14.5	17.8	3.8
Third house first day	original fences (brick/steel frames) hot mix street glass jalousie wind.	- temp. 29.9°C, RH 71.25% - no rain - wind speed 0.85 m/s (parallel to the fence)	1= 123 2 = 93 3 = 92 4 = 76	24.4	25.2	38.2	1.1	18.3	17.4
second day	original+brick fences hot mix street glass jalousie wind.	- -temp. 28.3°C, RH 81.75% - rainy afternoon 17 mm - wind speed 0.78 m/s (parallel to the fence)	1 = 111 2 = 79 3 = 36 4 = 55	28.8	67.7	50.5	454.4	30.4	-52.7

Table 11.8. First field experiment result in percentages of reduction
(Source: *BTKL*, March 1998)

Keys:
1 = point along the street
2= point beyond fences
3= point within the reference enclosure
4= point within the original house

As there were no significant difference in temperature, humidity and windspeed during day and night, the data collected during 24 hours were averaged.

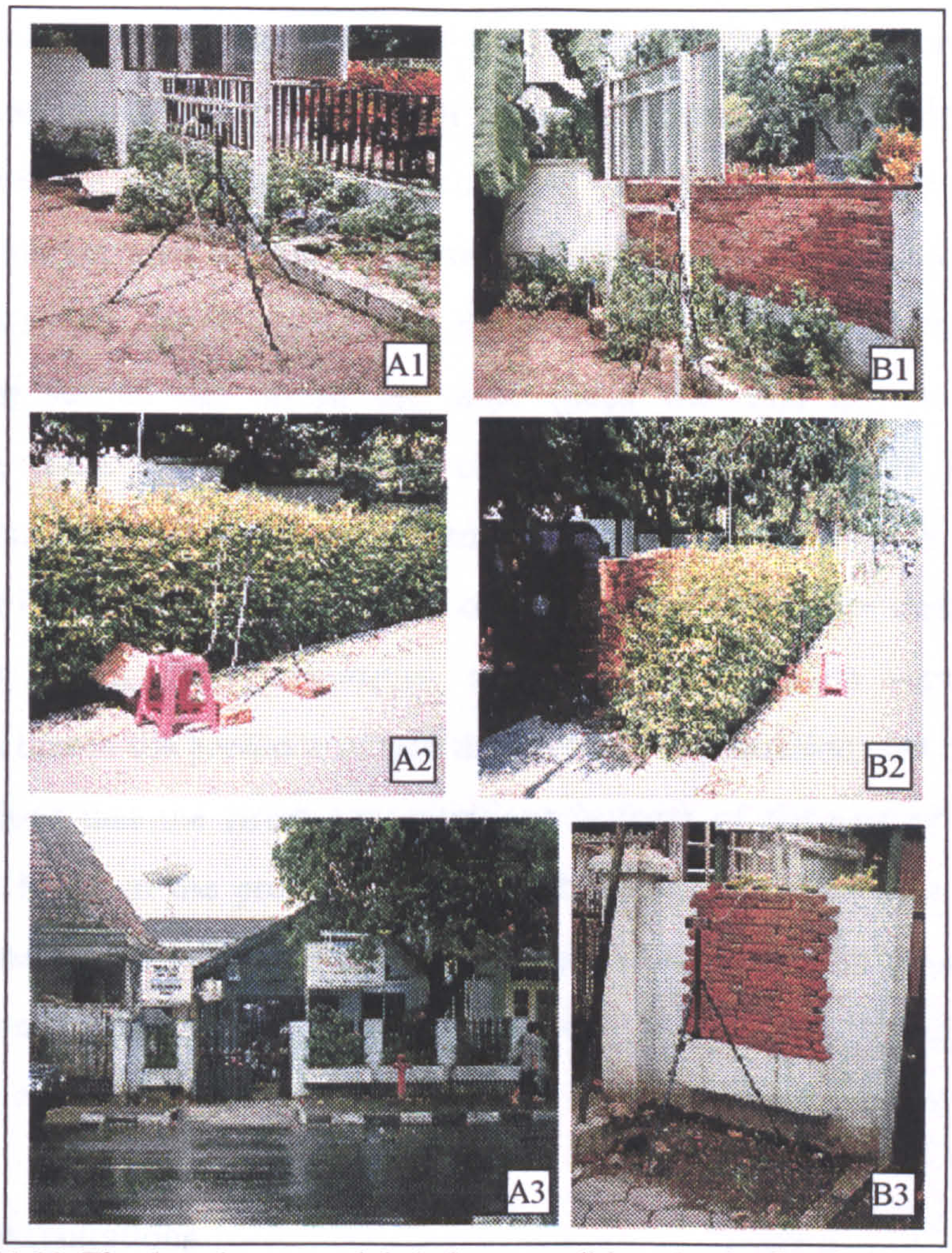


Figure 11.10. The three houses and their fence conditions for the first field experiment

Keys:
A = original fencing
B = original + bricks fencing
1 = first house
2 = second house
3 = third house

A. Weather conditions

The real weather conditions (i.e. temperature averaging 29.5°C, relative humidity averaging 75%, wind speed averaging 0.83 m/s and parallel wind direction) were generally similar throughout the experimental period. From this, it can be concluded that the relation of these factors to particulate removal process during the experiment period are less important and will not be considered further. An earlier study indicated that a strong wind would disperse airborne particulate matter to a wider area, therefore the concentration at a certain point would be less [Harrison, et al, 1997].

This can be seen from the experiment in the first house (first and second day) where the street concentration was lower when there was a stronger wind. However, this is not the case in the experiment of the second and third house. In the second house the concentrations between the two days were slightly different, even when the wind speeds were similar. In the third house, the concentration on the first day was higher than on the second day whilst the wind speed was less on the second day. Considering these results, it was predicted that the difference in the street concentrations throughout the experiment period was caused by rain. Earlier study showed that in the presence of rain, the concentration of particulate matter in the air is less [Monn, et all, 1997]. However, there was no evidence borne-out in this experiments that in the presence of rain the particle concentration was less. There are two indications that the street concentrations in front of the second and the third house were lower in the presence of rain, but this was not the case with the first house. As mentioned before, to what extent rain affects particulate removal process could not be studied in this research. However, it is thought that rain does not significantly affect the capability of the fence to reduce particulate matter.

B. Street concentrations

Regardless of the effects of rain, it can be seen in Table 11.7 that particulate matter concentration in the street of the first house was higher compared to the other two streets. This is due to the condition of the street which was constructed with poor quality asphalt. With a hot-mix and smooth asphalt street accommodating one way traffic and limited vehicles, the particulate concentration in the street of the second house was the lowest. Whilst in the street of the third house, the particulate concentration was slightly higher than that of the second house, even though the street also has a hot-mix and smooth asphalt. This was considered to be due to busier traffic, as the third street accommodates regional transport with heavy vehicles.

C. Fence conditions

From the fifth column (the shaded column) in Table 11.8, the capability of the fences to reduce particulate matter from the street concentration can be studied. From this column we conclude that the original fence of each house reduced particulate matter as follows:

- First house 6/128 = 5%
- Second house 21/84 = 25%
- Third house 30/123 = 25 %

The solid fence of each house reduced particulate matter as follows:

- First house 49/158 = 31%
- Second house 27/89 = 30%
- Third house 32/111 = 29 %

From the above calculations, we can see that the solid fences all reduced more particulate matter by around 30%. For the second and the third house this was 5% more than the reduction offered by their original fences. However, this was not the case with the first house. Here the improvement was 26%. This was because the original fencing only reduced particulate matter by 5% due to its porosity of approximately 90%. The other two original fences were less porous (vegetation and brick+frame+vegetation fences), and offered particulate reduction of 25%.

From these results, it does not seem that the presence of rain significantly affected the performance of the fences in reducing particulate matter. Rain might only affect the particulate removal process from the atmosphere regardless of the presence of such obstructions.

11.1.7 Conclusion on the capability of the fences to reduce particulate matter

Regardless of microclimatic conditions, there were some indications from both CFD and field experiments to suggest that the use of certain barriers may successfully reduce fine particulates. From the CFD experiments, the greatest and most stable particulate reduction was offered by solid fences with oblique wind, followed by porous or solid fences with parallel wind where the reduction was lower. The lowest reduction was offered by more porous fences set 1m in front of the windows. Each type of barrier reduced particulates by a small percentage. However, it can be reasonably assumed that a combination of these two barriers would work to give significantly fewer particulate intrusions from the outdoor air into the indoor air. From the field experiment, there were indications that solid fences reduced more particulate matter than porous fences.

Based on both experiments, it is suggested that the use of solid fences offers a significant particulate matter reduction from the street concentration. In the case where particulate concentration is still high, the use of porous barriers of climbing plants is suggested in the front courtyard in order to improve the performance of the fence in reducing particulate matter.

11.2 Examining noise attenuation by fences

11.2.1 The principal calculations for noise reduction by fencing

Noise attenuation can be achieved by using barriers. However, to achieve sufficient attenuation, a barrier needs to obey many criteria. The most significant is dimension. The critical dimensions can be found by using the appropriate formulae, chosen from a range of formulae. However, all formulae that have been developed mostly relate to noise conditions in developed countries, where the noise differs from those in developing countries. As traffic in developed countries is smooth, regular, consists of better-maintained vehicles and a limited number of motorcycles, noise levels tend to be lower.

Even though no single existing formula is available for noise measurement in developing countries, it was considered useful to choose one of the most suitable formulae for the data available to predict noise reduction that might be offered by certain barrier dimensions. Once the noise reduction offered by the certain barriers is determined, the reduction values to be achieved by low cost housing adjacent to traffic noise located in developing countries can be predicted. The range of the formulae considered for the calculation are given below:

1. Lawrence's Formula

   Lawrence suggests the use of large barriers in comparison to the wavelength (λ) of the sounds. The detailed dimensions are calculated using the following formula:

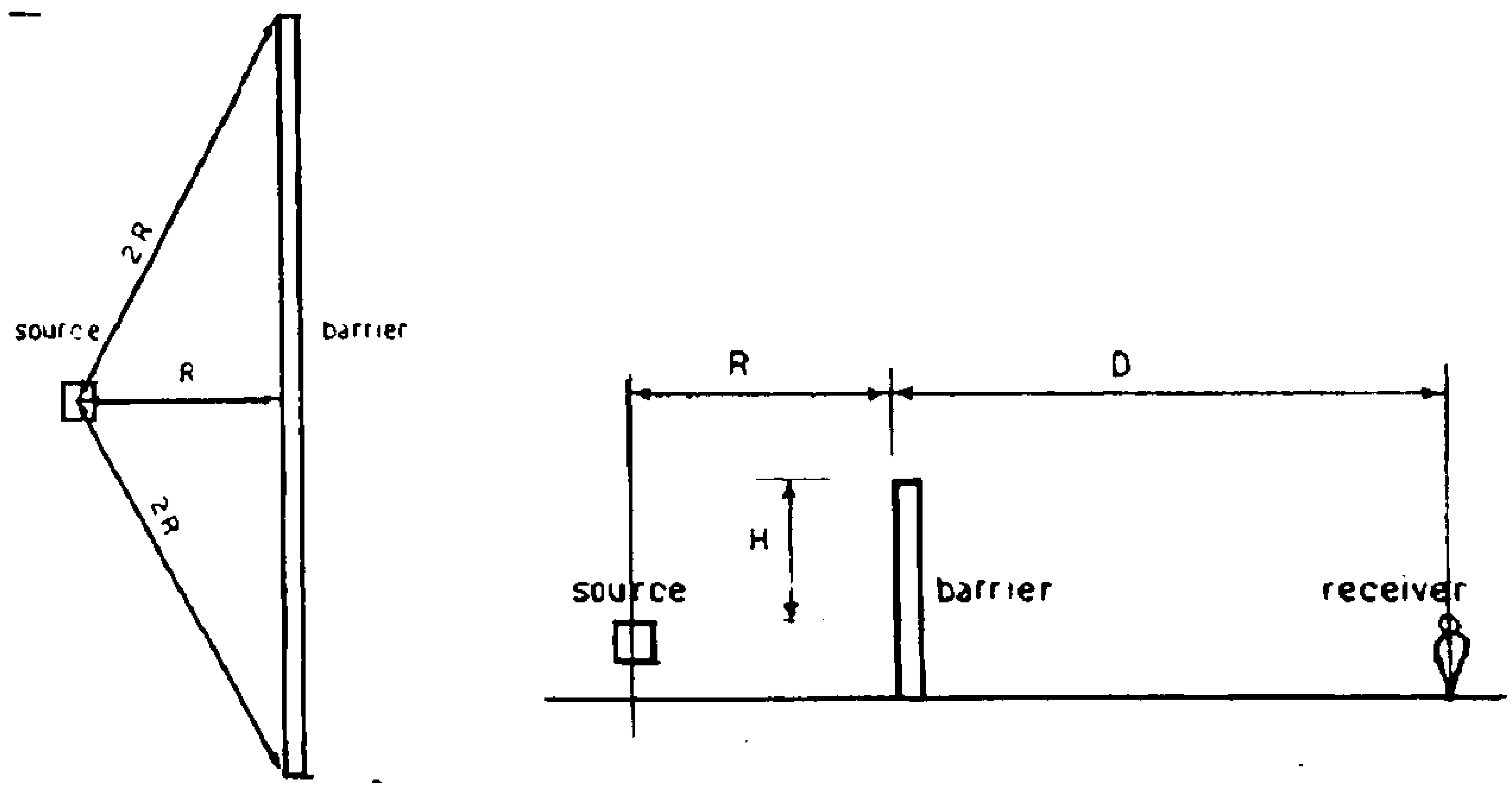


Figure 11.11. Lawrence's calculation for barrier dimensions
(After Lawrence, 1967)

$$\mathbf{N = 10 \log_{10} 20X}$$

Where N is the attenuation, dB re2 x 10 -5 N/m²

and X is found from :

$$X = \frac{2[R(\sqrt{1+(H/R)^2}-1)+D(\sqrt{1+(H/D)^2}-1)]}{\lambda[1+(H/R)^2]}$$

(if $D \geq R \geq H$ this may be reduced to $X = H^2/\lambda R$)

2. Egan's Formula

Egan's formula is an improvement of Lawrence's formula. This formula seems more suitable for houses with longer yards. This is obvious from the requirement that D be at least 4R. The first step in Egan's calculation is to determine the ratio of H^2/R by using barrier attenuation curves, which then will show the attenuation values.

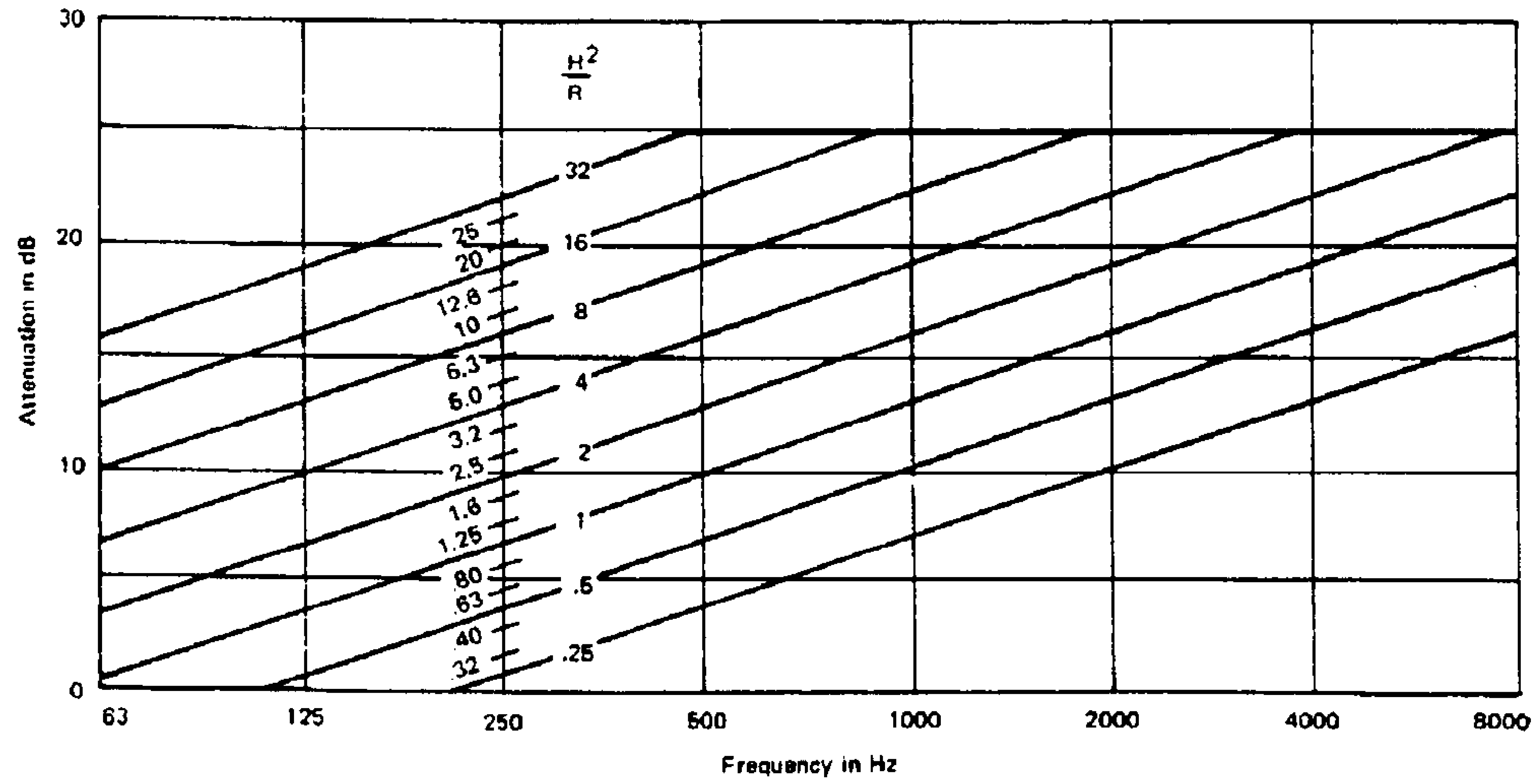


Figure 11.12. Charts to calculate sound attenuation given by barriers by using ratio H^2/R (After Egan, 1976)

Similar attenuation values can also be found by using Egan's formula (without using the curves):

$$\mathbf{A = 10 \log H^2/R + 10 \log f - 17}$$

Where **A** is the attenuation value in dB and **f** is frequency of the sound in Hz.

3. Barrier correction charts

   One method used to calculate barrier attenuation by using several charts, is employed by The Department of the Environment (Welsh Office, UK). These charts allow the users to calculate L_{10} and other L values on street traffic noises. Detailed steps in using this formula are discussed below.

It can be seen that the first two formulae need frequency measurements. This data is not available from the field measurements as these were made using a simple integrating sound level metre that does not measure sound at specific frequencies. The calculation using the third method needs an approximate measurement time of 18 hours. The field measurements were not made over 18 hour periods. However, the data required could be derived from the measured data. The third method is therefore more appropriate than the first two methods. To use the third method, predicted noise levels are calculated by using numbers of vehicles. As mentioned, the calculation using numbers of vehicles should give a different result for noise levels as between developed and developing countries. However, since there is no particular formula for traffic noise in developing countries, the use of the third formula was only used to predict generally the reduction that might be achieved.

The detailed calculations of the third formula are as follows:

Data required (taken from Tables 11.9 and 11.10 below) [BRE/CIRIA Report, 1993]:

A. Traffic flow rates per 18 hour-day
   Street type A: 26,205
   Street type B: 12,603
B. Mean traffic speeds
   Street type A: 35 km/h
   Street type B: 20 km/h
C. Heavy vehicles
   Street type A: 17 %
   Street type B: 12 %
D. Road gradient : 0°
E. Source height : 0.5 m
F. Height of receiver above the point source: 1 m

Types of Vehicles	Types of Engines	Numbers/ hour	
		Peak Hours (approximately from 7.30 am to 1.30pm).	Normal Hours (other than the peak hours)
Trucks	diesel	5	3
Small Commercial cars (similar to vans)	50% diesel 50% gasoline	540	300
Buses	diesel	40	40
Small Buses	diesel	30	30
Private cars	3% diesel 97% gasoline	660	360
Motorbikes	gasoline	960	540
Total/hours		2,235	1,300
Approx. total in18 hours		26,205	
Average/hour (18 h)		1,456	

Types of Vehicles	Types of Engines	Numbers/ hour	
		Peak Hours (approximately from 7.00am to 8.00am and from 1.00pm and 2pm)	Normal Hours (other than the peak hours)
Trucks	diesel	0.36	0.006
Small Commercial Cars (similar to vans)	50% diesel 50% gasoline	360	120
Buses	diesel	0.162	0.0027
Small Buses	diesel	0.3	0.005
Private cars	3% diesel 97% gasoline	480	120
Motorbikes	gasoline	660	300
Total/hours		1,500.822	540.0137
Approx. total in18 hours		12,603	
Average/hour (18 h)		700	

Tables 11.9 and 11.10. Numbers and types of vehicles in street type A and B

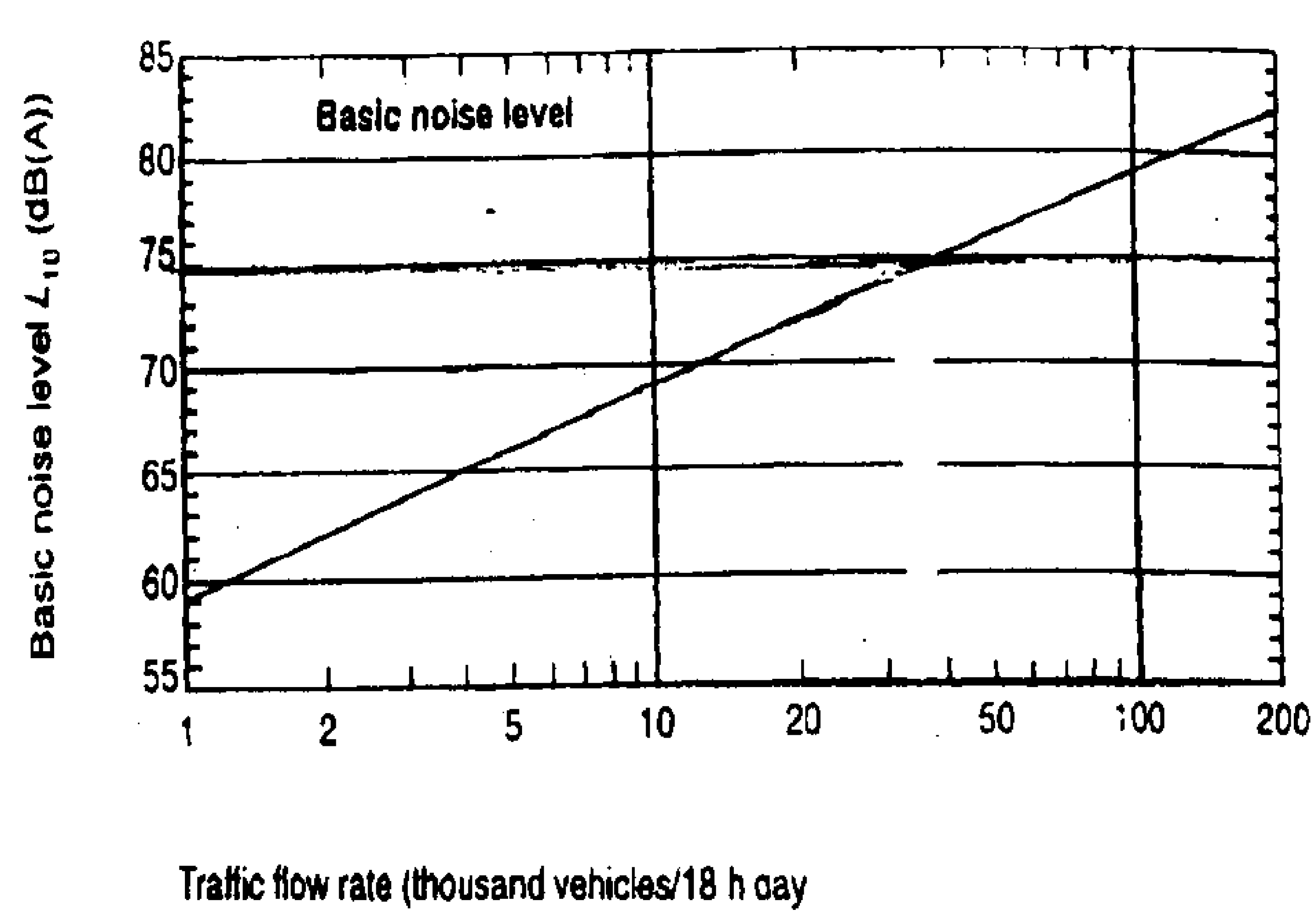


Figure 11.13. Basic noise level in relation to traffic flow rates (Source BRE/CIRIA Report, 1993)

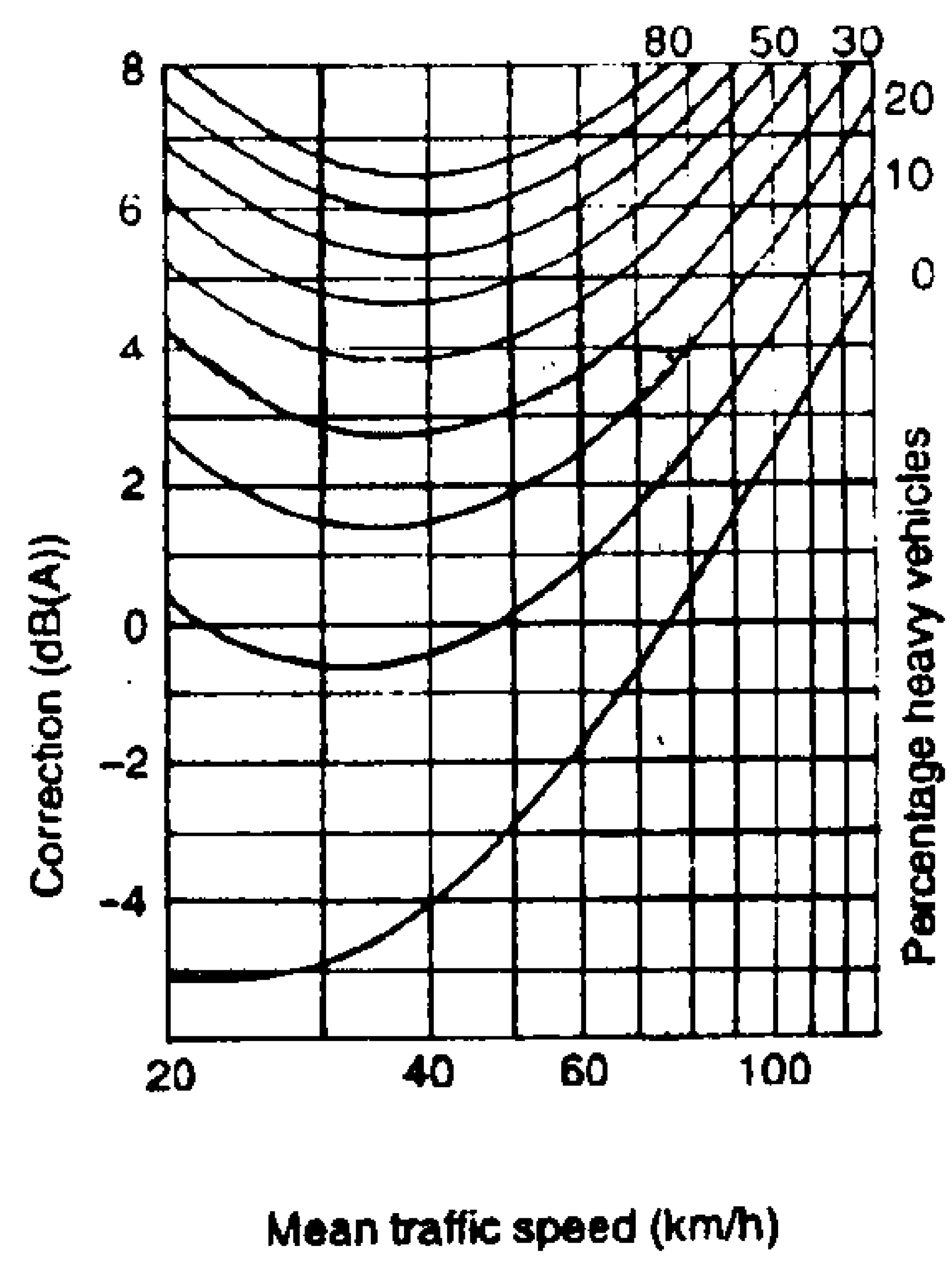


Figure 11.14. Correction level according to mean traffic speed and percentage of heavy vehicle (Source BRE/CIRIA Report, 1993)

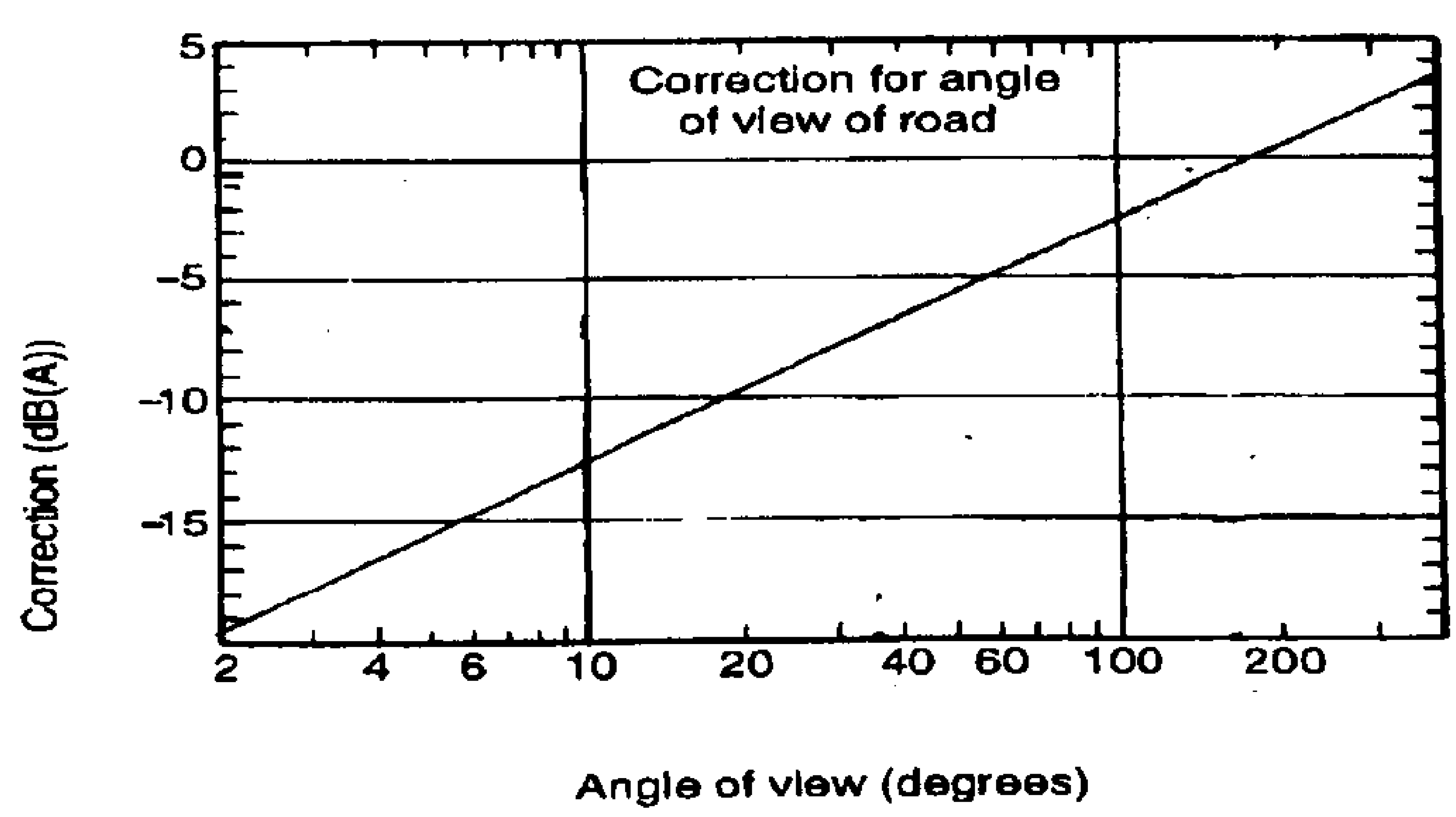


Figure 11.15. Angle of view corrections (Source BRE/CIRIA Report, 1993)

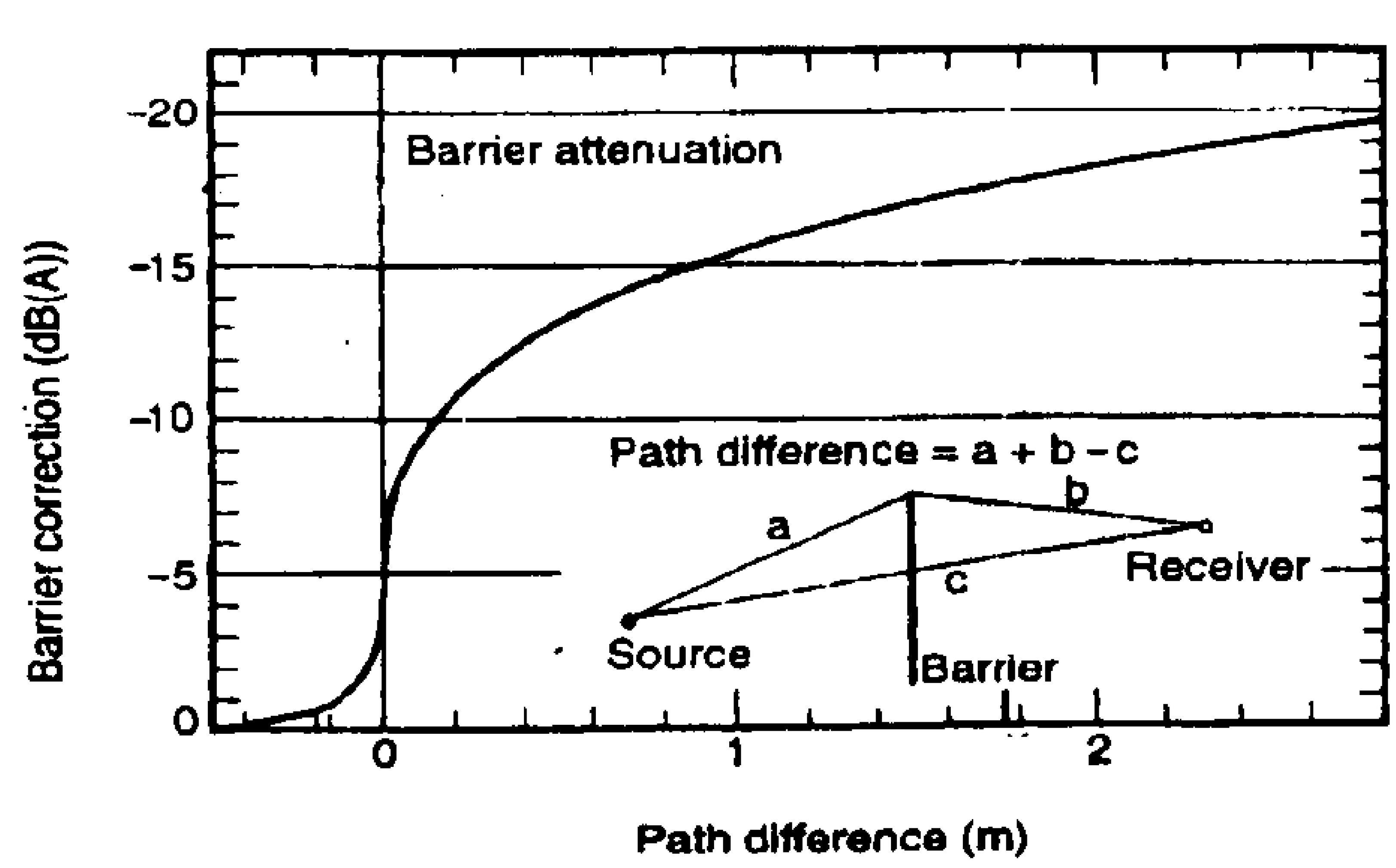


Figure 11.16. Barrier correction curve which has been normalised from a series of frequencies (Source BRE/CIRIA Report, 1993)

1. Calculation for street type A
    - noise level, traffic flow (Figure 11.13) : 73
    - correction for mean traffic speed and heavy vehicles (Fig 11.14) : +1
    - impervious road surface [BRE/CIRIA Report, 1993] : -1
    - basic noise level : 73
    - distance correction : 0
    - soft ground correction : 0
    - angle of view corrections (Figure 11.15)
        house type B (56°) : -5
        house type A (76°) : -4
    - reflection effect of building facade : +2.5

So that predicted noise level for street type A (73+1-1-5+2.5) : 70.5 –
(73+1-1-4+2.5) 71.5

L_{10} mean : **71 dBA**

2. Calculation for street type B
    - noise level, traffic flow (Figure 11.13) : 70
    - correction for mean traffic speed and heavy vehicles (Fig 11.14) : +1
    - impervious road surface [BRE/CIRIA Report, 1993] : -1
    - basic noise level : 70
    - distance correction : 0
    - soft ground correction : 0
    - angle of view corrections (Figure 11.15)
        house type B (56°) : -5
        house type A (76°) : -4
    - reflection effect of building facade : +2.5

So that predicted noise level for street type B (70+1-1-5+2.5) : 67.5-
(70+1-1-4+2.5) 68.5

L_{10} mean : **68 dBA**

From this calculation, L_{10} from field measurements (see page 70-73) were found to be much higher compared to the above results (about 18 dBA higher for street type A and 6 dBA higher for street type B during week days), even though for some levels, a measurement of 11 hours could not be compared to a prediction for 18 hours. This means that with similar number of vehicles, noise levels in developed countries will be much lower compared to those occurring in developing countries such as Indonesia. The much higher levels of noise in Indonesia are due to the following:

1. Many two stroke motorcycles.

   Two stroke motorcycles produce more noise and greater emission levels than four stroke engines. Unfortunately, this type of motorcycles is common in Indonesia. Many teenagers prefer noisier silencers on which there are no restrictions. This type of silencer was very popular among teenagers about five years ago. Some teenagers are still proudly installing them. Thus, improving noise regulations is essential, regardless of architectural design considerations.

2. The loudness of bus driver's assistants in offering the routes (shouting).

   Traditional operation systems (the driver's assistant shouts out the routes) of public transport (buses and passenger vans) are still commonly used in Indonesian middle cities. Abolishing this system would cause more unemployment, so this would hardly be accepted by the low income families. A possible solution is to strengthen the traffic regulations by forbidding buses, passenger vans, and other heavy vehicles to use residential streets, and load passengers only at determined bus stops. By eliminating the pick up points, the emission and noise generated when vehicles idle can also be eliminated.

From the above calculation, the noise reduction given by certain barrier dimensions can be predicted. First, the indoor noise standard in residential buildings needs to be considered. The standard is as follows:

Day and night standard is $L_{eq,16\,h} = 45$ dBA

(This is a standard which is close to the British standard of 43 dBA (based on British Standard 8233 and BRE Digest 266) and also a standard adopted by most countries including adopted by the Indonesian government as a proposal.)

The standard is in L_{eq}, so it is necessary to bring the L_{10} values from the calculation above to L_{eq} values by using the following formula, which is specific for traffic noise:

$\mathbf{L_{eq,16\,h} = L_{A10,18h} - 2dB\ (\pm 2\ dB)}$ [BRE/CIRIA Report, 1993]

- L_{eq} for street type A = 69 dBA
- L_{eq} for street type B = 66 dBA

As mentioned, the above L_{eq} values for both street types are for noise generated by traffic conditions in developed countries. Considering the above values, in order to satisfy the standard, the insulation of the building envelopes must provide at least:

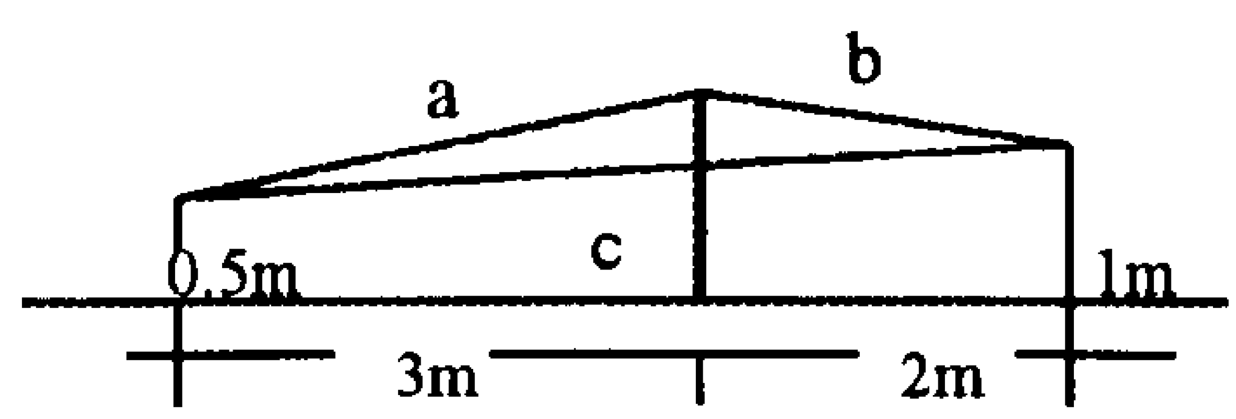
- 24 dBA (69 dBA - 45 dBA) for houses adjacent to street type A;
- 21 dBA (66 dBA- 45 dBA) for houses adjacent to street type B.

The next stage is to set a certain barrier dimension, as proposed in Chapter 9. This is to see the effect of the specified barrier in reducing noise. The calculation is as follows:

1. Barrier attenuation adjacent to street type A (for 1.3 m barrier height)

- basic noise level (from previous calculation, see page 176) : 73 dBA
- distance correction : 0
- angle of view correction (56° and 76°), mean : -4.5
- reflection effect of building facade : +2.5
- path difference

a = 3.10 m
b = 2.02 m
c = 5.02 m



(Height of the source is assumed to be at 50 cm above the ground, since the engine surface is the main contributor to noise. The height of the engine surface is approximately 50 cm above the ground [White, 1982])

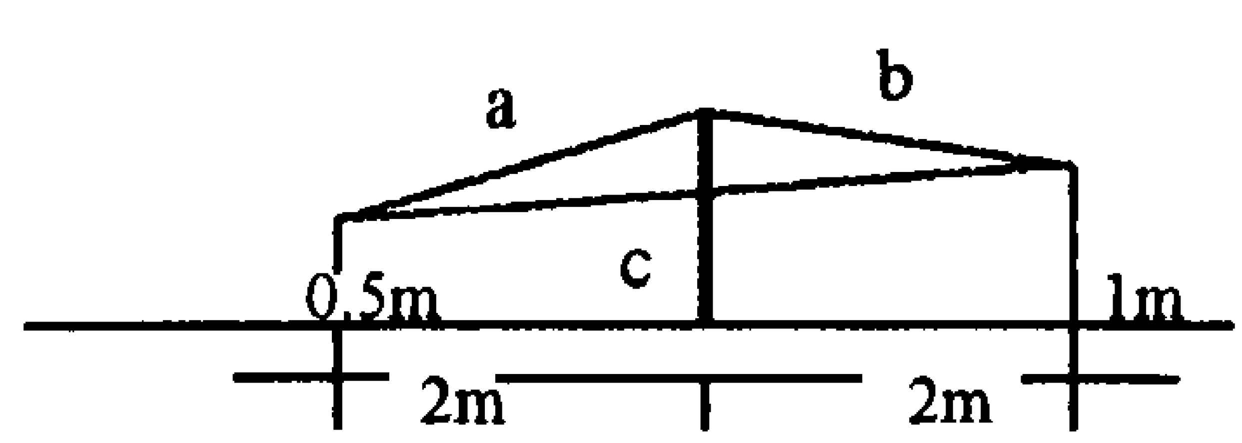
- a+b-c =0.1, according to Figure 11.16, the barrier attenuation is :-9 dBA

The predicted noise level in the front courtyard is: (73-4.5+2.5-9)= **62 dBA**

2. Barrier attenuation adjacent to street type B (for 1.3 m barrier height)

- basic noise level (from previous calculation, see page 176) : 70 dBA
- distance correction : 0
- angle of view correction (56° and 76°), mean : -4.5
- reflection effect of building facade : +2.5
- path difference

a = 2.15 m
b = 2.02 m
c = 4.03 m



- a+b-c =0.14, according to Figure 11.16, the barrier attenuation is :-10 dBA

The predicted noise level in the front courtyard is: (70-4.5+2.5-10)= **58 dBA**

From the above calculation, it can be seen that these barriers reduce noise by approximately 9 dBA to 10 dBA. Noise levels within the front courtyard after the reduction offered by barriers are calculated as follows:

To predict the noise levels within the front courtyard, subtract the L_{eq} value calculated above (see last paragraph in p.183) to the barrier attenuation. The predicted noise levels are:

- lowest predicted noise level for front courtyard adjacent to street type A :

  69 dBA- 9 dBA = 60 dBA

- lowest predicted noise level for front courtyard adjacent to street type B :

  66 dBA - 10 dBA = 56 dBA

In general the predicted noise levels in the front courtyard adjacent to street type A are between 60 dBA and 62 dBA and for the front courtyard adjacent to street type B are between 56 dBA and 58 dBA. Thus, according to the standard of 45 dBA, the building envelopes for houses with sound barriers must provide at least:

- houses adjacent to street type A : 15 dBA to 17 dBA
- houses adjacent to street type B : 11 dBA to 13 dBA

By using the same formula, the attenuation offered by different barrier heights can be calculated as follows:

Barrier Height	Attenuation offered by barriers adjacent to:		Rest of attenuation to be provided by the building envelopes	
	Street A	Street B	Street A	Street B
0.9 m	0-7 dBA	0-7 dBA	16.5 -23.5dBA	14-21 dBA
1.1 m	7.5 dBA	8.5 dBA	16 dBA	12.5 dBA
1.3 m	9 dBA	10 dBA	14.5 dBA	11 dBA
1.5 m	11 dBA	12 dBA	12.5 dBA	9 dBA
1.7 m	12 dBA	13.5 dBA	11.5 dBA	7.5 dBA

Table 11.11. Noise reduction offered by various heights of solid barrier

The range of barrier heights considered started at 0.9m as the lowest fencing height commonly used in Indonesia up to 1.7m as the maximum for natural ventilation and façade reasons. It can be concluded that to achieve approximately 9 dB to 10 dB noise reduction, for a house adjacent either to street type A or B, the minimum barrier height is approximately 1.3m.

11.2.2 Conclusion on the capability of the fences to reduce traffic noise

The calculation of noise attenuation based on formulae devised for traffic noise in developed countries shows that the use of fences to obstruct the sound pathways is a practical solution. A certain dimension of barriers (minimum 1.3 m high) would permit reduction up to 9 dBA to10 dBA. If we then relate these reduction values to noise conditions in Indonesia ($L_{eq,\ 11\ hours}$ up to approximately 80 dBA), it seems that with approximately 10 dBA reduction, the noise levels within the front courtyard will still be high. However, apart from that, these reduction values should be considered significant, as it can reduce noise as specified in the research aims by 10 dBA. Further reduction by another building element (i.e. windows) is expected to bring the street noise within the houses close to the standard of indoor noise level of 45 dBA.

CHAPTER 12

THE ABILITY OF VEGETATION TO REDUCE PARTICULATE MATTER AND NOISE

Several specific types of vegetation hat maybe effective in reducing particulate matter have already been proposed in Chapter 9. As the unique characteristics of vegetation are difficult to represent in computational simulations, the performance of this vertical element was examined in field trials.

12.1 Examining particulate matter reduction by vegetation

12.1.1 Experimental approach

The particulate reducing properties of vegetation have been discussed in Chapter 9. Since physical condition of vegetation (i.e. leaf surface characteristics) is difficult to represent by modelling, whether by a computational simulation or a simulation carried out in a controlled environment, the ability of vegetation to reduce particulates was examined in a field trial.

As discussed previously in Chapter 11, the effects of some microclimatic conditions, particularly rain, could not be studied in this research. Therefore, the results from the field experiment would then only show the capability of vegetation to reduce fine airborne particulate in the dry season. However, even in the dry season, moisture is present on the leaf surface, in the form of dew. As discussed in Chapter 7, the presence of dew in the morning will make the particles deposited the day before stick more strongly to the leaf surface. It was postulated that a compound of fine particulate matter and dew would perform in a similar manner to an adhesive. When there is no action to wipe the particulate matter that sticks to the leaf surface, the deposition process will occur continuously until the leaf fades (due to thick particulate layer which impedes photosynthesis) and falls to the ground [Grace, 1977 and Mathew, 1998].

The presence of dew over the leaf surface probably enhances the capability of vegetation to reduce particulate matter, as it prevents particulate resuspension as particulates adhere more strongly to the leaf surface.

12.1.2 Preparation for the experiment

As specified in Chapter 9, exploring local species to find an appropriate type of vegetation is very useful, particularly when resources are limited. Therefore, the first stage in the field experiment was to investigate local species that might give effective results in reducing fine airborne particulates.

Indonesian shrubs, bushes and climbing vegetation were the types of vegetation chosen for the field experiments. They were selected considering the following criteria:

- local species;
- durability;
- ease of growth, maintenance and regeneration;
- leaf characteristics (sticky, furry or shiny surfaces);
- aesthetic appearance.

The result from the first selection was:

NO.	Bushes	Shrubs	Climbing Plants
1	Allamanda schotii	Codiaeum veriegatum	Allamanda catharica
2	Ixora coccinen	Murraya paniculata	Stephanotis floribunda
3	Rosa sp.	Polyscias fruticosa	Monstera deliciosa
4	Sanseveira cylindrica	Bougainvillea spectabilis	Scindapsus sp.
5	Lantana camara	Gardenia florida	-
6	Jasminum sambac	-	-
7	Duranta repens	-	-
8	Raphis exelsa	-	-

Table 12.1. First selection of vegetation for field experiment
(Source: P. Mathew, 1998 and Purnomo, 1998)

The above selection was made by a literature search, a field search and with help from botanical expert P. Mathew (Glasgow Botanical Gardens) and Purnomo (Gadjah Mada University, Indonesia). Limitations on resources narrowed the selection to at least one species per leaf type (shiny and furry) for each vegetation type (shrubs/bushes and climbing vegetation). The second selection was then based on availability in the market and cost. The second selection produced four species: Polyscias fruticosa, Duranta repens, Scindapsus sp. and Stephanotis floribunda.

12.1.3 The experiment

An experiment was carried out in Yogyakarta in November 1998. The experiment focused on one type of street to study the effects of vegetation and particular types of window in reducing particulate matter. The experiment aimed to explore different leaf surfaces: shiny (waxy) surfaces and furry surfaces. Earlier research suggested that different types of leaf surface would probably result in different amounts of particles being deposited [Grace, 1977]. A furry surface was predicted to lodge more particles due to its roughness [Mathew, 1998]. This was proved by Schneider, who found that the presence of a rough surface would encourage slightly more particulate matter to be deposited than on a smooth surface [Schneider, et al, 1999]. An earlier prediction that waxy surfaces would lodge more particles caused by stickiness was not always borne out. Leaf waxes, which contain ethyl cellulose, do not easily melt even at high levels of solar radiation [Bennett, 1944].

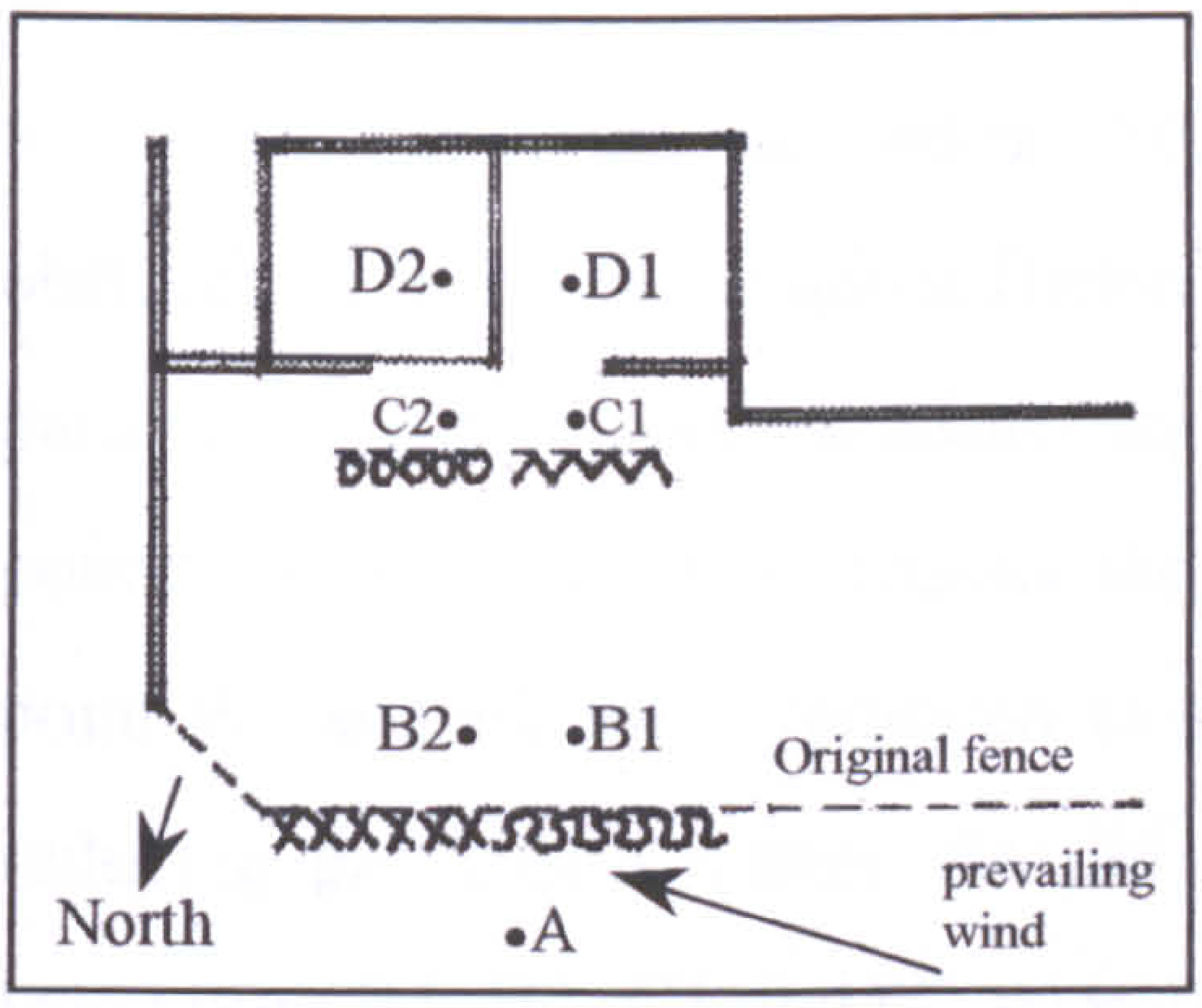
As mentioned, four selected species were used for this experiment. Two shrubs were used as fencing and two climbing plants were used as screens set approximately 1-1.5 m in front of the windows. Particulate matter concentrations before and after the planting of these plants and the concentration beyond different types of window were measured by the Bureau of Environmental Health (*Balai Teknik Kesehatan Lingkungan/BTKL*) with equipment as specified in Appendix 5, based on time and measurement points specified by the author. In this Chapter, only the performance of the vegetation is discussed, whilst the performance of the window will be discussed in Chapter 13. The types of vegetation selected for this experiment were those shown in Figure 12.1.

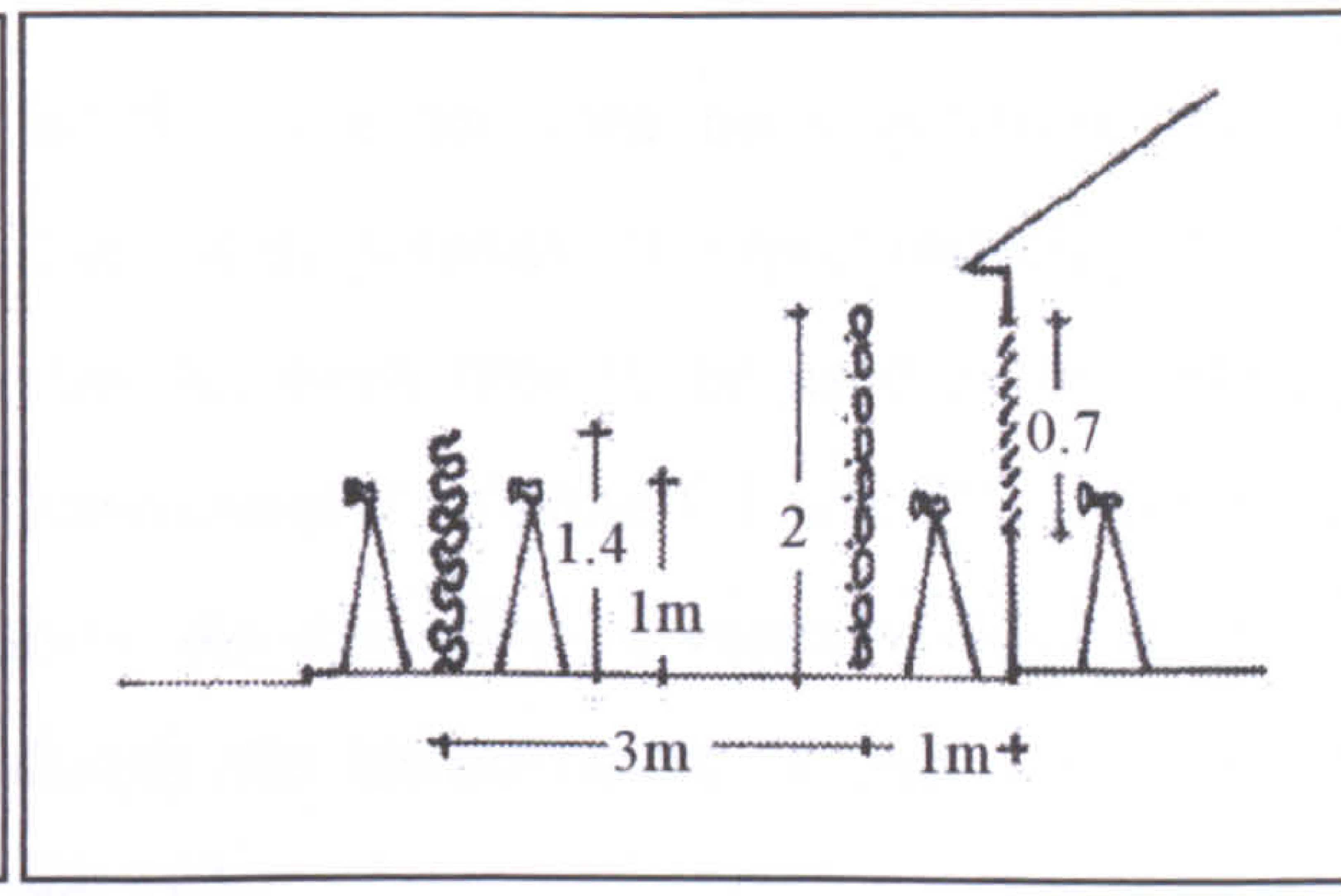
Figure 12.1. The four types of vegetation for the second field experiment

1. *Cikra-cikri/kedondong laut* (Polyscias fruticosa): thick shiny leaves
2. *Teh-tehan* (Duranta repens): thin shiny leaves
3. *Sirih gading* (Scindapsus sp.): thin shiny leaves
4. *Stepanut* (Stephanotis floribunda): thin furry leaves

The first and second species are shrubs, whilst the third and fourth species are climbing plants.

As with the first field experiment, several low volume air sampler (LVS) devices were used together to measure particulate matter concentration at certain points at the same time. One LVS was used to measure the street concentration in point A. Two LVSs were used to measure the concentration beyond Polyscias fruticosa (B1) and Duranta repens (B2). Two LVS were used to measure the concentration beyond Scindapsus sp (C1) and Stephanotis floribunda (S2). Two LVSs were used to measure the concentration beyond a casement window (D1) and a jalousie window (D2). Figures 12.2 and 12.3 show the detailed positions of the LVSs.





Figures 12.2 and 12.3. Plan and section of the LVS positions in the second field experiment

Figure 12.4. Front elevation of the house in the second field experiment

Results from the experiment:

Measurement points		Particulate matter concentration (µg/m³) on day : (measured over 8 hours from 0800 to 1600, the reading taken at 1600)									
		0	1	2	3	4	5	6	7	8	9
A		57	54	89	100	50	88	73	55	125	53
B	1	55	48	67	71						
	2		40	56	44						
C	1	53				45	43	59			
	2					41	35	65			
D	1	68							56	106	47
	2								53	97	37
Weather conditions (averaging from 8 hours, from 0800 to 1600) :											
Temperature		29.4 °C	28.1 °C	28.3 °C	29.9 °C	29.3 °C	29.4 °C	29.5 °C	29.7 °C	31.4 °C	29.4 °C
Humidity		72.75 %	80.75 %	81.75 %	71.25 %	74.25 %	76.25 %	72.50 %	71.13 %	63.13 %	67.50 %
Wind speed		0.86 m/s	1.16 m/s	0.58 m/s	1.35 m/s	0.97 m/s	0.75 m/s	1.2 m/s	0.95 m/s	1.27 m/s	0.73 m/s
Winddirection		NE	West	West	West	West	West	West	West	West	West
Rain level		30 mm	0 mm	25 mm	0 mm	0 mm	0 mm	24 mm	17 mm	0 mm	0 mm

Table 12.2. Experiment result of vegetation performances to reduce particulate matter (Source: *BTKL*, November 1998)

Keys:
- A street concentrations
- B1 concentration beyond Polyscias Fruticosa
- B2 concentration beyond Duranta repens
- C1 concentration beyond Scindapsus sp.
- C2 concentration beyond Stephanotis floribunda
- D1 concentration beyond casement windows
- D2 concentration beyond jalousie windows

Day 0 is the day when the LVSs were set with no vegetation, the only obstruction being the original frame fence with porosity of approximately 90%. The particulate matter concentrations on this day were then to be used as the reference points for analysis below. During the measurement of point C1 and C2, vegetation in point B1 and B2 were removed to show the capability of vegetation C1 and C2 in reducing particulate matter. So did during the measurement of points D1 and D2, vegetation B1, B2, C1 and C2 were removed.

A. Weather conditions

Throughout the experimental period, the wind speed and wind direction according to the Indonesian Bureau of Meteorological and Geophysics was10m/s NW. However, local building decreased the speed and changed the direction as can be seen in Table 12.2. From this table, it can be seen that temperature and relative humidity did not vary much throughout the experimental period. Any effect that temperature and humidity might have on particulate reduction could therefore not be assessed. However, the wind speed and wind direction did vary. Earlier study, which showed that a strong wind would disperse airborne particulate matter to a wider area, thereby reducing concentration [Harrison, et al, 1997], was not borne out in this field experiment. At the highest wind speed of 1.35 m/s, the street concentration was found to be the second highest. In the case of wind direction, it can be seen that, in general, wind direction (West) was parallel to the street almost throughout the experimental period, except for an oblique wind direction (Northeast) that occurred on Day 0, when the experiment was set without vegetation. The relation between wind direction and particle concentration was difficult to study, since within the similar direction (i.e. West) the particulate concentrations varied. Even when the wind direction was different (i.e. Northeast) the particulate concentration was similar to those in days 1,4,7, and 9, when the wind came from the west. From this, it can be seen that wind direction has a less significant effect than wind speed. As mentioned before, it was also difficult to determine the relationship between rain fall and particulate removal. In this experiment, it can be seen that the two highest particulate concentrations occurred in the absence of rain. However, it was also the case that the lowest particulate concentration occurred in the absence of rain. Thus, earlier study which showed that the presence of rain would lower the concentration of particulate matter in the air [Monn, et all, 1997] was not borne out in this study. As the effect of these factors (i.e. wind speeds, wind directions, and rain fall) were indeterminate, they are not assessed in detail in the following analyses.

B. Vegetation conditions

To study more details of particulate matter concentration at each point, below are three tables derived from Table 12.2. As in this Chapter only the performance of vegetation is discussed, the particulate concentration at points D1 and D2 are omitted. Table 12.3 shows the reduction in particulate matter concentration measured beyond the fence (points B and C) compared to the street concentration (point A).

Measurement points		PM concentrations at point B and C compared to point A, on day:						
		0	1	2	3	4	5	6
A		100%	100%	100%	100%	100%	100%	100%
B	1	96.49%	88.88%	75.28%	71%			
	2		74.07%	62.92%	44%			
C	1	92.98%				90%	48.86%	80.82%
	2					82%	39.77%	89.04%

Table 12. 3. PM concentrations at point B and C compared to point A
(Purpose: to differentiate PM concentration before and after passing through the vegetation)

From the above table, it can be seen that the reduction offered by certain types of vegetation used in this experiment varied. However, they were generally greater than the reduction offered by the frame fence (on Day 0), even though in some cases the reduction was slightly less. The particulate matter concentration at the measuring points compared to the street concentration and to Day 0 when there was no vegetation can be seen in Table 12.4. Table 12.5 then shows the total reduction offered by the vegetation.

Measurement points		PM concentrations at point B and C compared to point A and to Day 0						
		0	1	2	3	4	5	6
A		100%	100%	100%	100%	100%	100%	100%
B	1	100%	92.11%	78.02%	73.58%			
	2		76.76%	65.21%	45.60%			
C	1	100%				96.80%	52.55%	86.92%
	2					88.19%	42.77%	95.75%

Table 12.4. PM concentrations at point B and C compared to point A and to Day 0
(Purpose: to differentiate PM concentration between day 0/control and in the presence of vegetation)

Measurement points		The difference of PM10 concentrations after passing through the vegetation						
		0	1	2	3	4	5	6
A		0%	0%	0%	0%	0%	0%	0%
B	1	0%	-7.89%	-21.98%	-26.42%			
	2		-23.24%	-34.79%	-54.40%			
C	1	0%				-3.2%	-47.45%	-13.08%
	2					-11.81%	-57.23%	-4.24%

Table 12.5. The difference of PM concentrations after passing through the vegetation (Purpose: to see the total reduction of PM after passing through the vegetation)

The negative values shown in Table 12.5 indicate the percentage concentration reduction to be subtracted from the street concentration. The greater the negative value, the greater the reduction achieved beyond the vegetation.

C. Shrubs

At point B, it can be seen that the reduction offered by two types of shrub varied from approximately 8% to 54%. On the second and third days, shrub no.1 (B1) reduced particulate matter by 22% and 26%, but on the first day, it only reduced particulate matter by 8%. Shrub no.2 (B2) however reduced particulate matter progressively by around 23%, 35% and 54% over the three days. Regardless of the capability of the vegetation to impact and deposit particulate matter, this was predicted to have a strong relation with wind speeds on each day. However, from the above results, it can be seen that shrub no.2 (Duranta repens) reduced more particulate than shrub no.1 (Polyscias fruticosa).

D. Climbing plants

At point C, it can be seen that the reduction offered by two types of climbing plants varied from 3% to 57%. This variation occurred due to the rapid change of two important microclimatic factors, i.e. wind speed and wind direction. Even though the reduction values varied, it can be seen that from three days of measurements, there were two occasions when climbing plant no.2 (C2/Stephanotis floribunda) reduced more particulate matter than climbing plant no. 1 (C1/Scindapsus sp.).

Analysis of the ability of leaf surfaces to deposit particulates

Together with the second field experiment, the detailed anatomy of each leaf surface and the capability of each leaf type to deposit particles were also studied. Four types of leaf with particulate matter on their surfaces were examined three times each during the six-day period of field experiment. The leaves were washed carefully before starting the experiment, so only particulates generated during the experimental period were deposited on the leaf surfaces. The results of particulate deposition on each leaf can be seen in Table 12.6.

Days	Sample (B1)	PM mg	Leaf area mm^2	PM mg/mm^2	Sample (B2)	PM mg	Leaf area mm^2	PM $weight/mm^2$
#1	Polyscias fructicosa	0.2	655	**0.000305344**	Duranta repens	0.5	638	**0.000783699**
#2	Polyscias fructicosa	0.7	684	**0.001023392**	Duranta repens	0.9	977	**0.000921187**
#3	Polyscias fructicosa	0.3	586	**0.000511945**	Duranta repens	0.5	857	**0.000583431**

Days	Sample (C1)	PM mg	Leaf area mm^2	PM mg/mm^2	Sample (C2)	PM mg	Leaf area mm^2	PM $weight/mm^2$
#4	Scindapsus sp.	7.2	4920	**0.001465447**	Stephanotis floribunda	1.7	2716	**0.000618557**
#5	Scindapsus sp.	1.4	4128	**0.000329457**	Stephanotis floribunda	1.4	2082	**0.000662824**
#6	Scindapsus sp.	2.1	4224	**0.000487689**	Stephanotis floribunda	2.4	2140	**0.001107477**

Table 12.6. Weight of particulate matter on the examined leaves
(Source: *BTKL*, November 1998)

Table 12.6 shows that from three examinations of shrubs and three examinations of climbing plants, there were two occasions when Duranta repens (B2) and Stephanotis floribunda (C2) deposited more particulate matter compared to Polyscias fruticosa and Scindapsus sp. This probably indicates that Duranta repens and Stephanotis floribunda are capable of depositing more particulate matter compared to Polyscias fruticosa and Scindapsus sp. However, this analysis was not entirely conclusive. Further analysis is needed, including a study of the detailed anatomy of the leaf surface to strengthen this first conclusion.

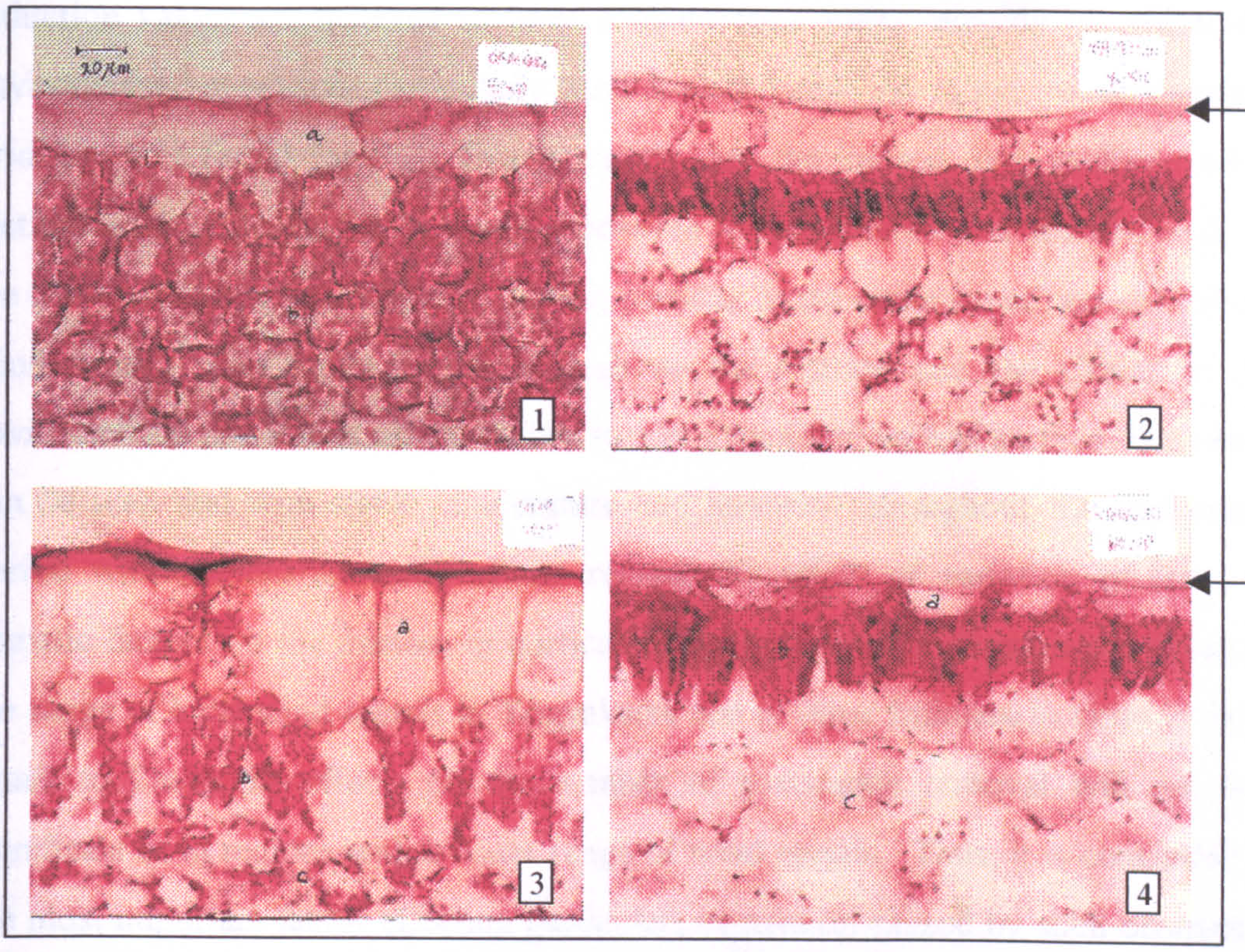


Figure 12.5. Leaf anatomy of the four types of vegetation in the second field experiment
(Source: *Mikro teknik UGM*, November 1998)
1. Polyscias fruticosa, 2. Duranta repens, 3. Scindapsus sp., 4. Stephanotis floribunda

Figure 12.5 shows that Duranta repens also has a slightly blurred surface (shown by the arrows) which explains that some parts of the leaf surface may be covered by fur. This provides a fuller explanation for the first result in which it was found that furry surfaces deposit more particulate matter than shiny surfaces. This conclusion is strengthened by the data in Table 12.2 showing that particulate concentrations beyond Duranta repens and Stephanotis floribunda were generally lower compared to particulate concentrations beyond Polyscias fruticosa and Scindapsus sp.

12.1.4 Conclusion on the capability of vegetation to reduce particulate matter

There were strong indications that particulate matter can be reduced by using particular types of vegetation. The principle of particulate matter removal was based on particulate behaviour specific to environmental conditions in Yogyakarta. Field experiments indicated that at low wind speeds, particulate matter could be trapped and deposited on the surface of low-growing vegetation such as shrubs or bushes. The reduction values are believed to have a relationship either directly or indirectly to environmental conditions particularly wind direction and rain. However, no conclusive evidence was found for this. This is mostly due the limited data available and by methodological limitations. It was not possible to fully analyse the specific surface of the leaf related to its capability to deposit particles in the presence of rain and different wind speed. This limits further analysis on the relation and the effects of these environmental conditions on particulate matter deposition on leaf surface. However, it can be seen that with stable temperature and humidity throughout the experimental period which is characteristic of the region, the effect of variation of these two climatic factors on the manner of particulate removal can be disregarded. Given that the range of local wind speeds in Yogyakarta and in other Indonesian cities is narrow (0m/s to 2m/s), its effects on the manner of particulate removal will not be as significant as in regions with a wider range of wind speeds. Thus, it is concluded that the most important factor effecting particulate dispersion caused by such obstructions is wind direction, as was indicated by the CFD experiment reported in Chapter 11. Rain is predicted to affect particulate removal from the atmosphere regardless the presence of obstructions. For regions with similar climatic characteristics as Indonesia, these phenomena are probably also similar, but for a region with a different climate, such as hot arid or clod arid, the case may be different.

It was borne out in the field trials that in typical climatic conditions of Yogyakarta (i.e. high temperature, high humidity, and low wind speed), furry leaf surfaces tended to have more particles deposited on them than shiny leaf surfaces.

12.2 Examining how vegetation can reduce noise

12.2.1 Experimental approach

Using barriers to reduce noise pollution may offer a solution. However, since sound is easily transmitted from one space to another through small openings, using porous barriers such as vegetation seems ineffective. An experiment carried out by BRE/CIRIA suggested that a 100-m thickness of tree belt would only reduce noise by 3 dBA [BRE/ CIRIA Report, 1993]. Based on this, the use of vegetation to reduce noise was not considered an important factor in this study. However, since the vegetation and the measurement devices were available, the effect of vegetation in reducing noise was also examined in a field experiment.

12.2.2 The experiment

The equipment used for this measurement were "digital sound level metres" owned by the Bureau of Environmental Health *(Balai Teknik Kesehatan Lingkungan/BTKL)* under the supervision of the Department of Health, Province of Yogyakarta, based on time and measurement points specified by the author. This device has already been used for many noise measurement purposes within Yogyakarta and other neighbouring cities. The detailed specifications of the devices can be seen in Appendix 5.

The results from the measurement were as follows:

Street noise levels ($L_{eq,\ 5\ min}$)	Indoor noise levels approx. 1m from the windows (opened top hung windows) ($L_{eq,\ 5\ min}$)	The difference
69.1 dBA	59.8 dBA	9.3 dBA
65.7 dBA	54.4 dBA	11.3 dBA
69.5 dBA	59.5 dBA	10.0 dBA
68.0 dBA	57.8 dBA	10.2 dBA
69.5 dBA	58.1 dBA	11.4 dBA
69.4 dBA	58.2 dBA	11.2 dBA
67.4 dBA	56.3 dBA	11.1 dBA
68.1 dBA	57.8 dBA	10.3 dBA
69.5 dBA	59.3 dBA	10.2 dBA
68.5 dBA	58.0 dBA	10.5 dBA
69.2 dBA	58.3 dBA	10.9 dBA
68.1 dBA	58.3 dBA	9.8 dBA
70.4 dBA	60.1 dBA	10.3 dBA
Average		**10.50 dBA**

A. Indoor noise levels without vegetation fence

Street noise levels ($L_{eq,\ 5\ min}$)	Indoor noise levels approx. 1m from the windows (opened top hung windows) ($L_{eq,\ 5\ min}$)	The difference
67.3 dBA	56.7 dBA	10.6 dBA
66.5 dBA	55.2 dBA	11.3 dBA
69.1 dBA	58.0 dBA	11.1 dBA
69.6 dBA	58.5 dBA	11.1 dBA
71.0 dBA	60.2 dBA	10.8 dBA
69.9 dBA	57.2 dBA	9.7 dBA
65.7 dBA	55.2 dBA	10.5 dBA
69.2 dBA	58.6 dBA	10.6 dBA
69.0 dBA	58.2 dBA	10.8 dBA
69.1 dBA	58.7 dBA	10.4 dBA
68.0 dBA	58.3 dBA	9.7 dBA
71.6 dBA	61.4 dBA	10.2 dBA
68.1 dBA	57.5 dBA	10.6 dBA
Average		**10.56 dBA**

B. Indoor noise levels with vegetation fence

Table 12.7. Field experiment result of the ability of vegetation to reduce noise (Source: *BTKL*, November 1998)

From the above table, it can be seen that vegetation is not effective to reduce noise, as indicated by BRE/CIRIA. In Yogyakarta noise conditions, the field experiment showed that a vegetation barrier with a thickness of approximately 50 cm to 75 cm and porosity of approximately 15% reduced noise by only 0.06 dBA.

12.2.3 Conclusion on the capability of vegetation to reduce noise

Earlier research suggested that a 100-m vegetation belt would only reduce noise by 3 dBA. It was therefore not surprising that the field trial indicated that a shrub belt thickness of 50 cm to 75 cm reduced noise less than 0.1 dBA. It is proposed that vegetation be used to reduce only particulate matter rather than to reduce noise.

CHAPTER 13

THE ABILITY OF THE PROPOSED WINDOW DESIGNS TO REDUCE PARTICULATE MATTER AND NOISE

The proposed design for windows for reducing both particulate matter and noise has already been described in Chapter 9. This design is examined below. An examination by CFD was carried out simultaneously with the examination of fence performance, followed by a field trial which was carried out simultaneously with the examination of vegetation performance. The field trial was held to confirm the result of the CFD simulation.

13.1 Examining particulate matter dispersion to the living space beyond jalousie windows

13.1.1 Experimental approach

The proposed window design for reducing particulate matter has been described in Chapter 9. A set of experiments was carried out to see how well the proposed window design could reduce particulate matter in real conditions. In the first stage, the experiment was carried out using a computational simulation, which was carried out simultaneously with the examination of fence performance.

As discussed in Chapter 11, the large scale of the CFD simulation could not represent such details as particulate trapping on certain surfaces. The CFD only represented the jalousie window in a condition similar to a porous opening with 75% porosity. Even though the detailed angled surface of the jalousie window could not be represented, the computational model was considered useful to see what percentage of particulate matter would be reduced by using an opening with a porosity similar to the porosity of a jalousie window. The CFD result was then confirmed with two field trials. The first of these used an enclosure with jalousie windows and the second a house that has jalousie windows with dimensions as identified for the CFD experiment.

13.1.2 The CFD experiment

As mentioned, the CFD experiment to examine window performance was carried out together with the CFD experiment to examine fencing performance.

Therefore, the specification of this experiment was similar to the specification of fencing experiment described in Chapter 11. Detailed positions of each point to measure the indoor particulate matter concentrations beyond the windows were as follows:

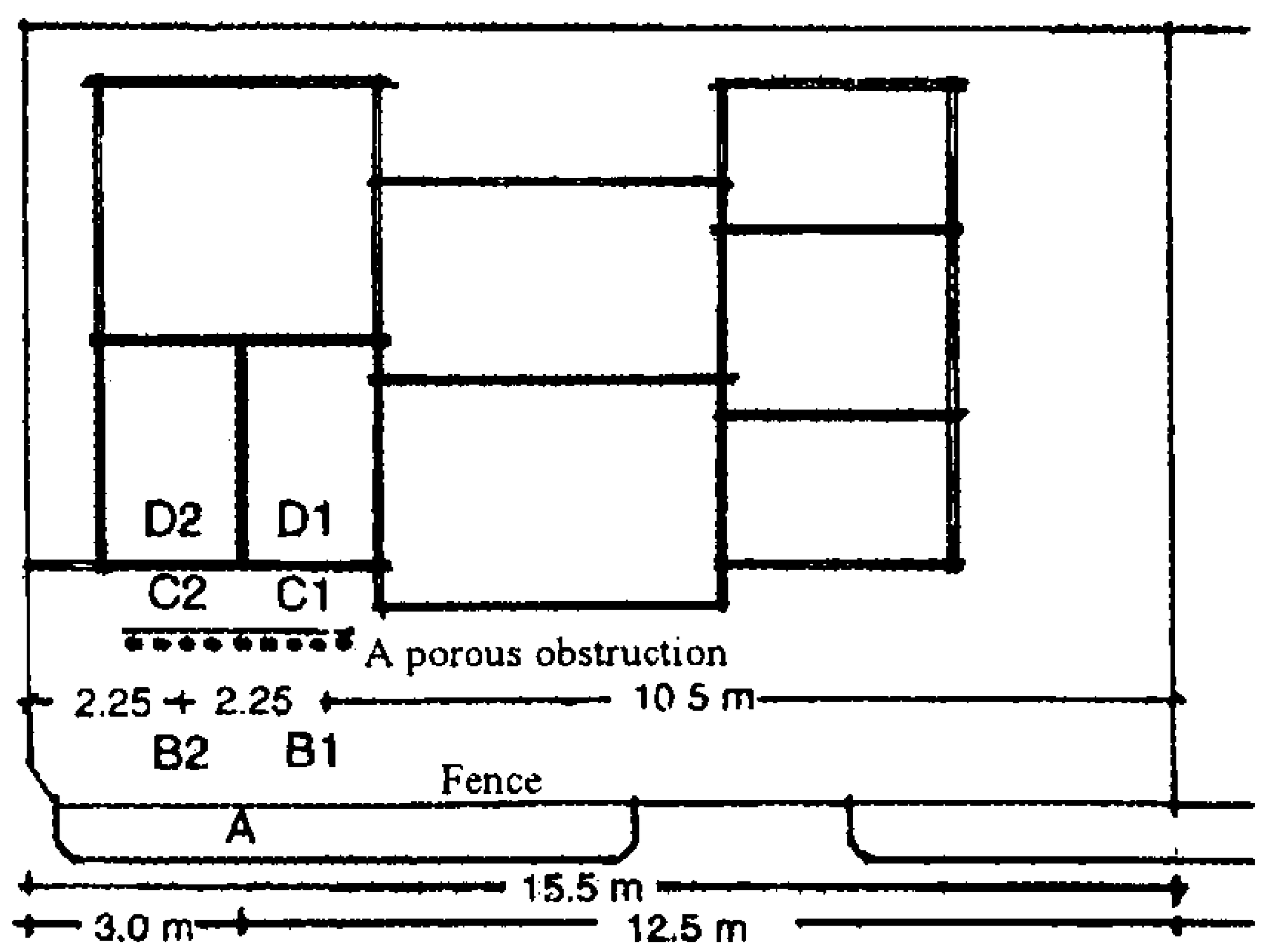


Figure 13.1. Plan of position of each measured point in the CFD experiment related to the window's capability to reduce particulate matter

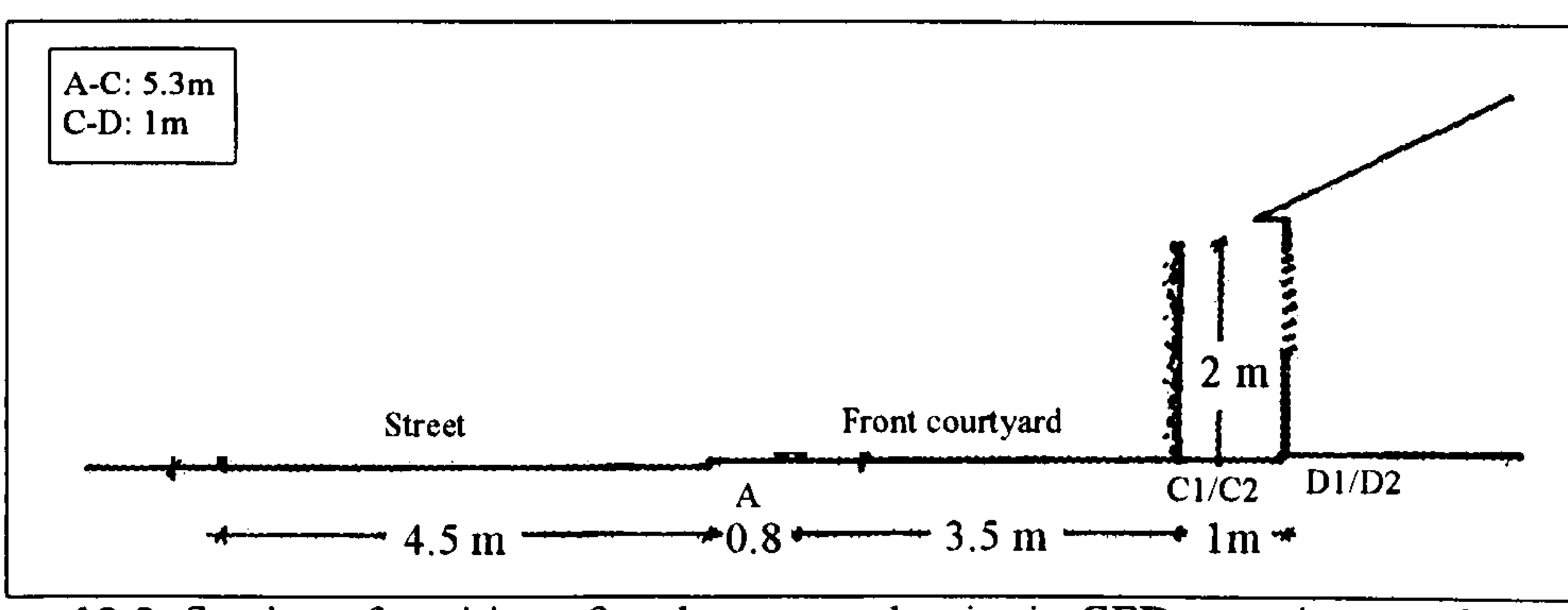


Figure 13.2. Section of position of each measured point in CFD experiment related to the window's capability to reduce particulate matter

Keys: distance between A and C was to be changed between 5.3 m and 3.3 m, depending on the length of the front courtyard determined in the inputs.

The capability of the jalousie window in reducing particulate matter is shown below.

Exp. No.	Specifications	Percentage of reduction at point D (%) compared to point C1 and C2	
		D1 (casement windows)	D2 (louvre windows)
1	Frame fence h=1.3m, yard width =4.5m, window=1m a.g.,	0.1	0.2
2	First porous fence h=1.3, yard width =4.5m, window=1m a.g.,	0.1	0
3	First solid fence h=1.3m, yard width =2.5m, window=1m a.g.	0.1	0.2
4	First solid fence h=1.7m, yard width =2.5m, window=1m a.g.	0.1	0.1
5	First solid fence h=1.3m, yard width =2.5m, window=0.6m a.g.	0.1	0.2
6	First solid fence h=1.7m, yard width =2.5m, window=0.6m a.g.	0.1	0.1
7	First porous fence h=1.3, second porous fence h=2m, yard width = 4.5m, window=1m a.g	0.1	0.1
8	First porous fence h=1.7, second porous fence h=2m, yard width = 4.5m, window=1m a.g	0.1	0.1
9	First porous fence h=1.3, second porous fence h=2m, yard width = 4.5m, window=0.6m a.g	0.1	0.1
10	First porous fence h=1.7, second porous fence h=2m, yard width = 4.5m, window=0.6m a.g	0.1	0.1
11	First porous fence h=1.3, second porous fence h=2m, yard width = 2.5m,	0	0.2
12	First porous fence h=1.7, second porous fence h=2m, yard width = 2.5m,	0.1	0.1
13	Frame fence h=1.3m, yard width =4.5m, wind=North West	0.5	0.1
14	First porous fence h=1.3, second porous fence h=2m, yard width = 4.5m, wind= North west	0.3	-0.7
15	First solid fence h=1.3m, second porous fence h=2m, yard width =4.5m, wind=North West	0	-0.4

Table 13.1. Result of the CFD experiments related to window performances (Source: the author and TJ. Scanlon)

Keys:
All the above experiments have West (W) wind direction, unless indicated North West (NW)
ag = height of window above the ground
h = height of the barrier
Point C1 and C2 = points just before the windows

From Table 13.1, it can be seen that:

1. There was no evidence that windows, either jalousie or casement windows offering any reduction of particulate concentration. The concentrations at points C and D are similar. The performance of jalousie windows relative to casement windows in reducing noise thus could not be concluded. This was predicted due to the computational model that could not represent the angled surfaces of the jalousie window. In real condition, it is expected that the reduction offered by a jalousie window would be greater due to the angled surfaces that may cause particles to impact and be deposited.

2. Another indication showed by experiments 3 to 10 that height of window above the ground has no significant effect in reducing particulate concentration. However, according to the ventilation flow rate calculations (Chapter 10), height should affect air change rates. Table 13.2 shows that window heights above the ground of 0.6 m and 1m gave the same result for indoor particulate matter concentrations (compare exp. 3 and 4 to exp. 5 and 6 and compare exp. 7 and 8 to exp. 9 and 10):

Exp. No.	Specifications	Concentration at point D1 and D2 (%) compared to point A	
		D1 (casement windows)	D2 (louvre windows)
3	First solid fence h=1.3m, yard width =2.5m, window=1m a.g.	-10.0	-10.1
4	First solid fence h=1.7m, yard width =2.5m, window=1m a.g.	-10.5	-10.7
5	First solid fence h=1.3m, yard width =2.5m, window=0.6m a.g.	-10.0	-10.1
6	First solid fence h=1.7m, yard width =2.5m, window=0.6m a.g.	-10.5	-10.7
7	First porous fence h=1.3, second porous fence h=2m, yard width = 4.5m, window=1m a.g	-10.2	-10.3
8	First porous fence h=1.7, second porous fence h=2m, yard width = 4.5m, window=1m a.g	-10.4	-10.7
9	First porous fence h=1.3, second porous fence h=2m, yard width = 4.5m, window=0.6m a.g	-10.2	-10.3
10	First porous fence h=1.7, second porous fence h=2m, yard width = 4.5m, window=0.6m a.g	-10.4	-10.7

Table 13.2. The CFD results on the effects of window height above the ground

3. In some cases, it was found that wind speed and particle concentration within a room with a jalousie window were slightly greater. According to the CFD result, these were caused by the window being adjacent to a high neighbouring wall, which caused the wind to deflect towards the room. This condition is shown in Figure 13.3. Regardless of window types, the CFD described that any room with openings or windows being adjacent to a high neighbouring wall might receive more particulate matter.

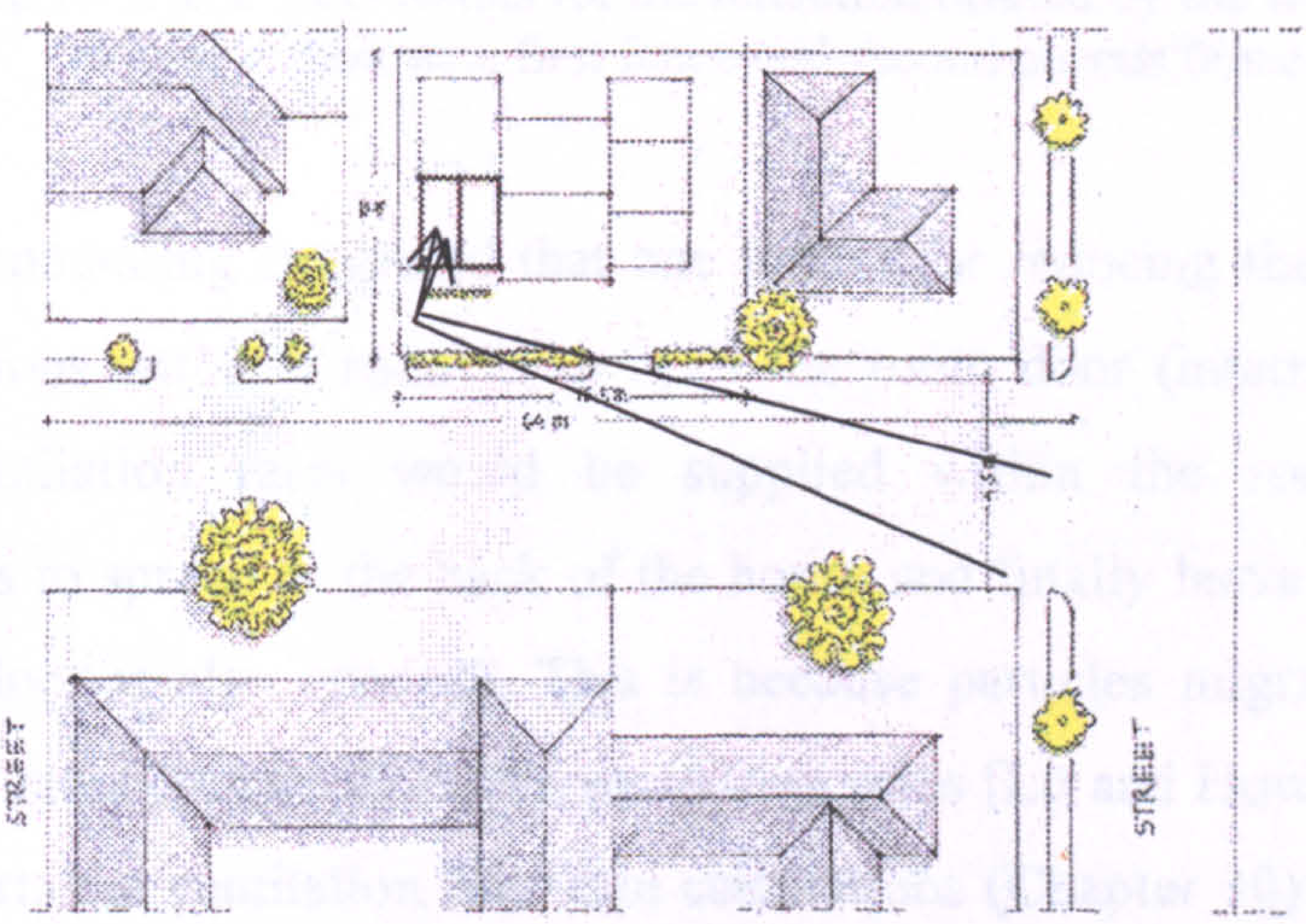


Figure 13.3. Wind deflection due to high neighbouring walls

4. A combination of a solid fence, a second porous fence (representing the performance of climbing plants), and an opened window gave a significant impact on the reduction of particles. The reduction offered by these features was up to 16%.

Exp. No.	Specifications	Concentration at point C and D (%) compared to point A					
		B1	B2	C1	C2	D1 casement	D2 louvre
1	Frame fence h=1.3m, yard width =4.5m, window=1m a.g.,	5.2	4.5	-9.6	-9.3	-9.7	-9.5
2	First porous fence h=1.3, yard width =4.5m, window=1m a.g.,	5.3	4.2	-9.5	-8.4	-9.6	-8.4
3	First solid fence h=1.3m, yard width =2.5m, window=1m a.g.	8.7	8.3	-9.6	-9.3	-10.0	-10.1
4	First solid fence h=1.7m, yard width =2.5m, window=1m a.g.	9.4	9.2	-9.7	-9.5	-10.5	-10.7
5	First solid fence h=1.3m, yard width =2.5m, window=0.6m a.g.	8.7	8.3	-9.6	-9.3	-10.0	-10.1
6	First solid fence h=1.7m, yard width =2.5m, window=0.6m a.g.	9.4	9.2	-9.7	-9.5	-10.5	-10.7
7	First porous fence h=1.3, second porous fence h=2m, yard width = 4.5m, window=1m a.g	6.6	6.3	-10.1	-10.2	-10.2	-10.3
8	First porous fence h=1.7, second porous fence h=2m, yard width = 4.5m, window=1m a.g	7.2	7.2	-10.3	-10.6	-10.4	-10.7
9	First porous fence h=1.3, second porous fence h=2m, yard width = 4.5m, window=0.6m a.g	6.6	6.3	-10.1	-10.2	-10.2	-10.3
10	First porous fence h=1.7, second porous fence h=2m, yard width = 4.5m, window=0.6m a.g	7.2	7.2	-10.3	-10.6	-10.4	-10.7
11	First porous fence h=1.3, second porous fence h=2m, yard width = 2.5m,	8.9	8.5	-10.1	-10.1	-10.1	-10.3
12	First porous fence h=1.7, second porous fence h=2m, yard width = 2.5m,	9.7	9.5	-10.5	-10.8	-10.6	-10.9
13	Frame fence h=1.3m, yard width =4.5m, wind=North West	5.7	4.9	-7.2	-7.1	-7.7	-7.2
14	First porous fence h=1.3, second porous fence h=2m, yard width = 4.5m, wind= North west	5.6	4.3	-7.2	-6.9	-7.5	-6.2
15	First solid fence h=1.3m, second porous fence h=2m, yard width =4.5m, wind=North West	12.4	10.1	-16.4	-15.9	-16.4	-15.5

Table 13.3. The CFD results for the reduction offered by the windows
In conjunction with first fence and second porous fence

5. The CFD modelling suggested that one option for reducing the high particulate concentrations within a room is to open the room door (internal door). Hence, higher ventilation rates would be supplied within the room, forcing the particulates to spread to the back of the house and finally leave the house (when the back door is also opened). This is because particles migrate faster at high ventilation rates compared to low ventilation rates [Lu and Howarth, 1996]. This will supports the ventilation flow rate calculations (Chapter 10) which suggested opening the back door to induce higher air motion within the house.

6. The CFD result shows that the indoor air velocity was low at approximately 0.04 to 0.07 m/s. This was due to outdoor air velocity which is often as low as 0 m/s and to the resistance of the openings.

13.1.3 Field experiments

A. The first experiment

The ability of windows to reduce pollutants was examined twice in the field. The first experiment was carried out simultaneously with the field experiment to examine fence performance as discussed in Section 11.1.6 of Chapter 11. The specifications (device, location and position) of this experiment are similar to those described in Chapter 11 and can be seen in detail in Appendix 5. The results of the field experiments in Chapter 11 is shown again below (the last column shows the experimental results related to the capability of windows to reduce the intrusion of particulate matter):

Figure 13.4. The reference enclosure

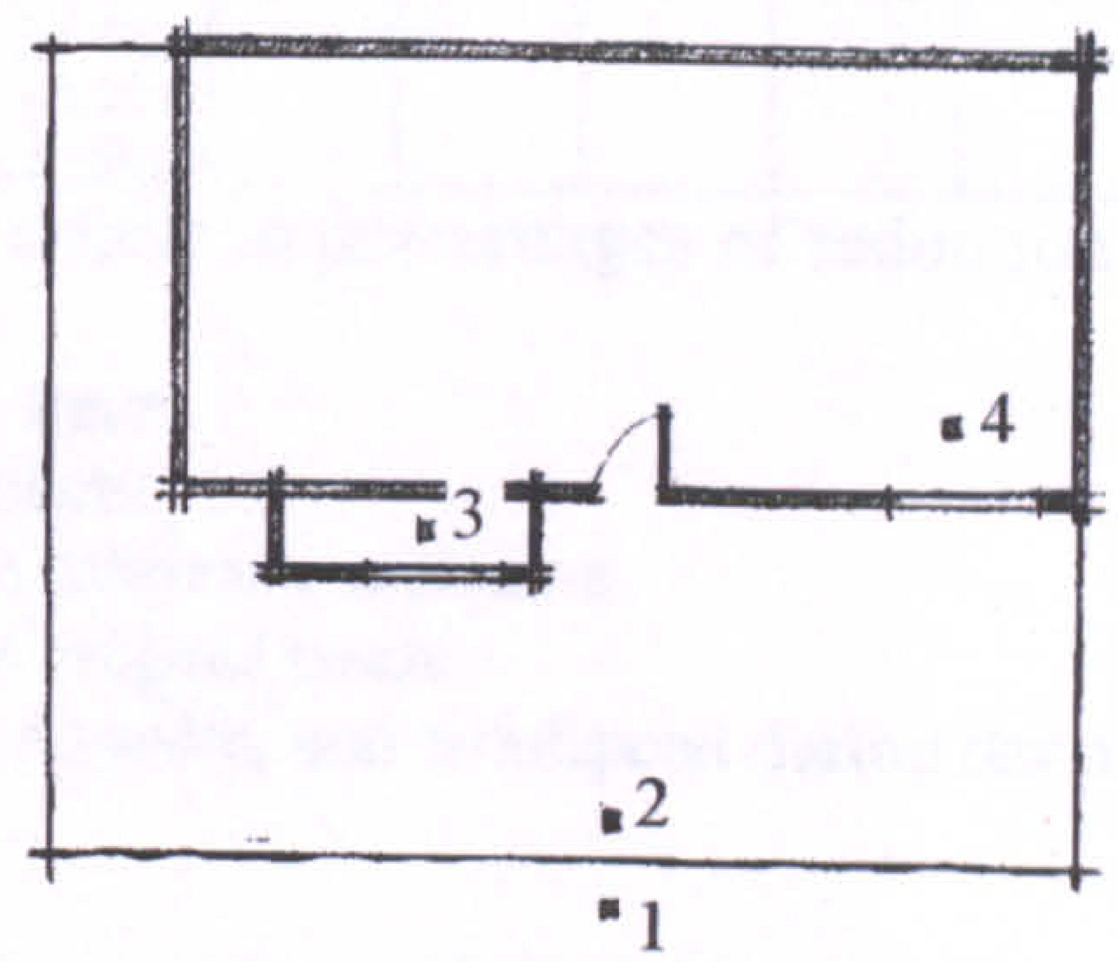


Figure 13.5. Plan of the LVS position

Location	Fence/Street types/ Window types	Microclimatic Conditions (averaging from 24 hours)	Concentration at points (µg/m³)	Reduction (µg/m³) at points					
				1-2	1-3	1-4	2-3	2-4	3-4
First house first day	original fences (steel frames) poor asphalt street side single hung wind.	- temp. 29.7°C, RH 74.25% - heavy rain in the afternoon 30 mm - wind speed 1.00 m/s (parallel to the fence)	1 = 128 2 = 122 3= 97 4 = 87	6	31	41	25	35	10
second day	original+ brick fences poor asphalt street side single hung wind.	-temp. 28.4°C, RH 82.17% - no rain - wind speed 0.84 m/s (parallel to the fence)	1= 158 2 =109 3 = 93 4 = 75	49	68	83	16	34	18
Second house first day	original fences (vegetation) hot mix street top single hung wind.	- temp. 29.4°C, RH 71.50% - rainy afternoon 22.5 mm - wind speed 0.75 m/s (parallel to the fence)	1 = 84 2 = 63 3 = 57 4 = 60	21	27	24	6	3	-3
second day	original+ brick fences hot mix street top single hung wind.	- temp. 30.8°C, RH 70.91% - no rain -wind speed 0.75 m/s (parallel to the fence)	1 = 89 2 = 62 3 = 53 4 = 51	27	36	38	9	11	2
Third house first day	original fences (brick/steel frames) hot mix street glass jalousie wind.	- temp. 29.9°C, RH 71.25% - no rain - wind speed 0.85 m/s (parallel to the fence)	1= 123 2 = 93 3 = 92 4 = 76	30	31	47	1	17	16
second day	original+brick fences hot mix street glass jalousie wind.	- -temp. 28.3°C, RH 81.75% - rainy afternoon 17 mm - wind speed 0.78 m/s (parallel to the fence)	1 = 111 2 = 79 3 = 36 4 = 55	32	75	56	43	24	-19

Table 13.4. Results of the first field experiment

Location	Fence/Street types/ Window types	Microclimatic Conditions (averaging from 24 hours)	Concentration at points ($\mu g/m^3$)	Reduction (%) at points					
				1-2	1-3	1-4	2-3	2-4	3-4
First house first day	original fences (steel frames) poor asphalt street side single hung wind.	- temp. 29.7°C, RH 74.25% - heavy rain in the afternoon 30 mm - wind speed 1.00 m/s (parallel to the fence)	1= 128 2 =122 3 = 97 4 = 87	4.7	24.2	32.0	22.9	32.1	10.8
second day	original+ brick fences poor asphalt street side single hung wind.	-temp. 28.4°C, RH 82.17% - no rain - wind speed 0.84 m/s (parallel to the fence)	1= 158 2 =109 3 = 93 4 = 75	31.0	43.0	52.5	13.1	27.9	18.6
Second house first day	original fences (vegetation) hot mix street top single hung wind.	- temp. 29.4°C, RH 71.50% - rainy afternoon 22.5 mm - wind speed 0.75 m/s (parallel to the fence)	1 = 84 2 = 63 3 = 57 4 = 60	25	32.1	28.6	9.5	4.8	-5.3
second day	original+ brick fences hot mix street top single hung wind.	- temp. 30.8°C, RH 70.91% - no rain -wind speed 0.75 m/s (parallel to the fence)	1 = 89 2 = 62 3 = 53 4 = 51	30	40.4	42.7	14.5	17.8	3.8
Third house first day	original fences (brick/steel frames) hot mix street glass jalousie wind.	- temp. 29.9°C, RH 71.25% - no rain - wind speed 0.85 m/s (parallel to the fence)	1= 123 2 = 93 3 = 92 4 = 76	24.4	25.2	38.2	1.1	18.3	17.4
second day	original+brick fences hot mix street glass jalousie wind.	- -temp. 28.3°C, RH 81.75% - rainy afternoon 17 mm - wind speed 0.78 m/s (parallel to the fence)	1 = 111 2 = 79 3 = 36 4 = 55	28.8	67.7	50.5	454.4	30 4	-52.7

Table 13.5. Results of the first field experiment in percentages of reduction

Keys:
1 = point along the street
2 = point beyond fences
3 = point within the reference enclosure
4 = point within the original house

As there were no significant difference in temperature, humidity and windspeed during day and night, the data collected during 24 hours were averaged.

From Table 13.5, it can be seen that from the six (day) experiments, there were only two occasions (shown by negative results) when the jalousie window reduced more particulate matter than the other window types, even though in the location of the field experiment there were no adjacent high neighbouring walls that would have deflected the wind carrying particulate matter towards the jalousie window as indicated by the CFD experiment.

Thus, in this experiment, even though there were some indications that the jalousie window was capable of reducing particulate matter, the reduction offered relative to other windows types was inconclusive. The performance of the jalousie window was expected to be more clearly shown by the second experiment.

From this experiment, the results of which are presented in Table 13.6, it can be seen that in most cases, the combinations of solid fencing and particular types of window that obstruct particulates (top single hung, glass jalousie and timber jalousie) gave greater reductions than the combination of the same windows and porous fencing.

B. The second experiment

The second experiment sought only to examine two types of window: casement and louvre/jalousie. This experiment was carried out during a 14 day period simultaneously with the vegetation experiment discussed in Chapter 12. Therefore, the data collected from this experiment was similar to that shown by Table 12.2 in Chapter Twelve. The table was then simplified to expose only the capability of window to reduce particulate matter by comparing points A and D. The simplified table is as follows:

Day	Microclimate conditions	Concentration at points ($\mu g/m^3$) (measured over 8 hours)	Reduction (%) at points	
			A-D1	A-D2
7	- temp. 29.7°C, RH 71.13% - rainy afternoon 17 mm - wind speed 0.95 m/s (parallel to the fence)	A=55 D1=56 D2=53	-2	4
8	-temp. 31.4°C, RH 63.13% - no rain - wind speed 1.27 m/s (parallel to the fence)	A=125 D1=106 D2=97	15	22
9	- temp. 29.4°C, RH 67.50% - no rain - wind speed 0.73 m/s (parallel to the fence)	A=53 D1=47 D2=37	11	30

Table 13.6. Second experiment result in relation to window types
(Source: *BTKL*, November 1998)

Keys:
A street concentrations
D1 concentration beyond casement window
D2 concentration beyond jalousie/louvre window
As the data in table 13.6 are parts of data in Table 12.2, the measurement day starts at day 7

The detailed position of each point is as follows:

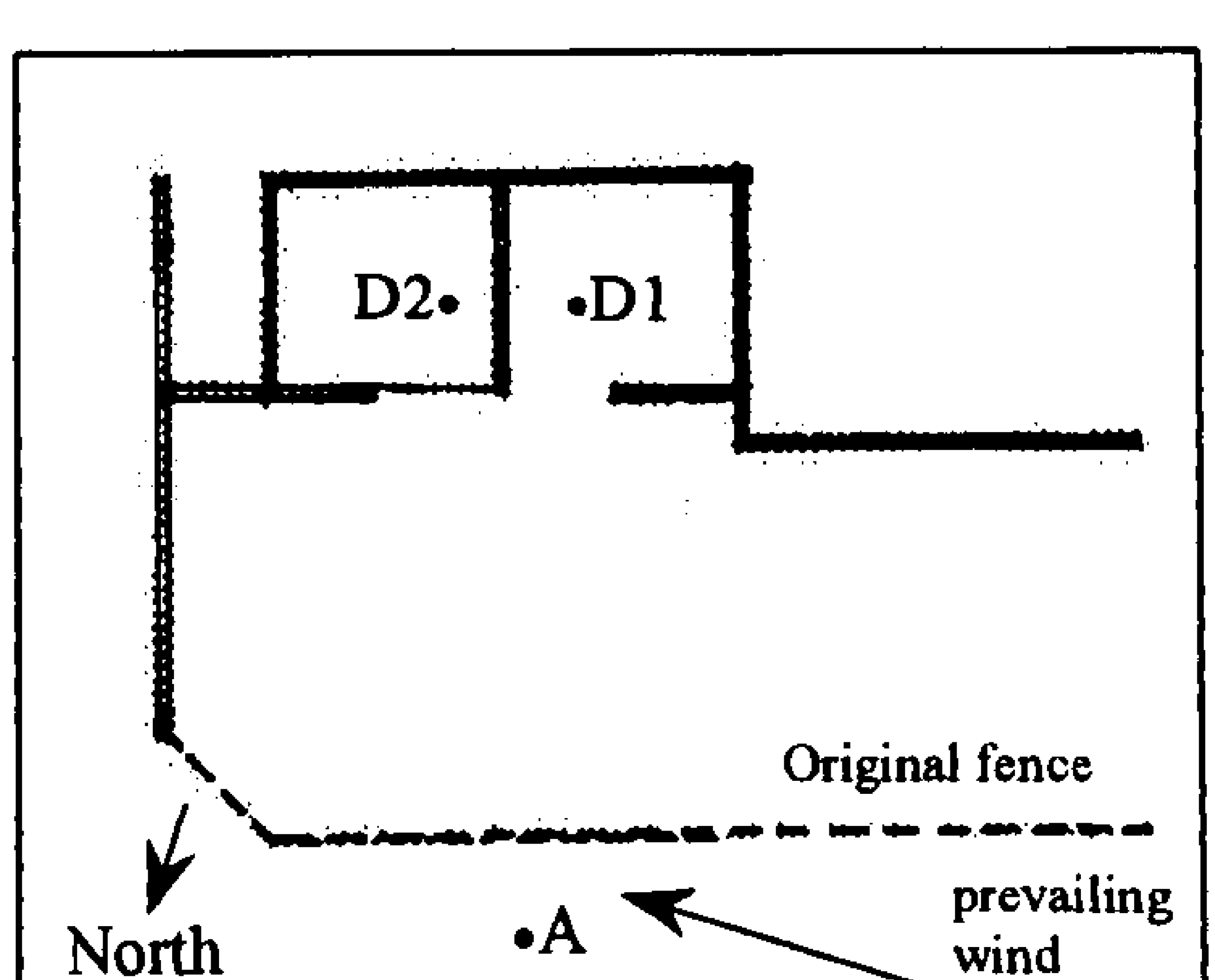


Figure 13.6. Plans of the LVS positions to examine the proposed window designs in the second experiment

Table 13.6 shows that at three different measurement times, jalousie windows reduced particulate matter slightly more than casement windows. The reduction varied from approximately 4% to 30%. The variation of the values was thought to be related to the wind speed, as other microclimatic conditions (i.e. temperature, humidity and wind direction) were similar throughout the experiment period).

13.1.4 Conclusion on the capability of the jalousie windows to reduce particulate matter

An accurate value for the reduction of particulate matter concentration offered by jalousie windows could not be determined in this study. According to the CFD experiments, there were cases when particulate concentrations beyond the jalousie windows were greater as the result of wind deflection from a neighbouring wall. However, from both the CFD simulation and the field experiments, regardless of the presence of adjacent high neighbouring walls, there were indications in using this type of window to reduce more particulate matter than using ordinary casement windows. The greater indoor concentrations of particulate matter could also be caused by domestic activities such as cooking and smoking [Harrison, 1997/1998]. However, the use of the jalousie window is still suggested for reducing the intrusion of particulate matter from the outdoor air. Further studies are necessary to explore the precise reduction of particulate matter concentration offered by jalousie windows.

13.2 Examining indoor noise levels beyond jalousie windows

13.2.1 Experimental approach

A type of opening to be used close to traffic noise which could also permit natural airflow has been proposed in Chapter 9. It is then important to examine the proposed design as to its ability to do its task of reducing noise intrusion in real conditions. Two methods were chosen for the examination. The first was a manual calculation method, which was used to calculate the net insulation offered by the proposed opening design and the surrounding walls. This calculation was carried out based on the proposed housing layout, opening position and dimension. However, since there is no specific theory to calculate the noise insulation offered by the proposed opening (i.e. jalousie window), in this calculation, the condition of the jalousie window was treated as an ordinary opened window (casement window). To find the actual noise reduction offered by the jalousie window, a field trial, which compared the noise reduction offered by three different types of window, was carried out. From the field trial result, the approximate insulation values offered by a jalousie window could be determined.

13.2.2 Net insulation of combined structural elements

It is very important to calculate the sound insulation offered by the combination of walls and openings, particularly those exposed to noise sources. The external noise and noise standard are set in dBA, whereas sound insulation is measured in dB and the figures quoted are the values averaged over the frequency ranges between 100 and 3150 Hz. The insulation of a window varies with the frequency of the noise that impacts the window. Thus its overall effect on noise will depend on the spectrum of the noise.

One way to get an accurate value is to take the spectrum of the noise, modify it according to the window insulation values and then calculate the loudness of the modified spectrum. However, for road traffic, a much simpler process is available with an acceptable loss of accuracy. It is to take the dBA level of the traffic noise and obtain the indoor noise level in dBA by subtracting the values shown in Table 13.7. These approximations apply to road traffic noise only and are accurate to within about ±5 dBA [Burt, et al, 1969].

Insulation values	Subtract from the outdoor noise levels
< 20 dB	< 20 dB
20-25 dB	20-25 dB
30 dB	28 dB(A)
35 dB	30 dB(A)
40 dB	35 dB(A)
45 dB	40 dB(A)

Table 13.7. Insulation values of vertical elements with regard to traffic noise (After W. Burt, et al., 1969)

The ratio between the openings/windows and the rest of the solid walls need to be calculated. The ratio will show the loss of insulation as can be seen in Figure 13.7. Once the insulation value of each element is determined, the difference of the insulation value is found and the loss of insulation deducted from the higher insulation of the two elements [JE. Moore, 1967]. The final combined insulation value then can be calculated using Table 13.8.

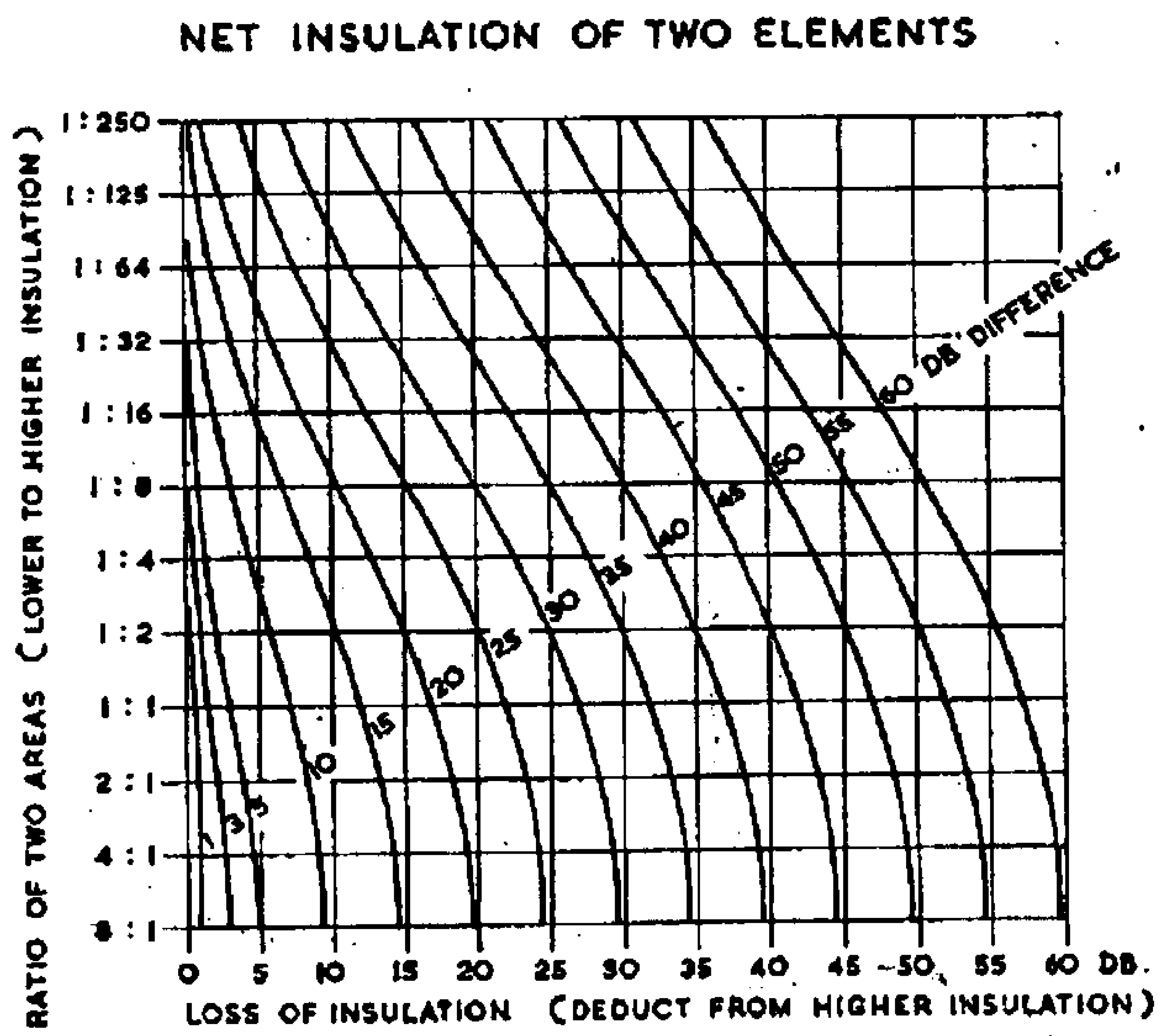


Figure 13.7. Graphic of net insulation of two elements (After JE. Moore, 1967)

By using the above method, the design resulting from the ventilation flow rate calculations were examined to find the net insulation of the combined structural elements. Sound insulation offered by an open window as received by a person in the middle of a room is approximately 12dB in a warm climate and 17 dB in a cold climate, the average being approximately 15 dB [Burt et al, 1969, EPA, 1974 (cited in Chunnif, 1977), Thomas 1996]. These insulation values decrease as the person approaches the window. Sound insulation offered by solid walls is shown by Table 13.8.

Wall types	Details	Insulation values (dB)
solid blockwork	paint finished	37
solid blockwork	plaster each side	43
12cm brickwork	unfinished	42
12cm brickwork	plaster each side	45
24cm brickwork	plaster each side	50

Table 13.8. Insulation value of various solid walls
(After BRE/CIRIA Report, 1993)

The most common walling in Indonesia is 12cm brick with both external and internal surface plastered (45 dB). However, for low cost housing, it is also common to use 12cm unplastered brick (42 dB). The net insulation values for low cost housing in Indonesia, with windows that result from the ventilation flow rate calculation, are calculated by using the minimum insulation value. Insulation for open windows is 12 dB [EPA, 1974, cited in Chunnif, 1977] and for walling 42 dB. Thus the difference is 30dB. Once the difference between the highest and the lowest insulation is determined, the next stage is to determine the ratio between the opening areas and the rest of the wall areas. Tables 13.9 and 13.10 show the ratio of the four walls, including the net insulation values derived from Figure 13.7. The specification of the windows is taken from the specification proposed for house for ventilation flow rate calculations (refer to Chapter 10). In this table, insulation values with closed glass windows on each surface are also calculated.

1. For house type A

surfaces/area	opened area (a)	closed glass area (b)	(a) + (b)	ratio to the rest of the wall		net insulation	
				a	a+b	a	a+b
1/14.40 m²	2.08 m²	0.90 m²	2.98 m²	1 : 5	1 : 3	20 dB	18 dB
2/10.80 m²	2.54 m²	0.90 m²	3.44 m²	1 : 3	1 : 2	18 dB	17 dB
3/114.40 m²	3.04 m²	0.90 m²	3.94 m²	1 : 3	1 : 2	18 dB	17 dB
4/5.40 m²	1.04 m²	0.90 m²	1.94 m²	1 : 4	1 : 1	19.5 dB	15 dB

Table 13.9. Net insulation value of house type A

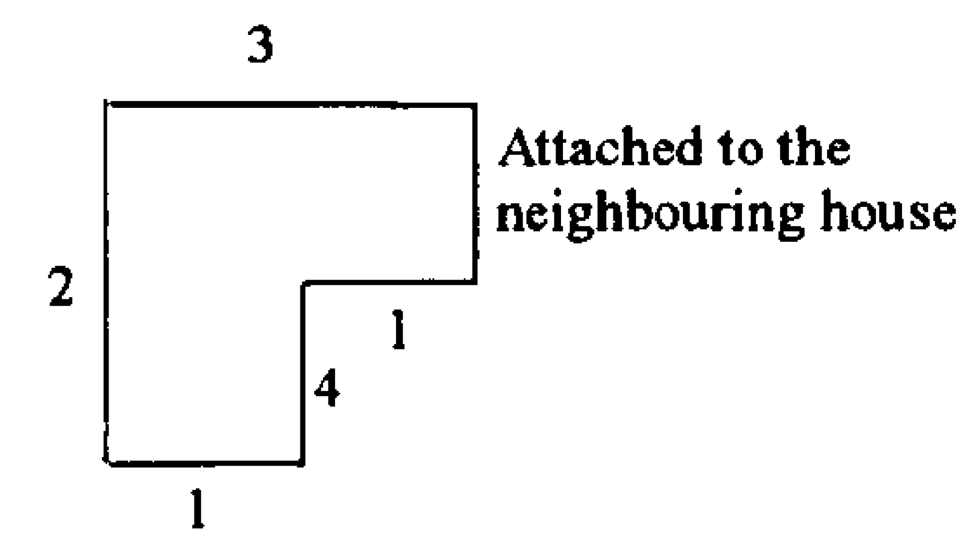
To find the combined insulation values that will be minimally provided by the house, the actual ratios are rounded down to the nearest whole number; for example a ratio of 1: 4.7 is simplified to 1: 4.

2. For house type B

surfaces/area	opened area (a)	closed glass area (b)	(a) +(b)	ratio to the rest of the wall		net insulation	
				a	a+b	a	a+b
1/14.40 m²	4.16 m²	0.90 m²	5.06 m²	1 : 2	1 : 1	17 dB	15 dB
2/ 19.20 m²	5.07 m²	0.90 m²	5.97 m²	1 : 2	1 : 2	17 dB	17 dB
3/14.40 m²	3.04 m²	0.90 m²	3.94 m²	1 : 3	1 : 2	18 dB	17 dB
4/9.60 m²	2.08 m²	0.90 m²	2.98 m²	1 : 3	1 : 2	18 dB	17 dB

Table 13.10. Net insulation value of house type B

Keys :



Surface 1 and 4 face prevailing wind and function as inlets and surface 2 and 3 as outlets.

From Tables 13. 9 and 13.10, it can be seen that the proposed housing design offers insulation values from 15 dB to 20 dB. Using Table 13.7 these values then to be converted into dBA. Tables 13.11 shows the net insulation values in both house types A and B in dBA.

Insulation values	Converted into dBA by using Table 13.7
15 dB	15 dBA
17 dB	17 dBA
18 dB	18 dBA
19.5 dB	19.5 dBA
20 dB	20 dBA

Table 13.11. The range of net insulation values in both house types A and B
When closed glass windows are used, the reduction offered will be of approximately 15 to 18 dBA.

As values in Table 13.11 are minimum values provided by the combination of windows and walls, in real conditions, these values are expected to be greater, especially when using louvre types that are predicted to be able to reflect and absorb noise. Calculations only consider louvre windows as regular opened windows with an insulation value of approximately 12 dBA. Louvre windows should be able to provide greater insulation values.

The most important surfaces to be examined are surfaces 1, 2 and 4, which will always be closer to the noise source. The net insulation values of these surfaces should therefore be maximised. In this case, installing glass windows in surface 1 of about 0.9 m² for views would reduce the insulation values by approximately 1 to 5 dB compared to a solid wall.

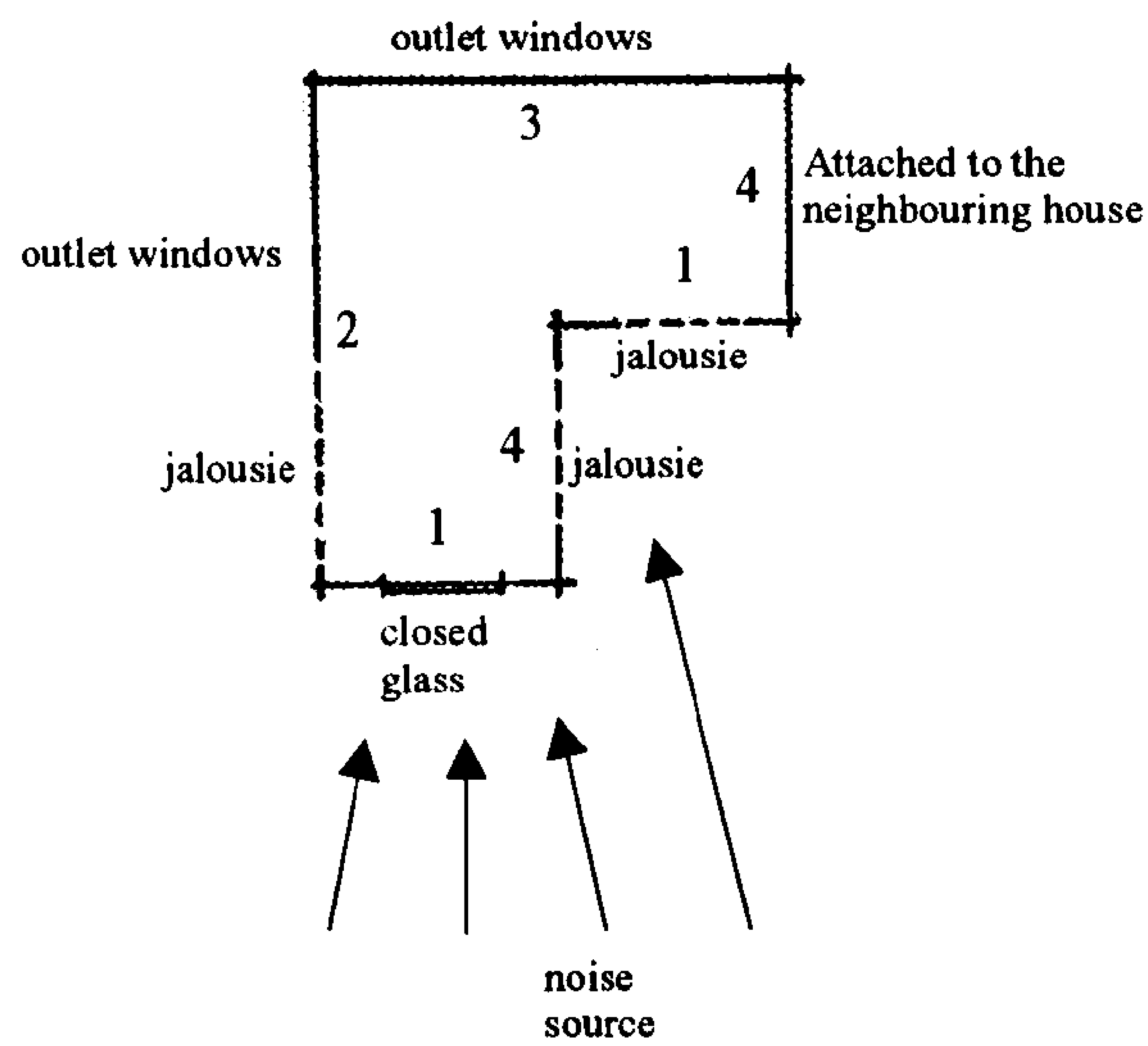


Figure 13.8. Placement of jalousie and closed glass windows

13.2.3 Field experiments

As mentioned above, the capability of jalousie windows to reduce noise compared to casement and top hung windows was examined in a field trial. The experiment was carried out in one location, by using a house that has three window types with similar dimension and position and within the same distance from the traffic noise source. The measurement was carried out by the Bureau of Environmental Health (*Balai Teknik Kesehatan Lingkungan/BTKL*) under the supervision of the Department of Health, Province of Yogyakarta, based on time and measurement points specified by the author. The specification of the sound level meters used in this experiment can be seen in Appendix 5. The walls are unplastered and the ratio between each window type and the rest of the wall is 1:2. The detailed positions of the measurement are as follows:

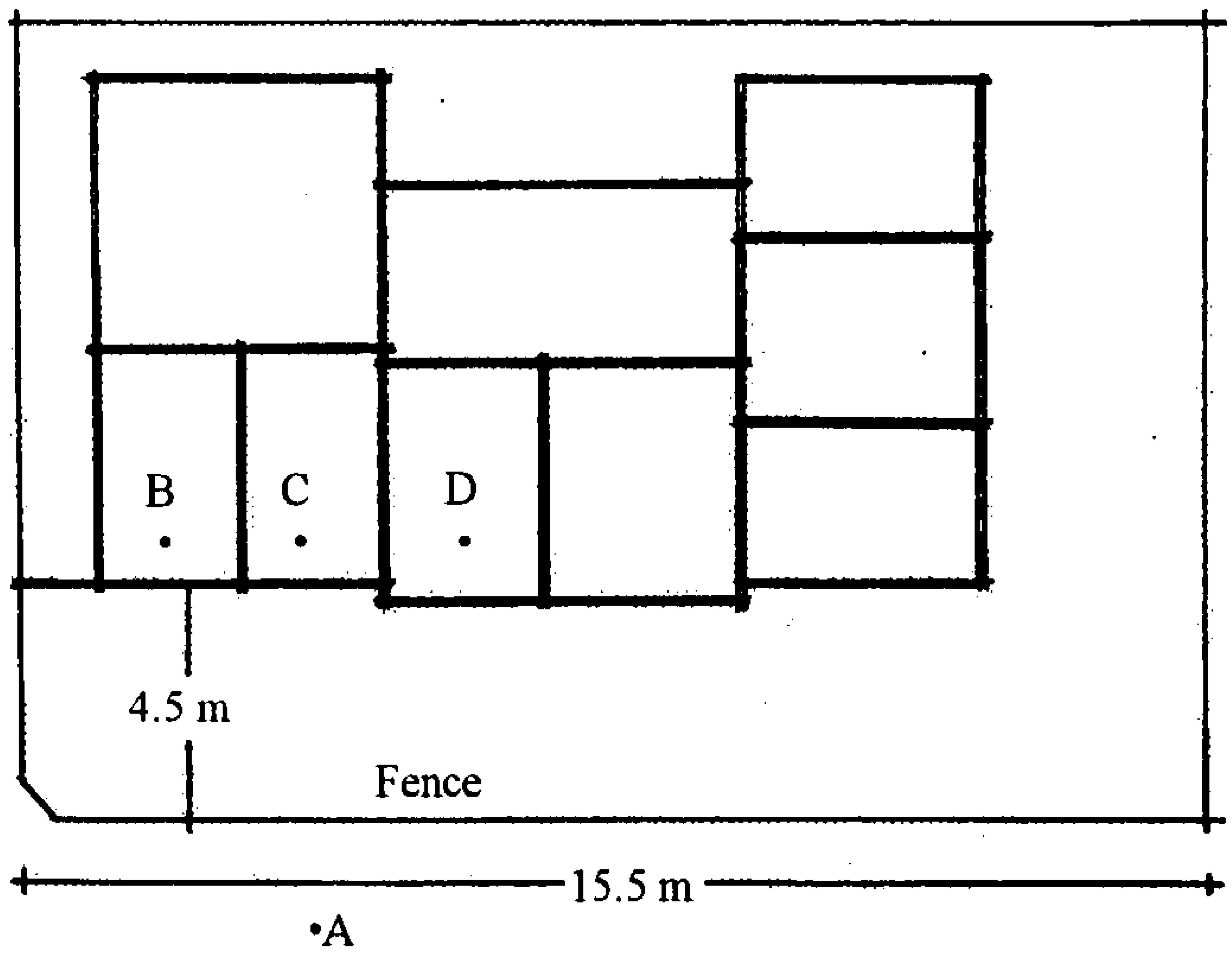


Figure 13.9. The positions of the sound level metres to measure noise insulation offered by three types of window

Keys:
A street noise levels
B noise levels 1 m beyond a jalousie window
C noise levels 1 m beyond a casement window
D noise levels 1 m beyond a top hung window
The difference between front walls of rooms C and D is only 20 cm

The results of the experiment are as follows:

Noise levels ($L_{eq, 5 min}$)			
Adjacent to the street	Beyond casement windows /and thus the reduction (dBA/ dBA) (point C)	Beyond top hung windows / and thus the reduction (dBA/ dBA) (point D)	Beyond jalousie windows / and thus the reduction (dBA/ dBA) (point B)
69.1 dBA	58.7/10.4 dBA	59.8 / 9.3 dBA	57.4/11.7 dBA
65.7 dBA	65.7/10.0 dBA	54.4 / 11.3 dBA	54.3/11.4 dBA
69.5 dBA	59.3/10.2 dBA	59.5/ 10.0 dBA	58.6/10.9 dBA
68.0 dBA	57.9/10.1 dBA	57.8 /10.2 dBA	58.1/11.4 dBA
69.5 dBA	59.5/10.0 dBA	58.1 / 11.4 dBA	56.4/11.6 dBA
69.4 dBA	59.1/10.3 dBA	58.2 / 11.2 dBA	57.7/11.8 dBA
67.4 dBA	56.5/10.9 dBA	56.3/ 11.1 dBA	57.5/11.9 dBA
68.1 dBA	57.9/10.2 dBA	57.8 / 10.3 dBA	55.3/12.1 dBA
69.5 dBA	59.9/9.9 dBA	59.3 / 10.2 dBA	56.0/12.1 dBA
68.5 dBA	58.1/10.4 dBA	58.0 /10.5 dBA	56.6/11.9 dBA
69.2 dBA	58.7/10.5 dBA	58.3 / 10.9 dBA	57.8/11.4 dBA
68.1 dBA	57.8/10.3 dBA	58.3 / 9.8 dBA	57.2/10.9 dBA
70.4 dBA	60.0/10.4 dBA	60.1 / 10.3 dBA	59.2/11.2 dBA
The average of reduction	**10.28 dBA**	**10.50 dBA**	**11.56 dBA**

Table 13.12. Noise reduction offered by different types of window in the field experiment (Source: *BTKL*, November 1998)

Table 13.12 shows that a jalousie (louvre) window in combination with the surrounding walls offered insignificant noise reduction of only 1 dBA greater than those offered by casement and top hung windows. Therefore, there is no conclusion could be made at this stage related to the ability of jalousie windows to reduce outdoor noise. However, as the windows used in the experiment are ordinary timber jalousie windows, it is expected that jalousie windows finished with absorbent lining either on both side or only on the inner side would offer more significant noise reduction [Thomas, 1996].

13.2.4 Conclusion on the capability of the jalousie windows to reduce outdoor noise

The calculation shows that the proposed window design in combination with the surrounding walls can reduce noise by 15 dBA to 20 dBA. This is significantly greater than that provided by conventionally designed houses, such as one used for the field experiment to examine the capability of windows in reducing noise, which reduced noise by 10 dBA to 12 dBA. There is no conclusion could be made from field trials related to the ability of ordinary timber jalousie windows in reducing outdoor noise, as the reduction offered by these windows was insignificant. However, as mentioned, it is expected that timber jalousie windows finished with absorbent lining on both side or only on the inner side would offer more significant reduction in real conditions [Thomas, 1996]. A detailed laboratory test is required to calculate this.

PART V

DESIGN GUIDANCE

CHAPTER 14
DETAILED DESIGN OF VERTICAL BUILDING ELEMENTS

The previous chapters have studied and examined the vertical building elements which can limit the amount of fine airborne particulates and noise entering the house. This chapter will describe the detailed design of such vertical elements.

14.1 Design Planning

14.1.1 Improving regulations applied to vehicles and traffic

Ideally, the first aspect to consider in reducing particulate matter and noise pollution is the regulations applied to vehicles and traffic, as these will involve less cost and provide better results compared to other treatments. From the discussion in the earlier chapters, there are several regulations in Indonesia which need to be improved, particularly those related to traffic pollution:

1. Traffic regulations to limit access of heavy vehicles to certain streets, especially residential streets. This is expected to reduce the emission and noise through residential areas.
2. Traffic regulations to limit public transport from stopping and loading passengers by strictly determining bus stops. It is expected that this will reduce the number of traffic jams and thus reduce vehicles' idling time, which also means reducing the emissions and noise that are generated by stationery (idling) vehicles.
3. Regulations to limit the use of poor quality vehicles including poor quality and noisy silencers. This will reduce the total emissions and noise.
4. Regulations to encourage the use of four- stroke motorcycles to reduce noise. The significant difference between two-stroke and four-stroke motorcycles is that four-stroke motorcycles, due to their combustion systems, produce less noise. The difference between the two combustion processes in relation to emission standard was not been studied in detail. However, it is likely that this type of engine produces more emissions, as air and fuel (i.e. gasoline) passes a lubrication oil chamber before entering the combustion chamber. This brings some of the lubrication oil into the combustion chamber which generates darker exhaust. Within four-stroke engines, air and fuel (i.e. gasoline) go straight to the

combustion chamber, so that lubrication oil is not included in the combustion system [Ganesan, 1994]. This explains why four-stroke motorcycles generally produce fewer emissions.

Because it takes many years for new regulations to be implemented in Indonesia, any attempts to reduce pollutants from street traffic should be focused on the improvement of the receiver conditions, even though this means higher cost. In this case, improvements need to be focused on buildings (i.e. houses), particularly as people spend most of their time indoors.

14.1.2 Global planning of low- cost housing in Yogyakarta

In order to achieve the best design for new low-cost houses, it is important to consider overall planning as it relates to the specific conditions in Yogyakarta. Thus the design will become a "green design" which will create a symbiosis with its environment.

- Site

  It is generally believed that new low cost houses should be built away from the city centre, so that for the same price, the owners will get larger areas, whilst also avoiding traffic pollution. However, in this case there will be more transportation generated, since most people still work and pursue their leisure within the city centre. This generates more emissions and more noise. So, it seems that the most practical solutions are not to avoid the problems, but to overcome them. Hence, whether the location of the housing is within the city centre or city boundaries, it is necessary to draw up regulations which limit the numbers of heavy and commercial vehicles passing through residential streets and streets that are adjacent to residences.
- Housing plan (orientation, building layout and open space/courtyard)

  A north-south orientation is suggested to avoid east and west solar radiation. However, since the street in front of the house will be relatively narrow, it is unlikely that the house will be subject to perpendicular wind, thus, the purpose of the orientation is mostly to avoid solar radiation. This orientation then should allow openings such as doors and windows, particularly glass windows, to be placed in positions where they are not exposed to solar radiation.

Where the space for low cost housing is limited, it is important to create a building layout which provides more open spaces to induce air motion and create possibilities for openings to face away the pollution source. The best building layout is L-shape since a U-shape is not practical for a house occupying a small area. The L-shape permits the house to have more openings facing away pollution and permits designers to place public rooms on the outer side and private rooms on the inner side.

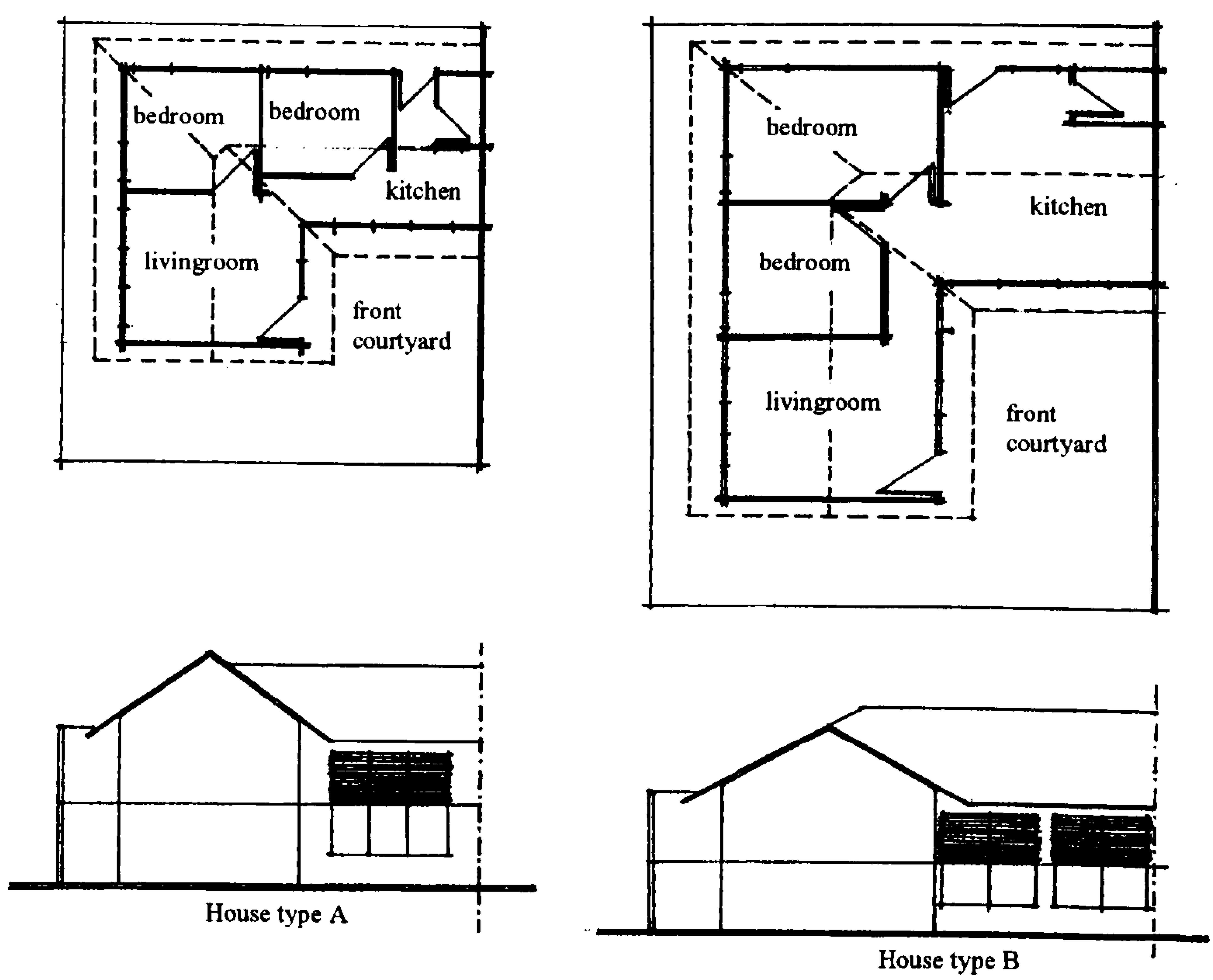


Figure 14.1. Detailed building layouts of the proposed designs

- Facades (general appearance of the house including roofs)

  There is not any significant difference in the facade of the proposed house compared to conventional facades. The roof of the new house will still be triangular, but will be slightly higher compared to the current roof, as the new house has an angle of 35° compared to ordinary angle of approximately 30°, as shown in Figure 14.2. The increase in roof height is suggested by Kindangen to induce a higher rate of ventilation [Kindangen, et al, 1997].

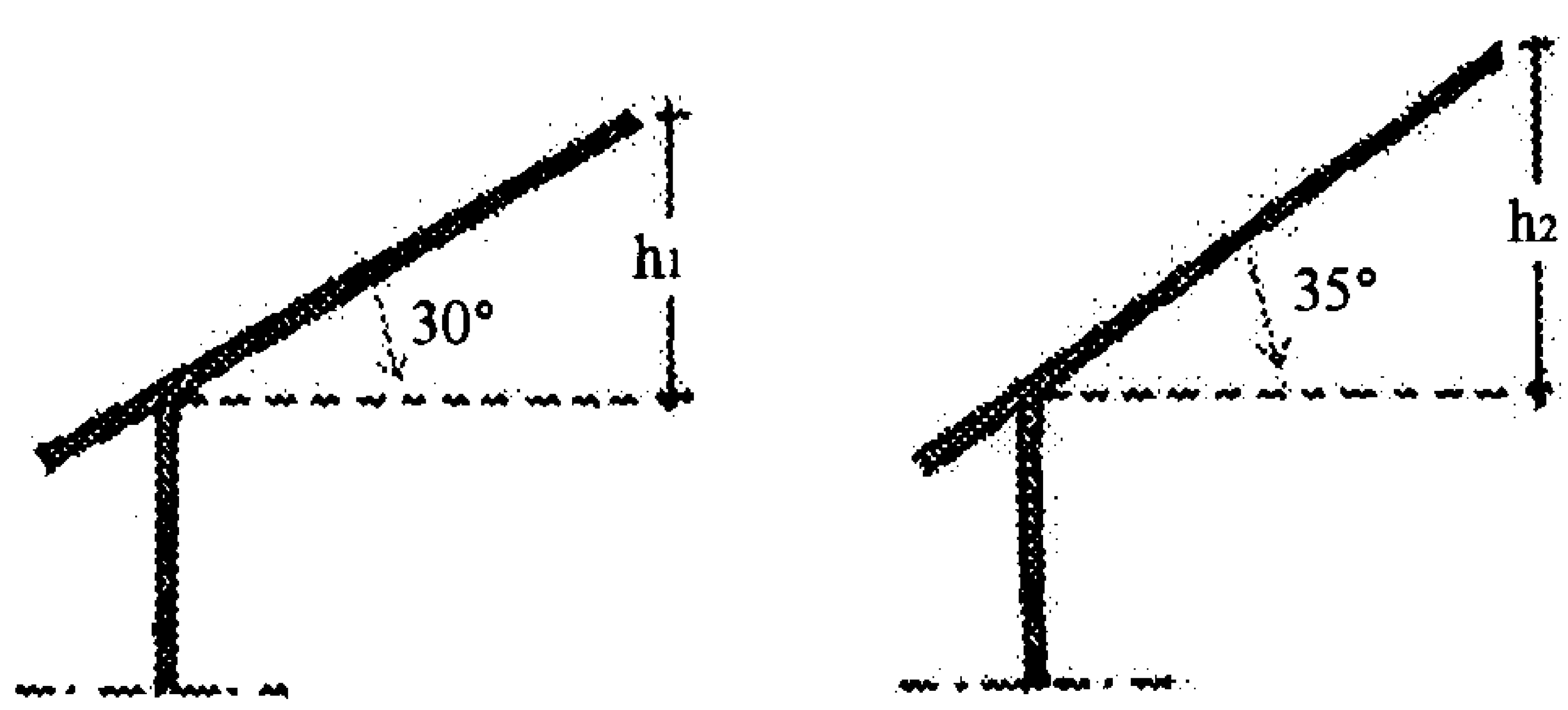


Figure 14.2. Pitched roof of 30° and 35°, $h_2 > h_1$

To induce greater indoor air motion and provide comfort cooling with approximately 30 air changes per hour (ach), the use of roof openings on the leeward wind is suggested. The number of suggested roof openings is between one and three.

Because the roof openings are on the leeward side, the new housing design will have insignificant difference in the front facade. The difference can only be seen in the positions and styles of the windows.

14.2 Detailed design

14.2.1 Design for the facade including roof

As Kindangen [Kindangen, et al 1997] proved that triangular roofs with higher pitch angle were capable of inducing more indoor air motion, it is proposed that the angle be increased from 30° to approximately 35°, which will increase the roof height accordingly. The suggested roof material is similar to the conventional material i.e. clay tiles. This will give benefits in maximising the roof slope up to 35°, since asbestos or zinc materials usually require an angle of approximately 25° for safety reasons. Small clay tiles help roof openings to draw hot indoor air through the gap between the tiles and also rain falling on the roof produces less noise.

As mentioned earlier, the use of roof openings in the leeward side of the roofs is also suggested, particularly for a house where heat-generating activities, such as cooking, are carried on.

14.2.2 Fence as barriers

The fence is the first vertical barrier against fine particulate matter and noise. It was shown that by using a solid fence, particulate matter could be reduced by up to 11% (varying in reality depending on wind speed and wind direction). But considering that the wind speed was consistently low throughout the experimental period and throughout the year in Yogyakarta, it was wind direction that mostly affected particulate matter dispersion.

This solid fence could also reduce noise up to 10 dBA compared to most porous Indonesian fences which provide very small noise reduction. The detailed design of the fence for these purposes is described in the following sections.

14.2.2.1 Position

Fences that will significantly reduce fine particulate matter and noise should be placed close to the receiver to maximise the 'sound shadow' effect. In this case, this is parallel to the street and at the outer edge of the front courtyard (or at the near edge of the kerb), as shown by Figure 14.3. This is a common position for a fence in Indonesian housing.

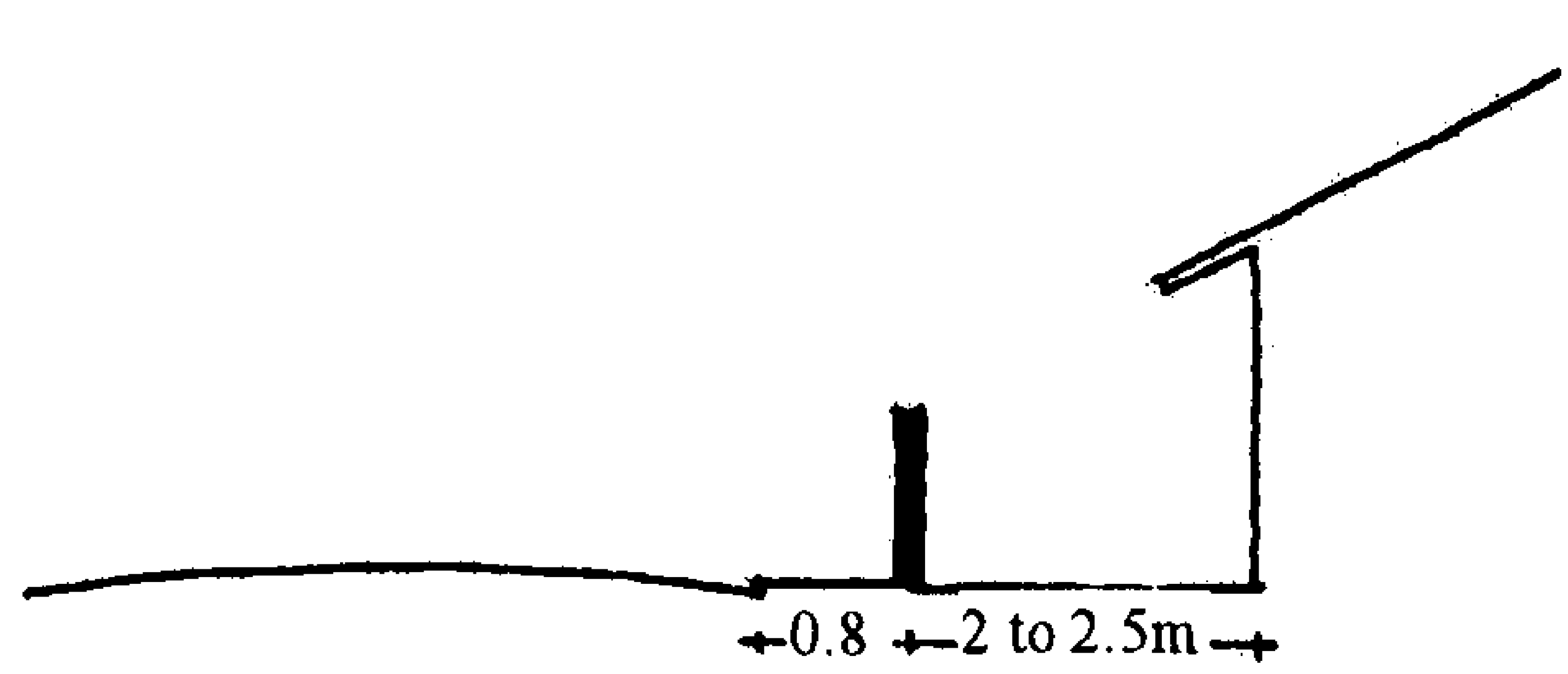


Figure 14.3. Solid barrier is placed at the near edge of the kerb.

14.2.2.2 Dimensions

As calculated in the earlier chapters, particularly in Chapter 11, the fence should be as long as the length of the front courtyard, with a sufficient gap for a gate for access. The suggested height averages approximately 1.1m to 1.5m. This is based on the CFD experiments and calculations of barriers for reducing noise. The presence of gate will not detract the capability of the fence in reducing noise, as the windows are installed in a position shaded by the solid fence. Figure 14.4 sketches the suggested barrier dimensions.

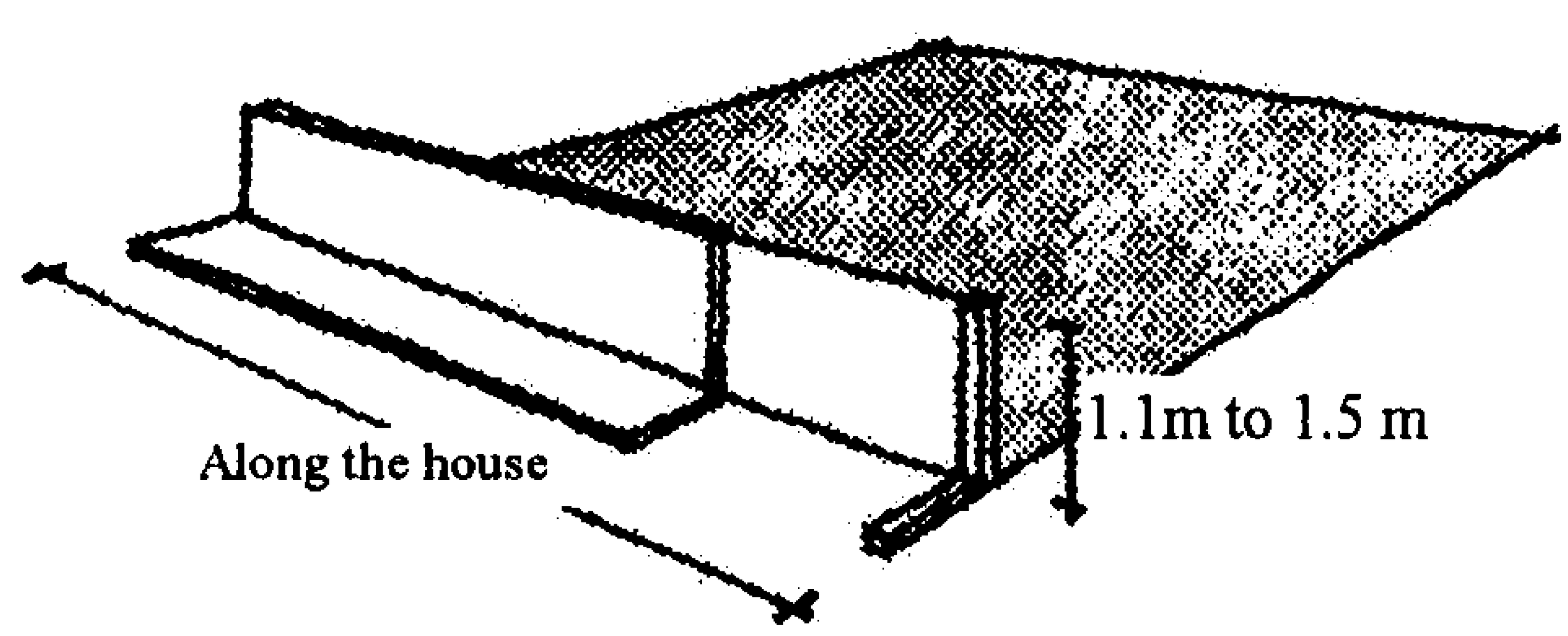


Figure 14.4. Suggested barrier dimensions: along the front line of the house with heights approximately 1.1m to 1.5m, depending on the type of the house

14.2.2.3 Style, material and surface finishing

The suggested fence is a solid barrier with a minimum density of approximately 5 to 10 kg/m^2, which can be achieved by using 15 cm red brick or 15 cm concrete or prefabricated concrete (grey brick), as the most common building materials used for low cost houses. However, solid and massive fences are usually dull and unaesthetic. A combination of a solid fence and vegetation is suggested particularly as it was proved that vegetation could also reduce fine particulate matter.

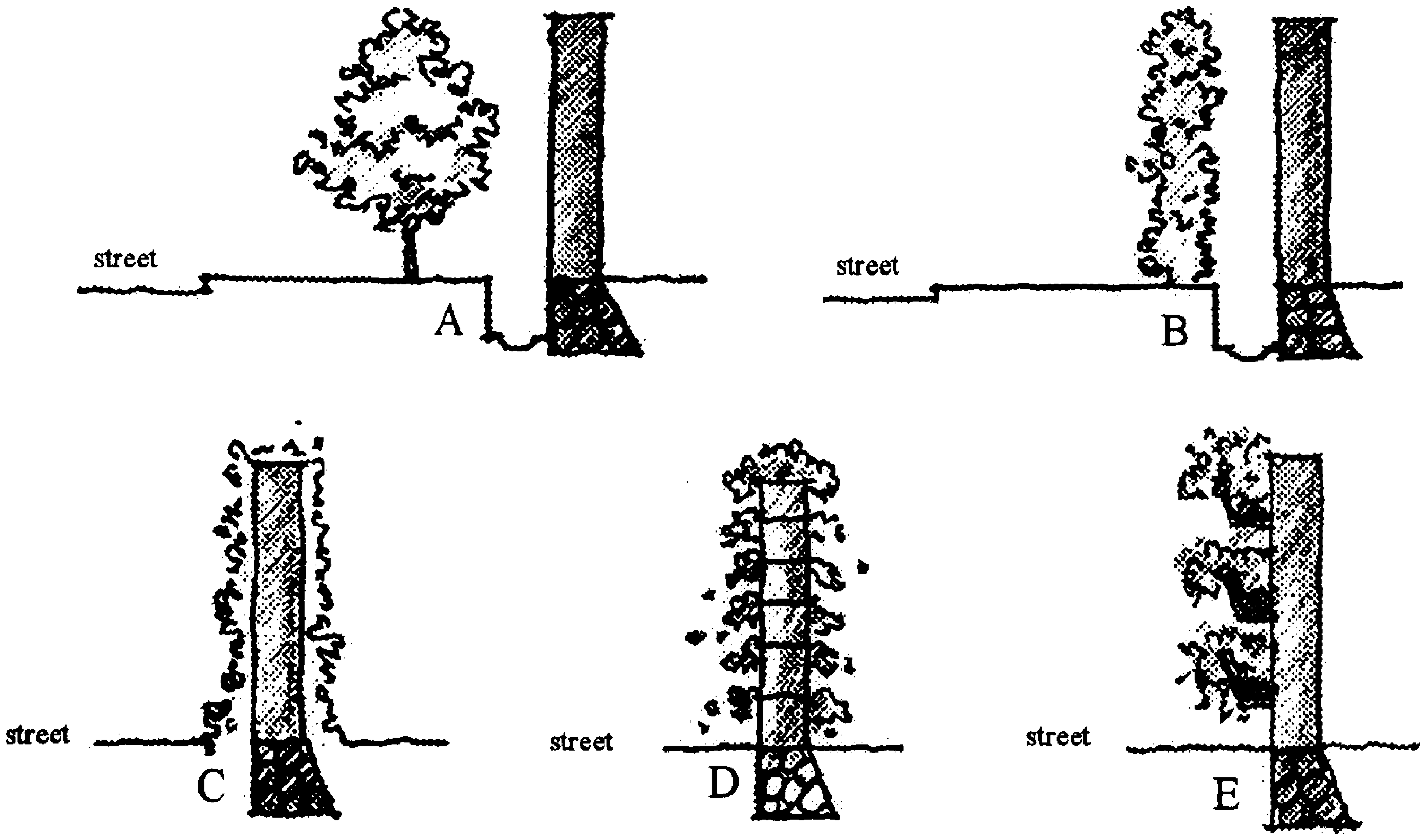


Figure 14.5. Suggestions for using solid barrier combined with plants
(Source: the author; some are adapted from Lord and Templeton, 1996)

A. Section of solid barrier with several single shrubs in front after drainage
B. Section of solid barrier with continuous shrubs in front after drainage
C. Section of solid barrier directly covered with climbing plants
D. Section of solid barrier from prefabricated hollow concrete with climbing plants
E. Section of solid barrier with fix cement plantation bucket

If possible, it is also suggested to use sloped fencing. This will reduce more noise by reflecting the noise upward. Figure 14.6 shows that a sloped fence reflects the noise above the house, whilst an ordinary fence reflects noise off the opposite fence several times and thus increases the sound pressure levels within the street. The house with the narrowest street (approximately 4 m to 5 m wide) and the narrowest front courtyard (approximately 2 m wide) was used to calculate the degree of slope and thus the increase of fence thickness. In this case, the height of the fence is approximately 1.5 m, and the noise source is assumed to be in the middle of the street 0.5 m above the ground [White, 1982].

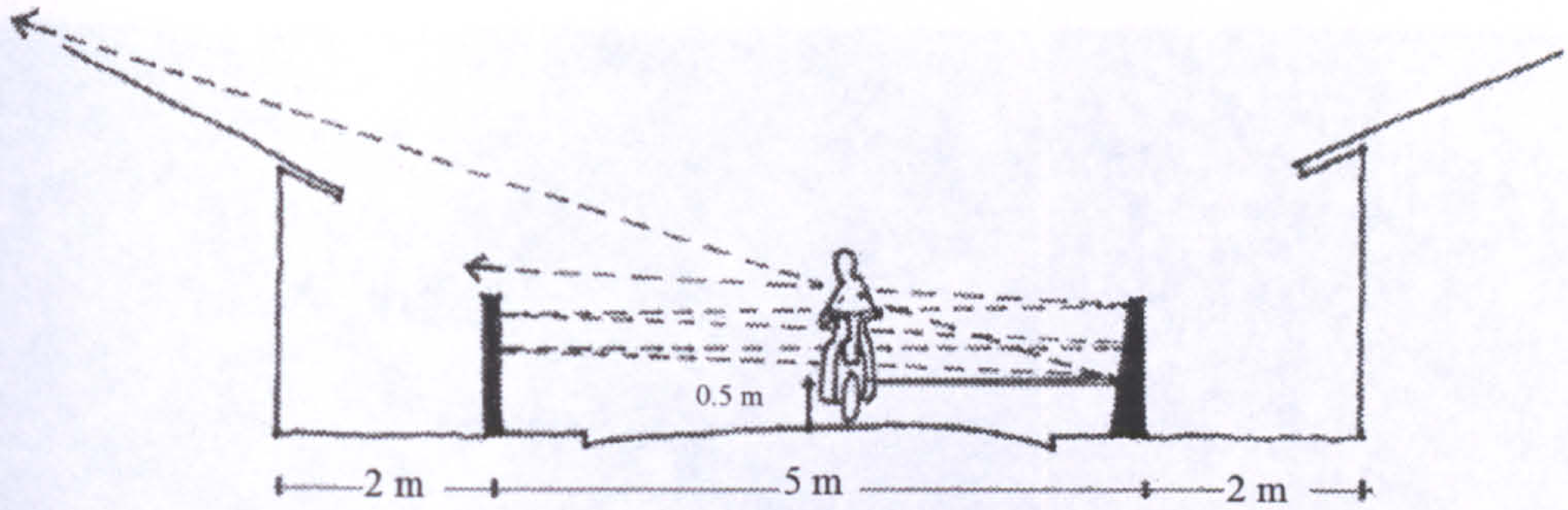


Figure 14.6. The paths of the reflected noise with sloped fencing and ordinary fencing.

In this housing condition, to reflect the noise above the opposite house, a fence approximately 1.5m high needs to increase the thickness to approximately 50 cm, which is twice the common thickness of 25 cm. By sloping both sides, the fence thickness will be approximately 75 cm (Figure 14.7). However, in a narrow street and a narrow front courtyard, it seems that one sloping side is more practical.

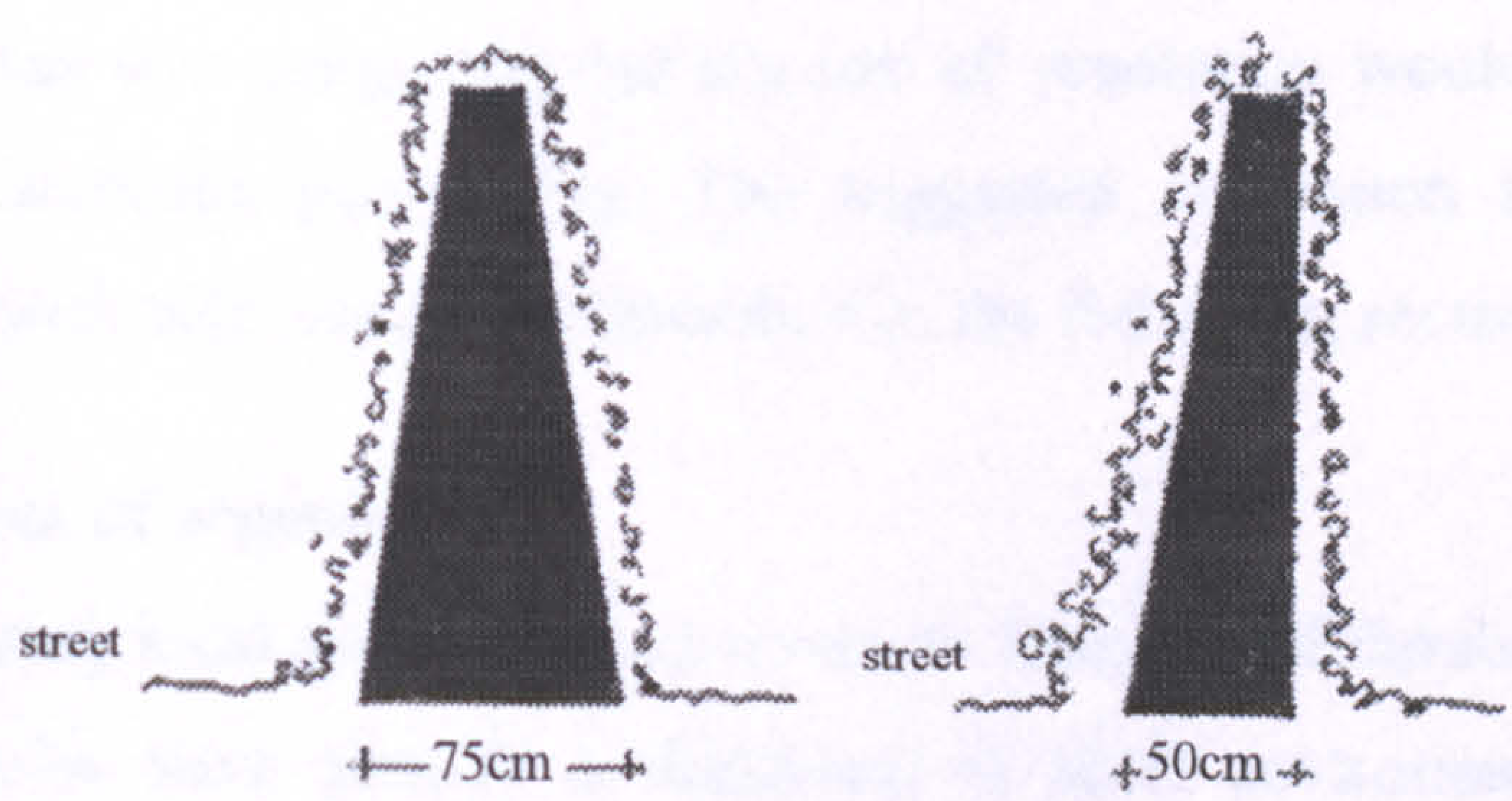


Figure 14.7. Detailed thickness of two sloped barrier types.

Some combinations of a fence and vegetation have already been implemented in Indonesia and other countries, as can be seen in the Figures 14.8 and 14.9.


Figure 14.8. Continuous shrubs after drainage (Source: the author)

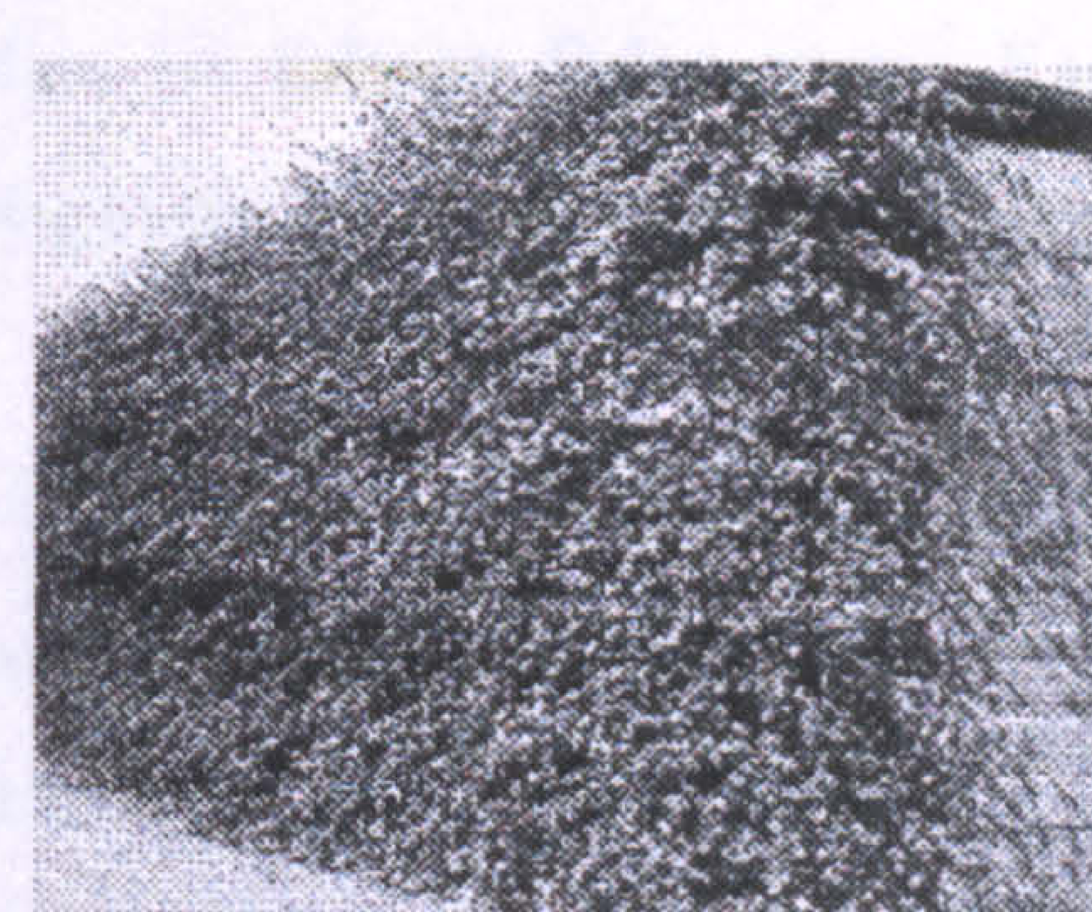


Figure 14.9. Solid fence covered by climbing plants (After Prockter, 1973)

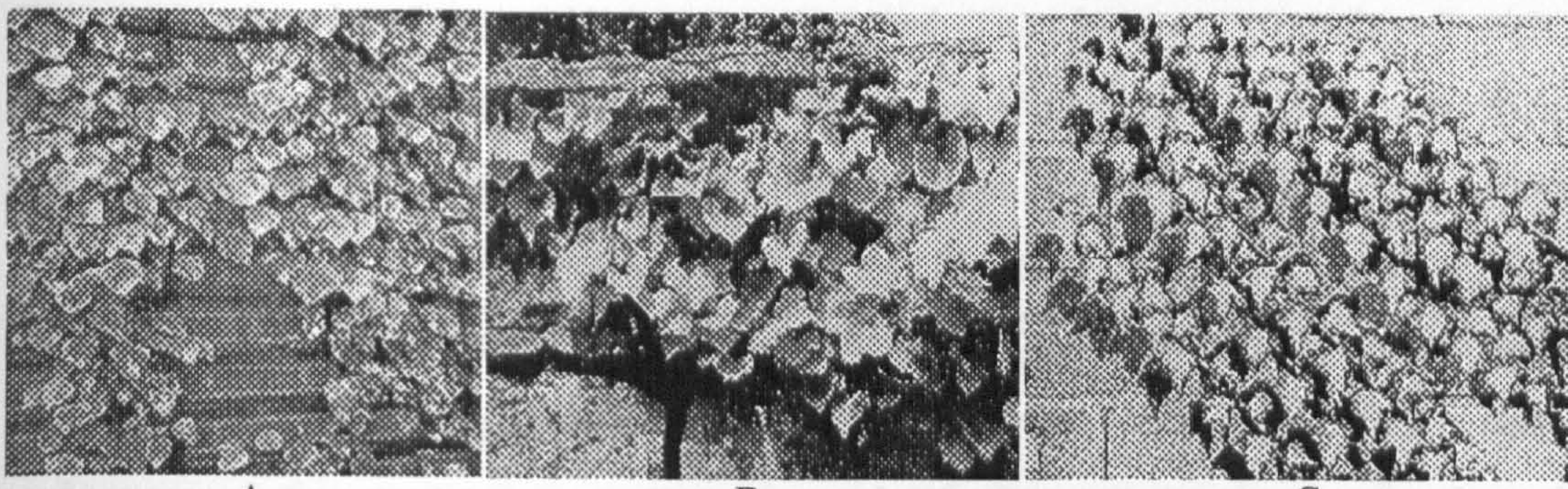


Figure 14.10. Several types of climbing plant for use in combination with solid barriers (A (After Prockter, 1973), B and C (After Lloyd, 1973))

14.2.3 Vegetation

It was mentioned earlier that even without any particular purpose, the use of vegetation in building designs would provide many benefits for the building and thus the occupants, such as creating a better facade and reducing solar radiation by its shadow. It was also suggested that the use of vegetation would in addition help to reduce fine airborne particulates. The suggested vegetation types to be used in conjunction with solid fence are described in the following sections.

14.2.3.1 Types of vegetation

By using local species, the cost can be limited and durability can be achieved as local species have already acclimatised to local environments. Other essential criteria are that the vegetation should be dense in foliage, easy to grow, easy to regenerate and easy to maintain. Dense in foliage means that the leaves are mostly overlapping to provide minimum porosity. Easy to grow means that the vegetation only needs months or at most a year to grow to its full height. Easy to regenerate means that the vegetation is easy to regrow when its foliage fades away. Easy to maintain means that when the vegetation is overgrown it can be easily reshaped by cutting or other simple treatment.

As is indicated in Chapter 12, there are several types of vegetation that may fulfil the above criteria whilst also being capable of depositing fine airborne particulates. Some of these were tested during the field experiments. Generally, most bushes, shrubs or climbing plants that fulfil the criteria specified above and which have dense foliage can be used for fine particulate matter reduction purposes to use

The species listed in Chapter 12 are recommended. The plants to be combined with a solid fence based on model A or B in figure 14.4 are Allamanda schotii, Ixora coccinen, Rosa sp., Sanseveira cylindrica, Lantana camara, Jasminum sambac, Duranta repens and Raphis exelsa. Whilst to be combined with solid fence based on model C, D or E in Figure 14.4 are Codiaeum veriegatum, Murraya paniculata, Polyscias fruticosa, Bougainvillea spectabilis, Gardenia florida. To achieve better reduction of fine particulate matter, the use of Duranta repens or Stephanotis Floribunda is suggested, as it has already been shown in the field experiment that these plants have the highest capacity for depositing particulate matter compared to other types of vegetation tested. It is also expected that similar vegetation with slightly furry leaves would also filter particulate matter effectively.

14.2.3.2 Spatial arrangements

The suggested spatial arrangement of the vegetation can be easily achieved by low income families and is based on the limited space of the front courtyard. The first suggestion is to plant low-growing vegetation (bushes or shrubs) in front and along the solid fence or to use climbing plants to cover the whole solid fence. The use of climbing plants may give benefits as climbing plants can also cover the fence gates and thus reduce the porosity of the gates. Bushes or shrubs of similar height to the solid fence are recommended. Once the vegetation is higher than the fence, the vegetation should be trimmed to the height of the fence. Low-growing vegetation that has the same height as the solid fence would not obstruct the required airflow. Planting low-growing vegetation or climbing plants in the front courtyard will also help to deposit particulate matter before it enters the houses. In the case when there are climbing plants of approximately 1 to 1.5 m in front of the windows, the air will not be supplied perpendicularly (due to obstruction by the vegetation), but from either side and above the vegetation.

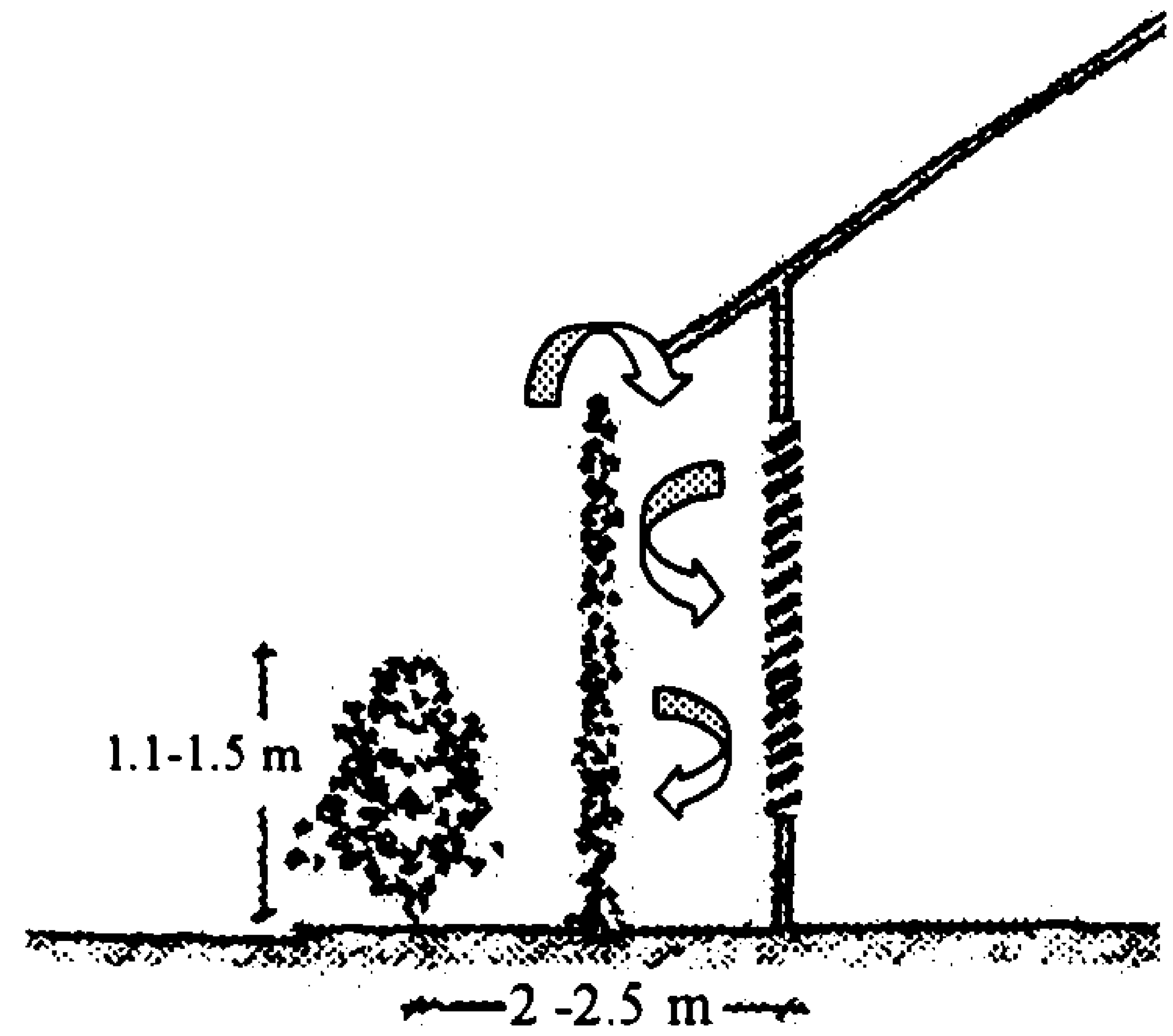


Figure 14.11. Spatial arrangements between low-growing and tall vegetation (climbing vegetation and its frames).

14.2.3.3 Climbing plants

Both CFD and field experiments indicated that climbing plants might reduce fine particulate matter, especially if these are denser in foliage than those used in the experiments. However, the use of climbing plants parallel with fence barriers positioned approximately 1 m in front of the windows is not recommended for the new housing layout (L-shape), which already has open windows positioned away from the pollutant source. Figure 14.11 shows that the presence of climbing plants will be useful for opened windows that have already been installed facing pollutant sources.

14.2.4 Windows and other openings

14.2.4.1 Windows

Both computational simulation and field trial gave no clear indication on the use of an open window (i.e. jalousie window) to reduce fine particulate matter. According to the CFD simulation, the reduction values offered by jalousie windows were only 0.1% higher than those offered by casement windows. The CFD also showed that when the windows are adjacent to high neighbouring walls, the concentrations beyond the jalousie windows were higher than those were beyond casement windows. The second field trials showed that the concentrations beyond the jalousie windows were always lower than those were beyond the casement windows. However, the reduction values varied considerably and thus precise reduction values offered by jalousie windows could not be provided in this study. As shown by the CFD experiment, it was the configuration of fence, climbing vegetation, and jalousie windows that reduced the indoor particulate matter concentration of approximately 16 % less than the street concentration. Regardless of the inconclusive result on the study of jalousie windows, the use of jalousie windows is still proposed as these windows may reduce some of the outdoor dirt from entering the house.

Both manual calculation and field trials showed that the same configuration of elements used to reduce fine particulate matter could reduce noise by approximately 15 dBA in both house type A and B. This is the minimum insulation value offered by walls closest to the noise source. The total noise reduction is 24 dBA to 25 dBA. The 24 dBA noise reduction comes from 9 dBA reduction of barriers adjacent to street type A added to the minimum insulation offered by house type A of 15 dBA. The 25 dBA insulation comes from 10 dBA reduction of barriers adjacent to street type B added to the minimum insulation offered by house type B of 15 dBA. Detailed design for the suggested windows is as follows:

14.2.4.1.1 Orientation and position

The best orientation for windows according to most theories is an orientation that permits wind to enter obliquely. This will enable the window to supply air to most of the room's corners [Lechner, 1991]. This condition can be achieved by the oblique wind that is created by the narrow streets in front of the house. It is suggested that opened windows be placed away from the pollution source i.e. in the side walling rather than in the front walling.

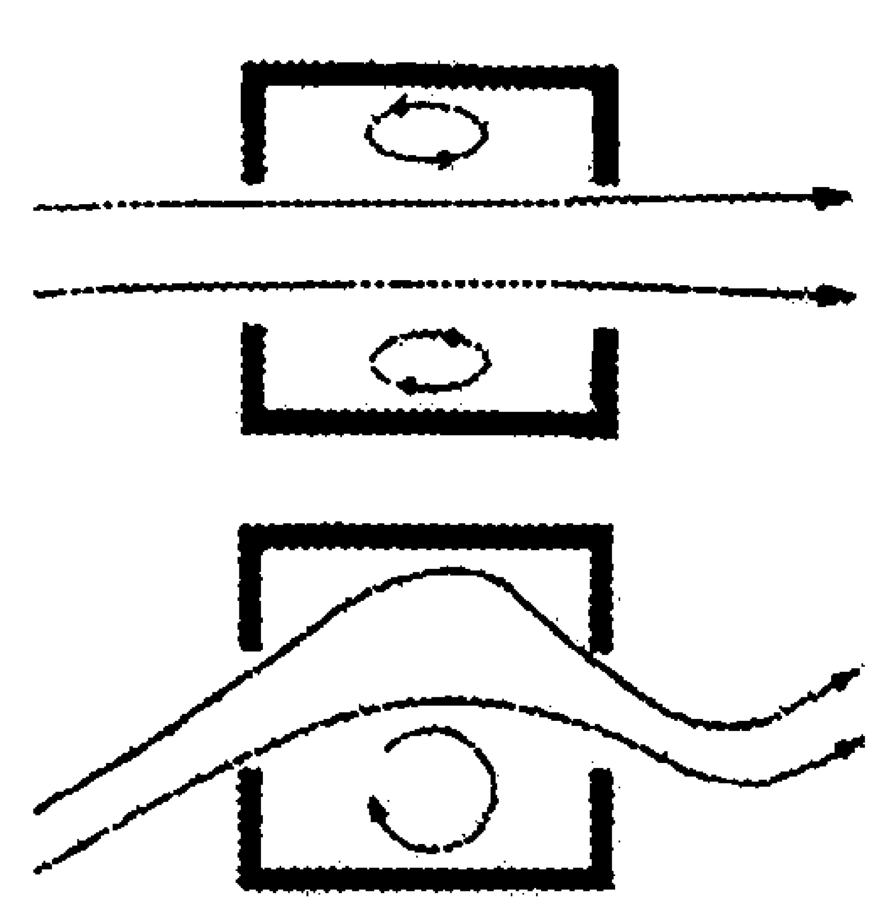


Figure 14.12. Plan of two rooms each with parallel and oblique wind direction.
It can be seen that oblique wind direction will ventilate most of room area.
(After Lechner, 1991)

14.2.4.1.2 Style

As mentioned, the use of jalousie window is still proposed as this may reduce some of the outdoor dirt from entering the house. As described in Chapter 9, in using this type of window, the windows should be installed slightly lower than the occupant levels, as louvre windows deflect air slightly upwards. There are several other factors to consider in using this type of window in Yogyakarta.

Single-side hung jalousie windows are likely to give more benefits to the Yogyakartanese. This type of window will permit occupants to have a full casement window if they need more air changes per hour (when indoor temperature increases caused by either occupant activities or the increase of external temperature). When the casement system of the jalousie windows is used (the windows open widely), the intrusion of pollution may increase accordingly. In using this type of window, a good sealant should be installed around the window edges, both between window frames and walls and between window frames and casements. This is to prevent noise intrusion when the casement is closed.

The use of a fly or mosquito screen should also be considered. This is important for comfort and health, particularly at night, and is designed to slide aside during the day. The presence of a fly and mosquito screen will reduce the supplied air changes per hour (ach), caused by the increase of window (surface) resistance. At night this is less important as night temperatures are slightly lower than day temperatures, and thus fewer air changes per hour are required.

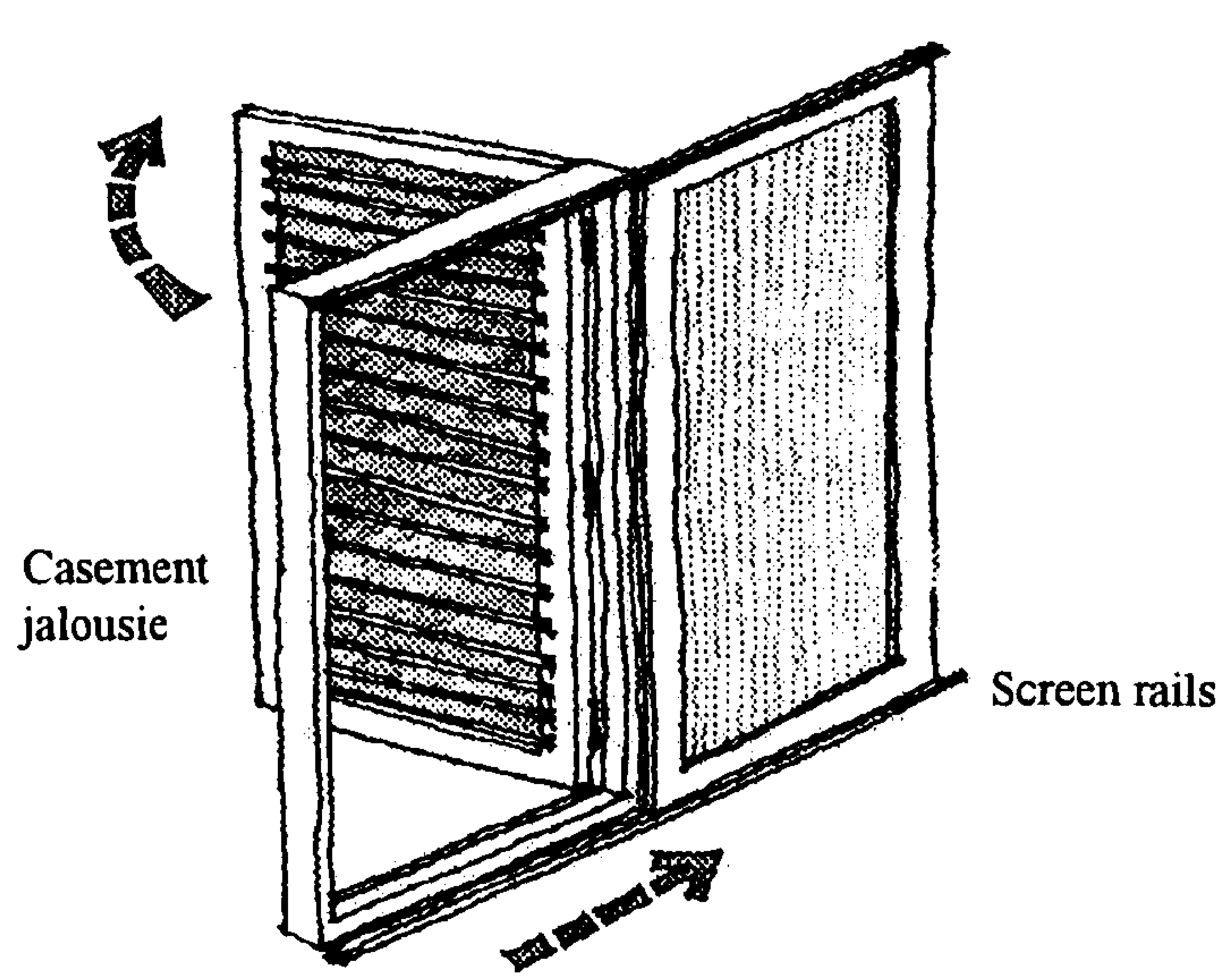
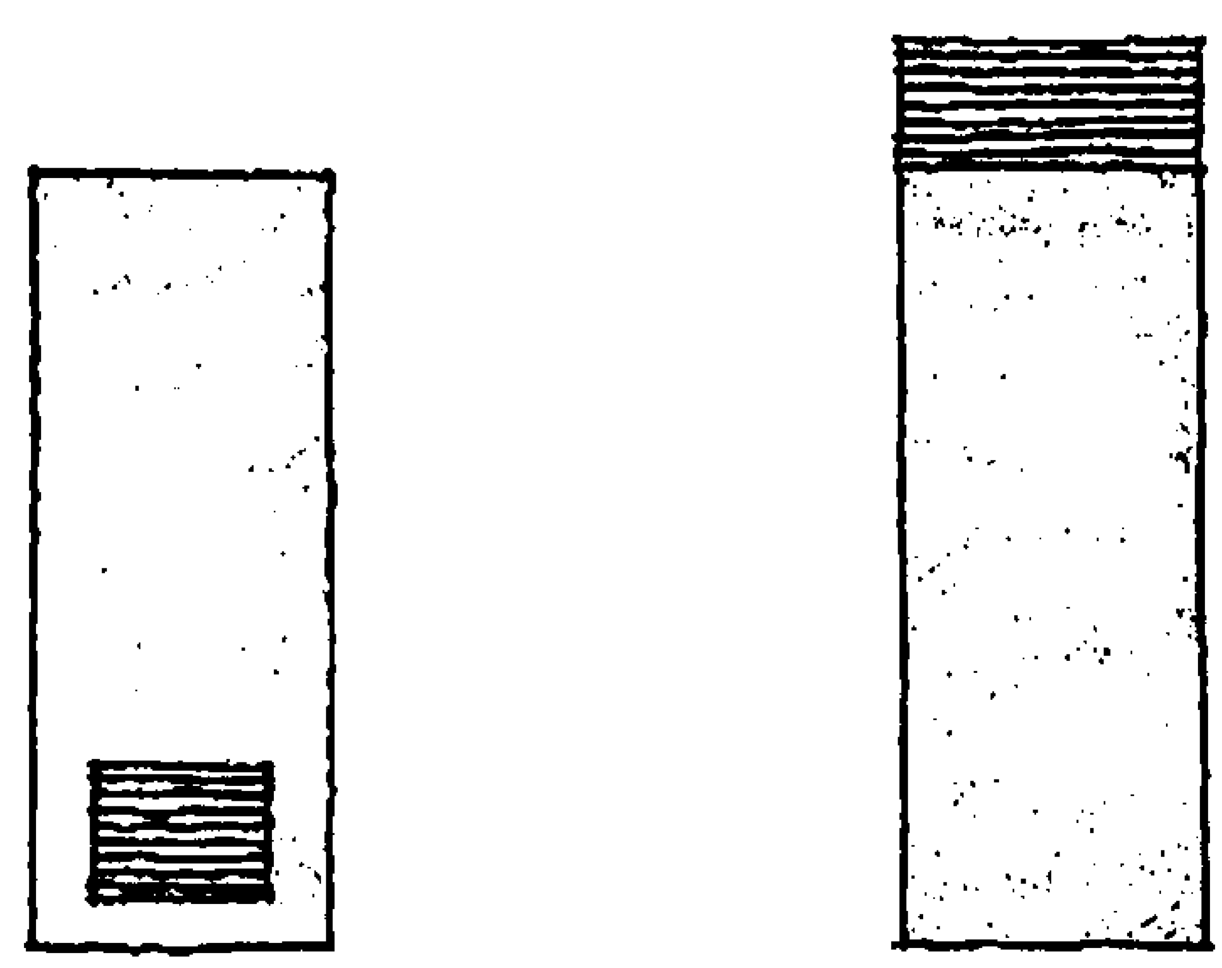


Figure 14.13. Detailed window design.

Private rooms, which are placed away from the noise source, may use normal full casement windows to provide more air changes per hour, particularly those windows placed in the rear wall, which do not experience either prevailing or oblique winds. In order to supply more air changes per hour in these rooms, the use of jalousie doors is suggested, as this may permit air from public rooms to flow to private rooms. Jalousie openings with angle of approximately 45° will still give privacy for the room from view. The use of jalousie openings above doors will help to remove heat from rooms if the doors function as outlet openings. But if doors are design to supply air into rooms (as inlet openings), it is better to have jalousie openings at the bottom of the doors or slightly below the occupant zone to easily ventilate the occupant zone as described in Chapter 9, and it will be best to have the door louvred throughout its height.



A B

Figure 14.14. Detailed design of the suggested internal doors function as inlet (A) and function as outlet (B)

From the net insulation calculations in Chapter 13, it is still possible to install closed glass windows in the front wall for view. According to the net insulation calculation based on the insulation values of opened windows (of approximately 12 dB), the minimum glass thickness for this view window is approximately 2 mm. Glass windows with 4 mm thickness will provide insulation values of approximately 25 dB. However, for long use, safety and security reasons, glass windows with 6mm thickness are suggested: the thicker the glass used, the greater the net insulation achieved.

Glass thickness	Mean sound insulation (100 to 3150 Hz) in dB
2 mm	18
4 mm	25
6 mm	27
6 mm (laminated)	29
8 mm	29
10 mm	30
12 mm	31
12/14 mm (nominal laminated)	34

Table 14.1. Sound insulation values of glass in various thickness
(After Templeton and Saunders, 1987)

14.2.4.1.3 Number of windows

According to the ventilation flow rate calculations, the appropriate numbers of window to obtain the required air changes per hour (i.e. 30 ach when external wind speed v= 0m/s) are shown by Figure 14.15 and Table 14.2.

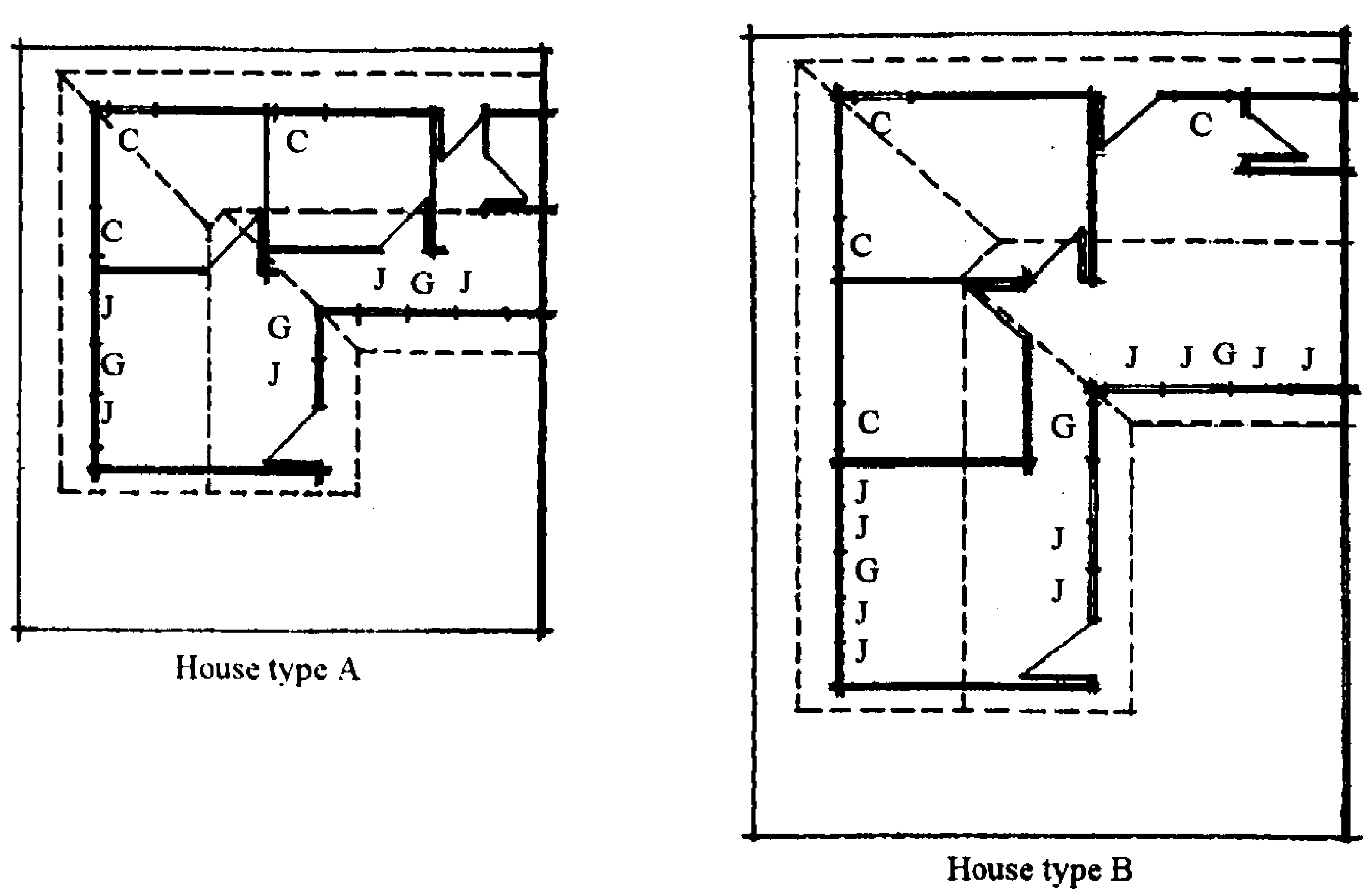
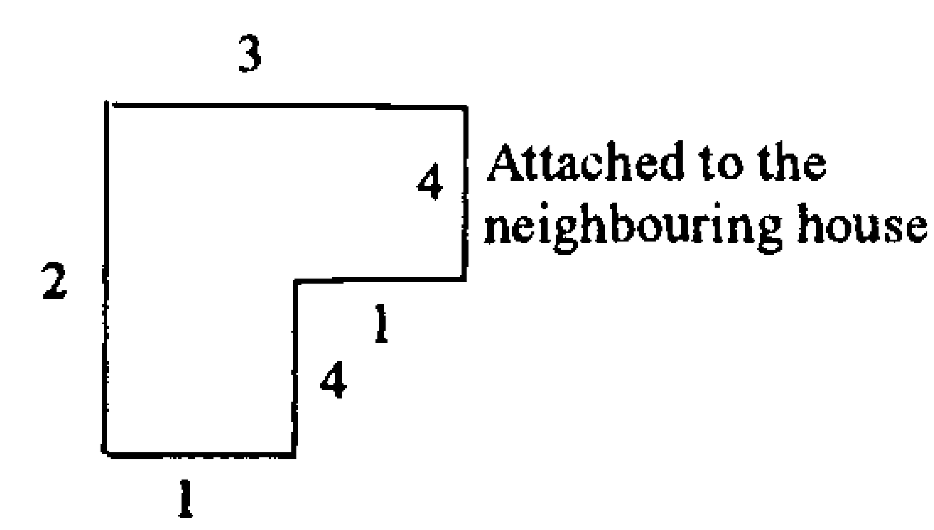


Figure 14.15. Position of the suggested windows
Keys: J = jalousie, C = casement, G = closed glass

	Number of windows	Number of openings	Types
House type A			
surface 1	3	-	2J and 1G
surface 2	4	-	3C, and 1G
surface 3	2	1 (opened door)	2C
surface 4	2	-	1J and 1G
House type B			
surface 1	5	-	4J and 1G
surface 2	7	-	6C, and 1G
surface 3	2	2 (opened door and upper opening)	2C
surface 4	3	-	2J and 1G

Table 14.2. Detailed number of windows

Key of surfaces:



14.2.4.1.4 Dimensions

According to the ventilation flow rate calculations, each window type that is suggested should have specific dimensions in order to obtain the required air changes per hour (i.e. 30 ach when external wind speed v= 0m/s and temperature difference $\Delta t \neq 0$). The detailed window dimensions can be seen in the following table:

	Types of windows and openings	Dimensions
House type A		
surface 1	2 jalousie	J = 0.65 x 1.6m², 0.6 a.g
surface 2	3 casement	C = 0.65 x 1.3 m², 0.9 a.g
surface 3	2 casement and back door as casement	C = 0.65 x 1.3 m², 0.9 a.g Door = 0.75 x 1.8 m²
surface 4	1 jalousie	J = 0.65 x 1.6 m², 0.6 a.g
Total opening areas		8.7 m²
House type B		
surface 1	4 jalousie	J = 0.65 x 1.6 m², 0.6 a.g
surface 2	6 casement	C = 0.65 x 1.3 m², 0.9 a.g
surface 3	2 casement, back door as casement and 1 upper opening	C = 0.65 x 1.3 m², 0.9 a.g Door = 0.75 x 1.8 m² O = 0.5 x 0.2 m², 1.8 a.g
surface 4	2 jalousie	J = 0.65 x 1.6 m², 0.6 a.g
Total opening areas		14.5 m²

Table 14.3. Detailed window dimensions (a.g = above the ground)

14.2.4.1.5 Material

Due to low budget, timber is the most practical material for jalousie windows. This material is also adequate to the demand for pollutant reduction and durability. However, in order to increase their durability and capability to deposit particulates, these timber windows should be finished with a special paint or varnish.

14.2.4.1.6 Accessories

A jalousie window does not need any extra screens to reduce glare and solar radiation. However, in a country with a high rain fall like Indonesia, a screen to protect the window materials from either rain or solar radiation is also suggested. This increases the durability of the timber windows and is of significance when the window is used in a bigger house. Bigger houses usually have a wide gap between the window and the lower edge of the roof. A small house such as is under discussion here will generally not need any sun screens to protect the windows, as the walls are relatively low, and so are close enough to the lower edge of the roof to be protected from the rain.

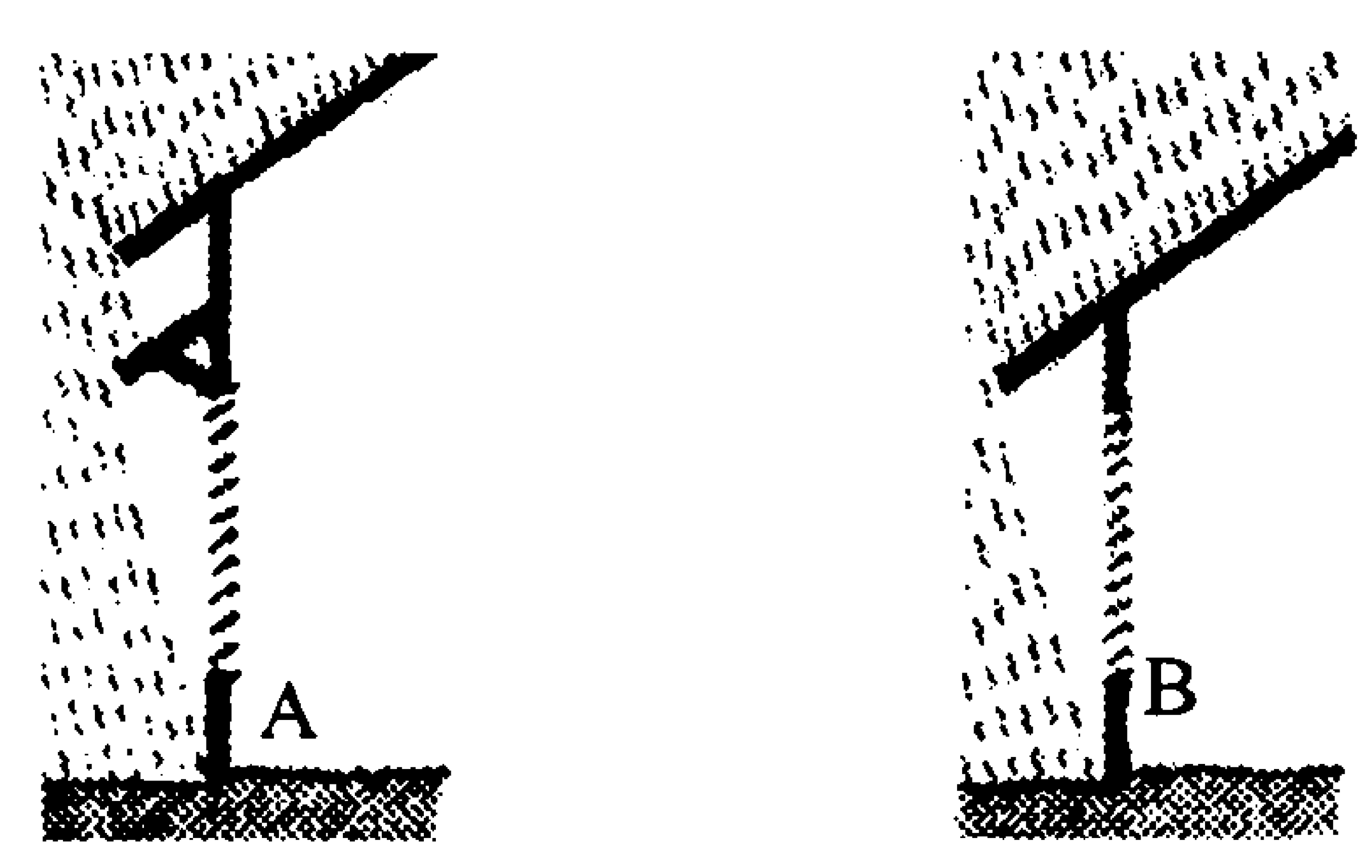


Figure 14.16. High roofs which need additional sun screens (A) and short roofs which are automatically protect the windows (B).

When installing sun screens or overhangs, the style of the sun screens should not obstruct the airflow and, ideally, should induce greater indoor air velocities. As suggested by Lechner, overhangs that are placed high above the windows or overhangs with approximately 15cm horizontal gap will help the jalousie windows to ventilate the occupant levels [Lechner, 1991]. However, as the areas in the walls are very limited the use of high overhangs seems impractical; moreover, the wide gap between the windows and the overhangs offer little protection from rain.

Detailed design of the suggested overhangs comprises both a horizontal gap of approximately 15 cm and a small roof to cover the gap, thus protecting the window from rains while still permitting air to flow toward the window, as can be seen in Figure 14.17.

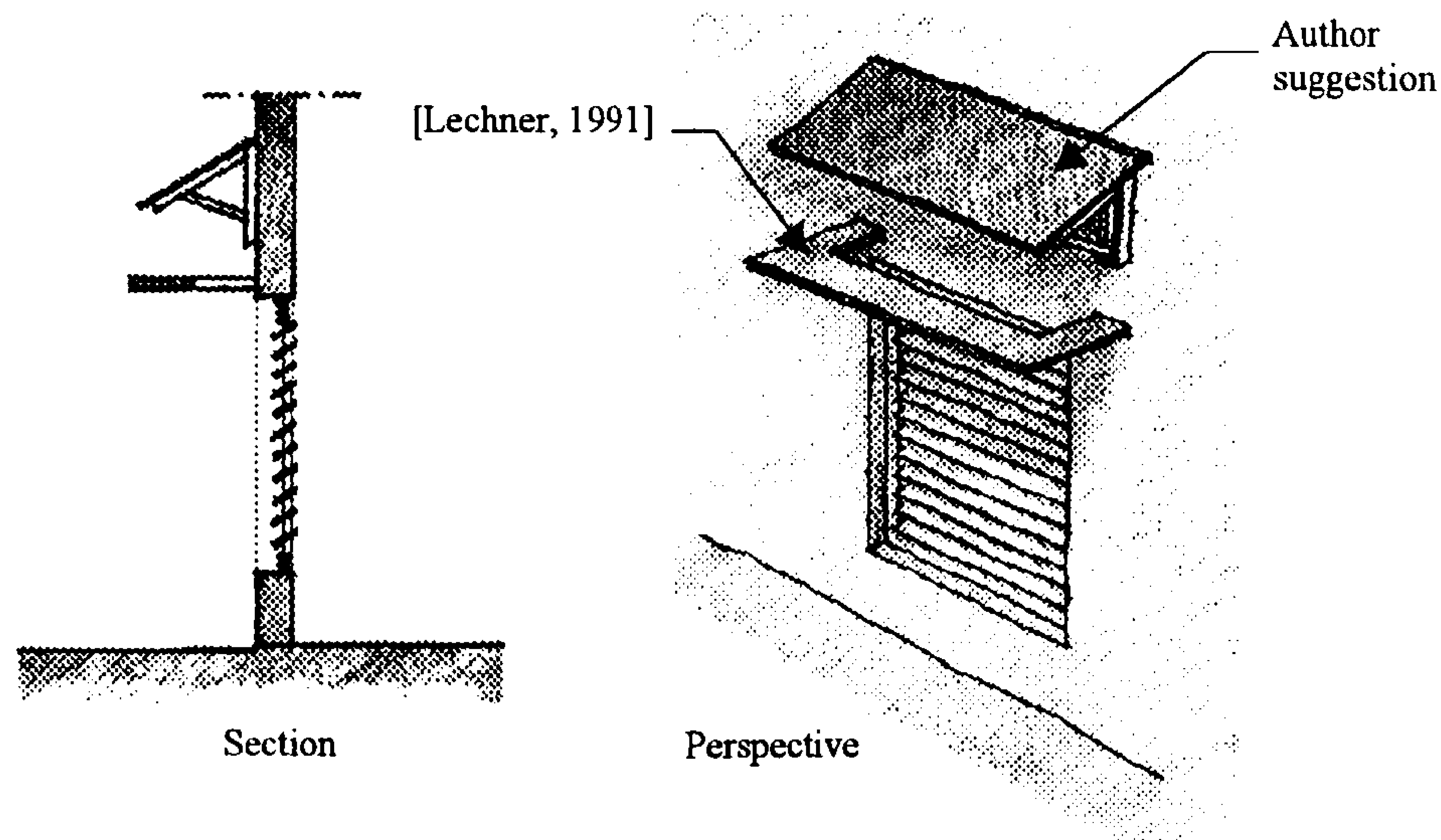


Figure 14.17. Detailed design of the suggested overhangs

14.2.4.2 Roof openings

The ventilation flow rate calculations in Chapter 10 showed that certain types, numbers and dimensions of window, without any roof openings, are able to supply air changes per hour (ach) close to the level (30 ach) suggested for comfort cooling. However, the existence of roof openings may increase the ventilation rates closer to 30 ach. Thus the use of roof openings is suggested in conjunction with ceiling openings.

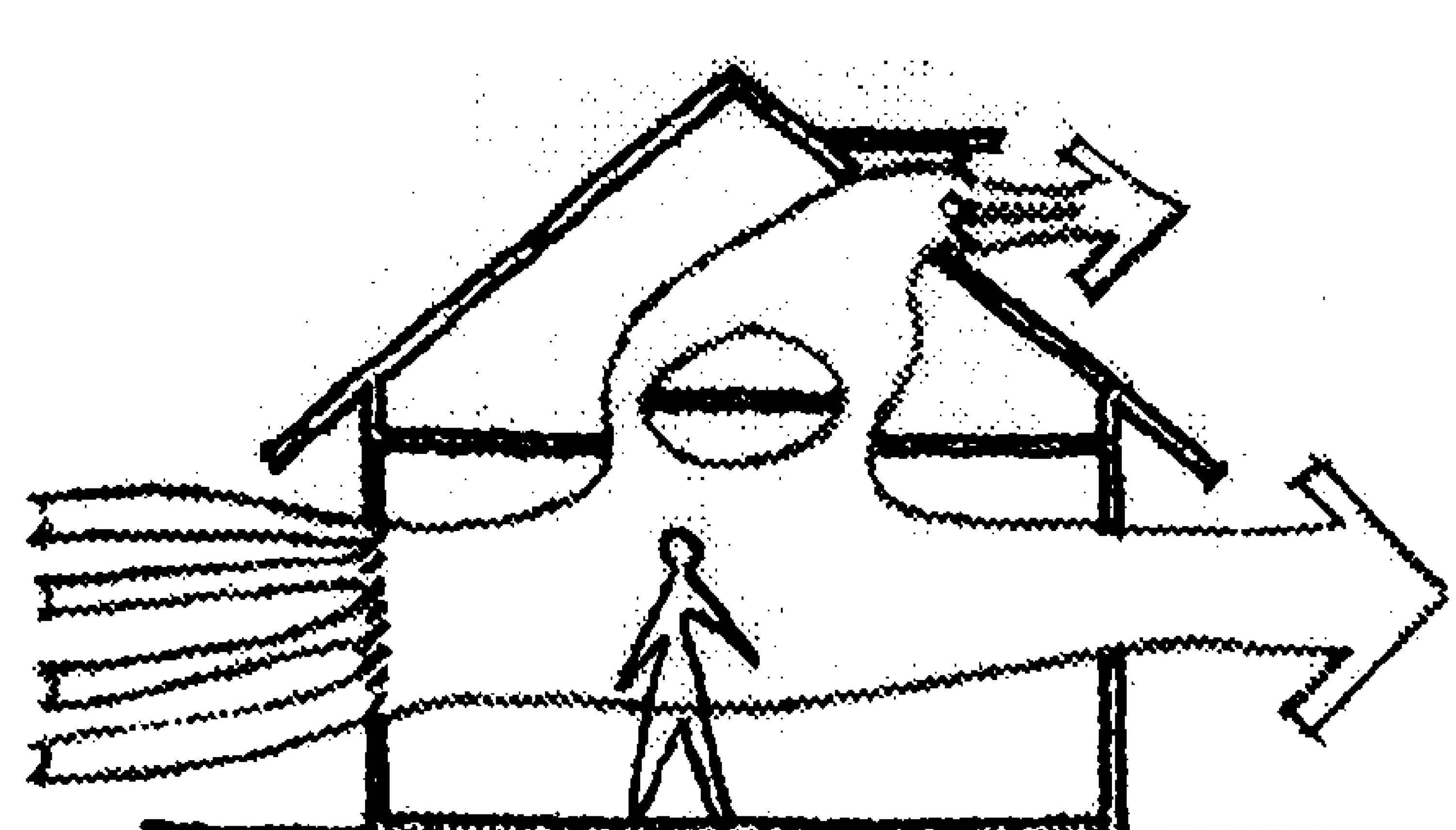


Figure 14.18. Ceiling openings to support roof openings
(Shape of airflow is probably not quite as in the figure, which gives an impression only of how the hot indoor air will be drawn by the openings)

The suggested roof openings are between one and three roof openings which are installed in the leeward side of the roof to function as outlet openings. Detailed design of the proposed roof openings is shown in Figure 14.19.

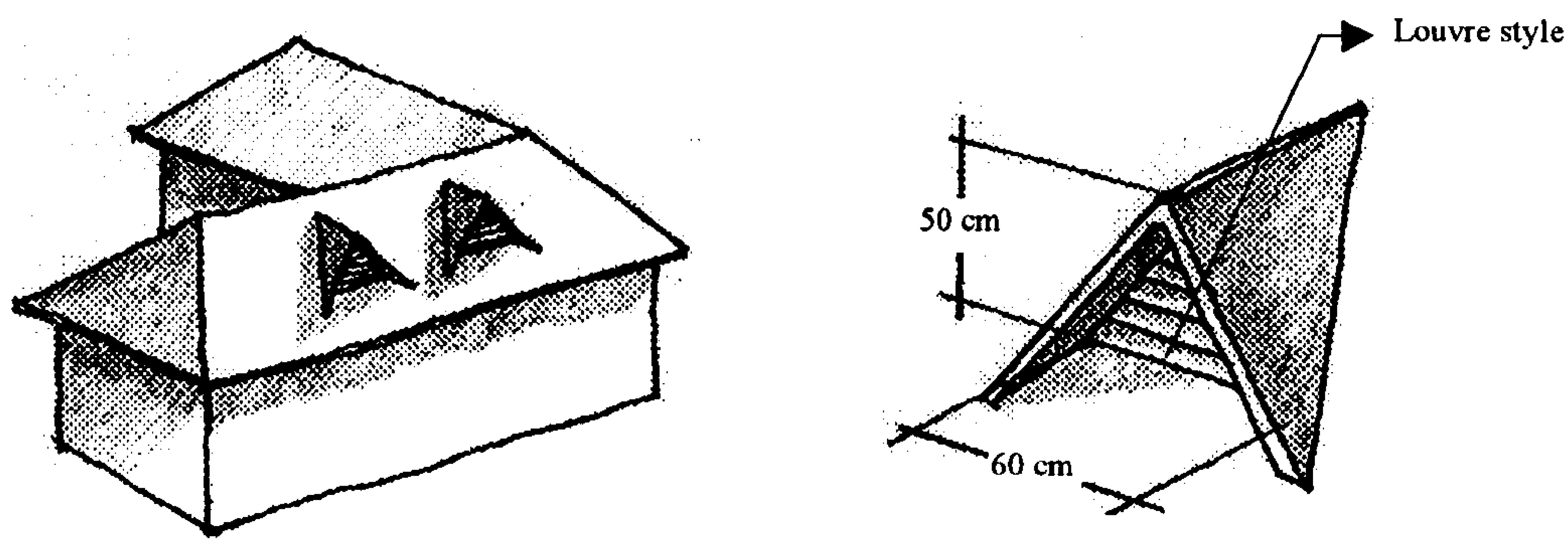


Figure 14.19. Detailed positions and design of roof openings

14.2.4.3 Doors as openings

The rear door does not require any particular design, except for house type B where a small upper opening is suggested in order to increase the function of the door as an outlet. As mentioned earlier, a suggestion to open the back door is practical since low-income families traditionally keep the back door open while they work.

14.3 Summary

The previous sections have described the details of the proposed designs. A sketch of the proposed housing design and its surroundings is shown in Figure14.20.

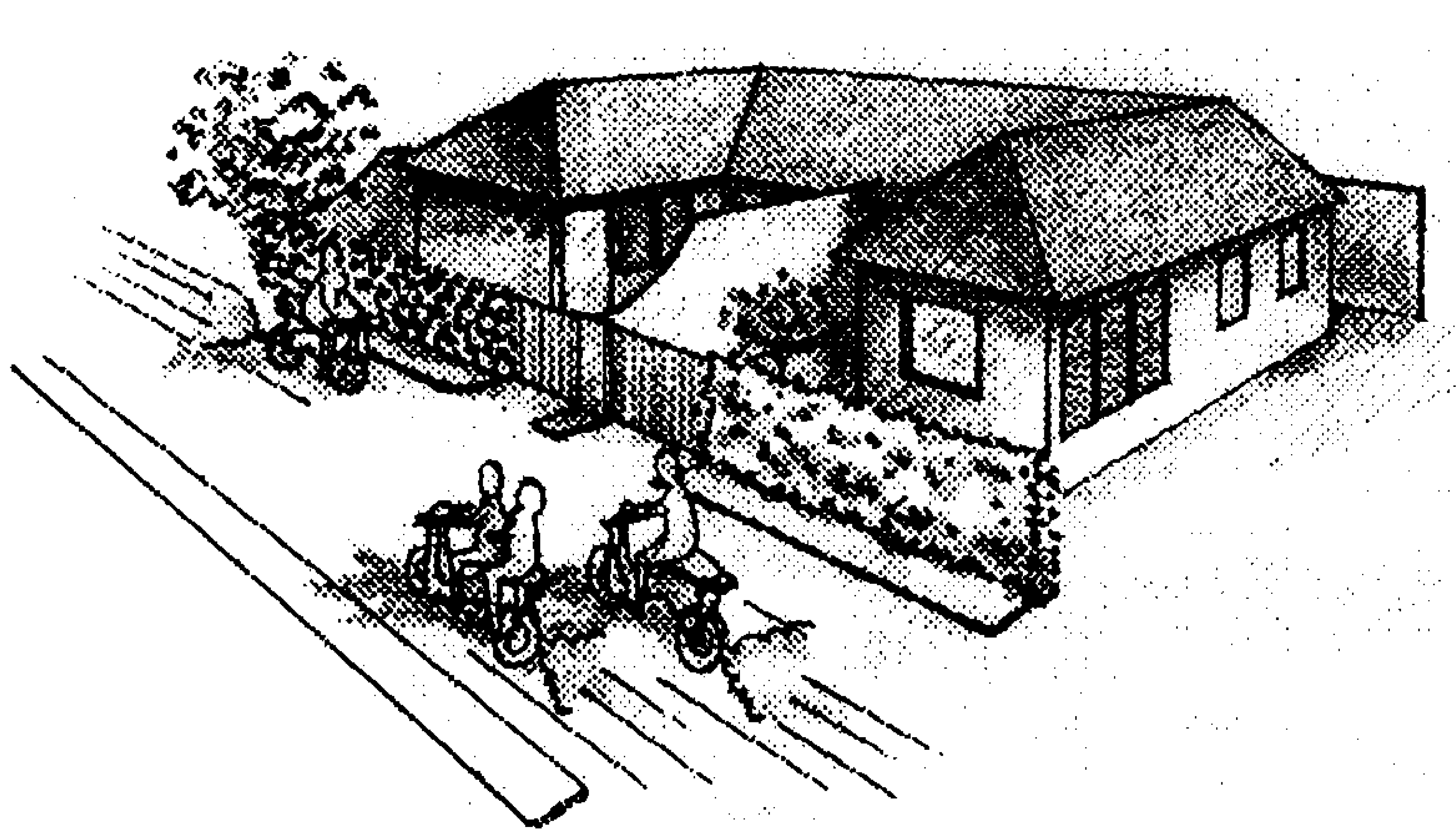


Figure 14.20. Perspective of the suggested house and its surroundings

The overall airflow within the new housing is sketched in Figure 14.21. The detailed shapes of the airflow are not quite as in the figure. However, this figure is sufficient to give an idea of how the cross-position of inlets and outlets may ventilate most of the corners in the rooms and in the house. The new design will, it is expected, satisfy the rates of ventilation that are demanded by the occupants.

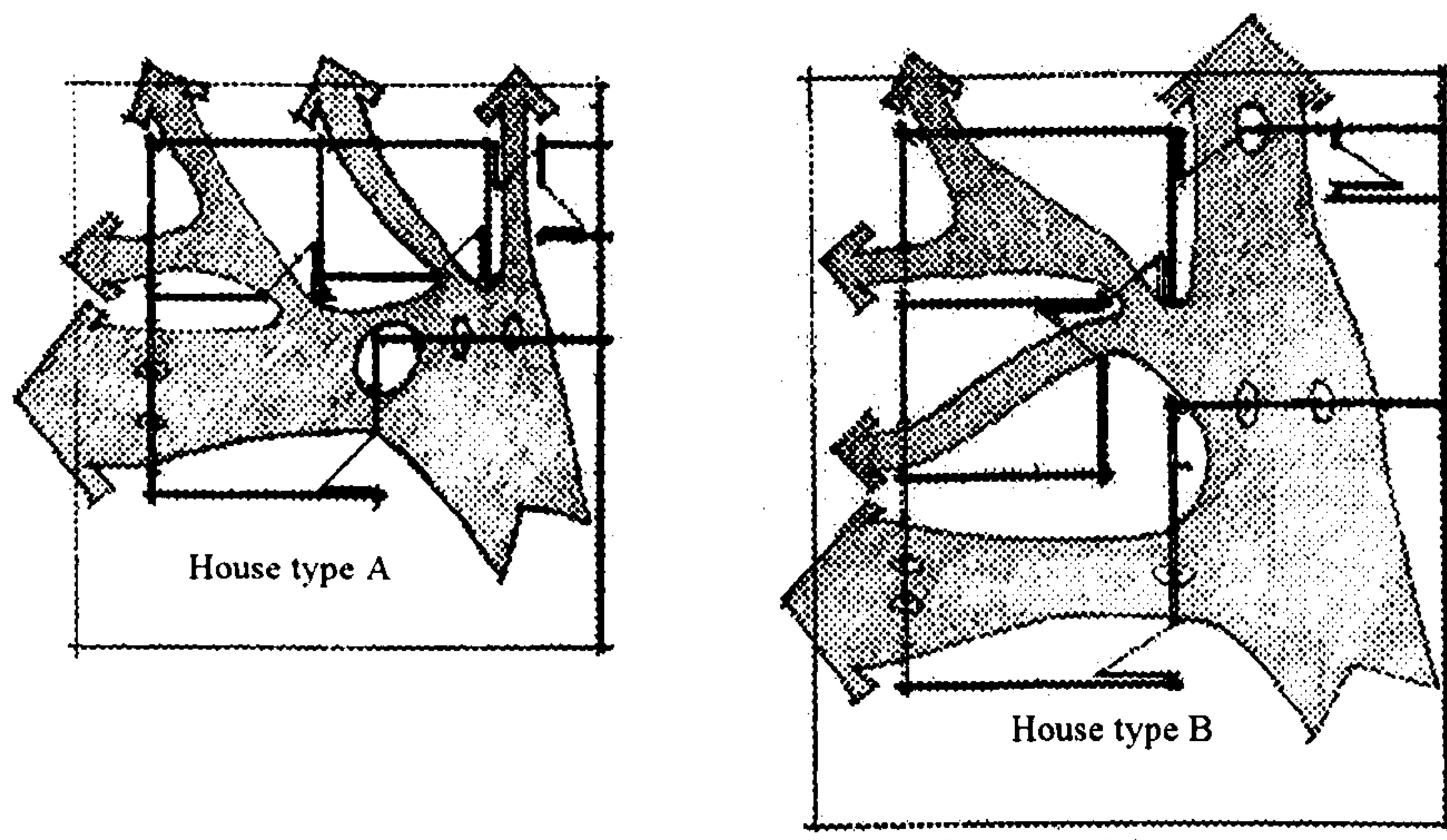


Figure 14.21. General ideas of the indoor airflow within the new design

14.4 Conclusion

Some options for the new design are proposed in this Chapter for improving the indoor environment within Indonesian low cost housing. These are based on the design propositions, computational experiments (which in some cases were confirmed with field trial) and calculations that have been described in the previous chapters. The numbers of options presented by the new designs enable developers to choose the most practical design. A summary of the indoor thermal comfort and pollution concentrations within the suggested design is presented in Chapter 15.

CHAPTER 15

CONCLUSIONS AND RECOMMENDATIONS

15.1 Introduction

Climatic conditions of hot humid developing countries create difficulties for building design in providing, by natural means, both thermal comfort and pollution-free or less polluted indoor environments for the occupants. It is particularly difficult for low-income families living in small simple houses within a busy city centre to achieve a reasonable level of comfort. Fortunately, this study has indicated that there is a practical solution by considering some detailed designs that involve little extra cost. By implementing the detailed designs as proposed in Chapter 14, the indoor environment within this type of housing can be improved.

15.1.1 Indoor thermal comfort

The most important consideration in creating a new design for buildings is indoor thermal comfort, particularly if the proposed design reduces the number and the dimension of openings in the conventionally designed housing. In this study, indoor thermal comfort is to be maintained by regulating the rates of air changes per hour, since other comfort factors, i.e. temperature and humidity are difficult to control without air conditioning. The rates of air changes per hour within the proposed design are as follows:

Specifications	House type A	House type B
When v=0m/s and w = oblique 30°, the average ach is:	33.5 ach	33.5 ach
When v=0m/s and w = oblique 60°, the average ach is:	33.5 ach	33.5 ach
When v=1m/s and w = oblique 30°, the average ach is:	37.0 ach	37.0 ach
When v=1m/s and w = oblique 60°, the average ach is:	37.5 ach	38.0 ach
When v=2m/s and w = oblique 30°, the average ach is:	43.0 ach	44.0 ach
When v=2m/s and w = oblique 60°, the average ach is:	45.5 ach	47.5 ach

Table 15.1 Ventilation rates within the suggested housing designs

Keys:
v = outdoor air velocity,
w = wind direction,
ach = air changes per hour (30 ach is recommended for warm humid regions)

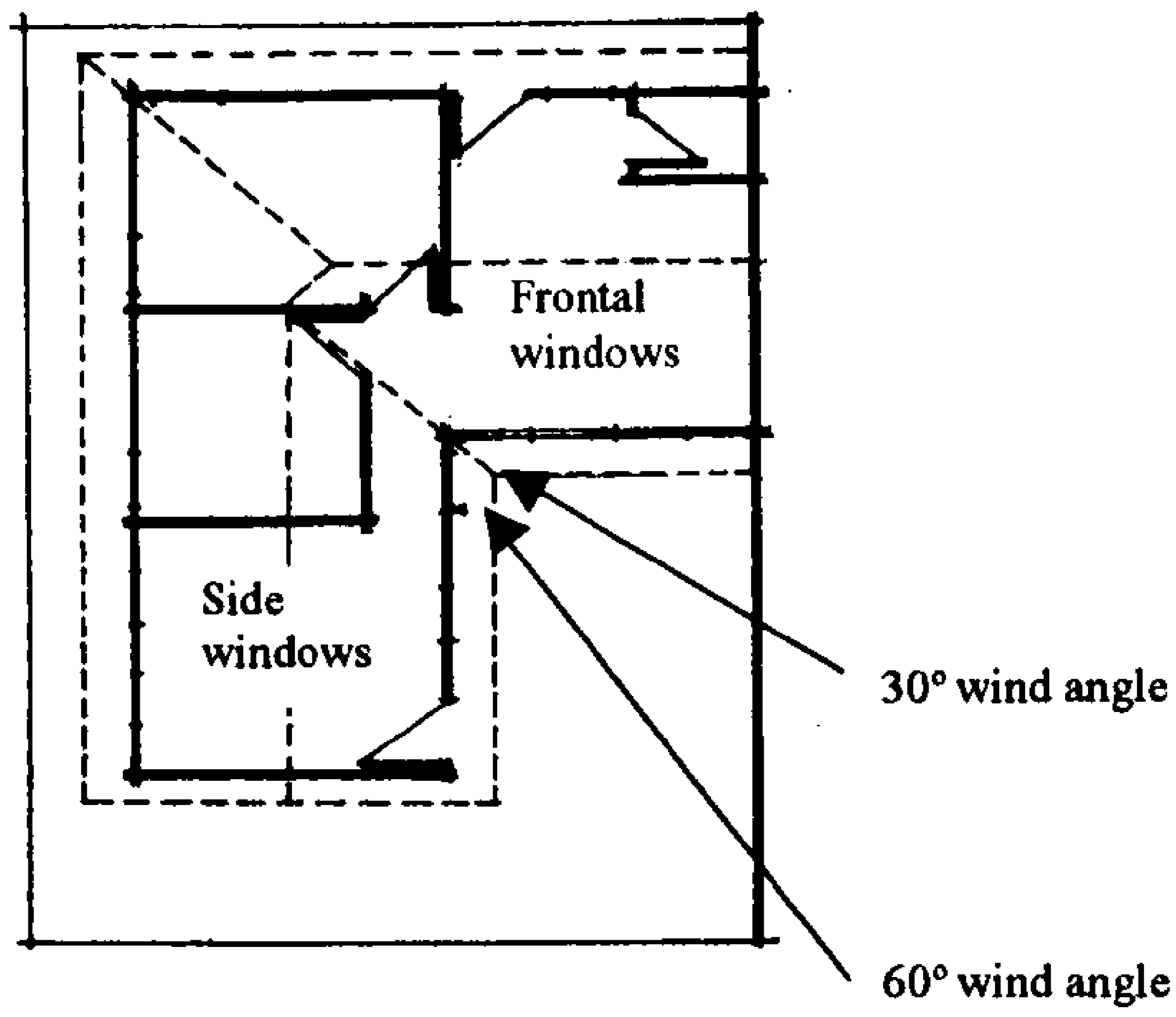


Figure 15.1 Wind direction can be either obliquely 30° or obliquely 60° depending on the position of the windows

From the above table, it can be concluded that the rates of air changes per hour in both house types are between 33.5 and 47.5. However, since within the street the wind speeds rarely exceed 2 m/s [*Dinas Navigasi Udara, Adisucipto*, Yogyakarta, 1995], the air changes per hour is unlikely to reach more than 40.

15.1.2 Indoor particulate matter concentrations

Particulate matter is a significant pollutant resulting from either street traffic or industrial processes. Very fine particulate matter has a significant effect on human respiratory systems. However, as the effects develop more slowly compared to those caused by gaseous pollutants, people tend to ignore this type of pollutant. Most Indonesian research has been carried out with regard to gaseous pollutant; research on particulate matter has produced results insufficient to lead to a practical solution in reducing this type of pollutant in the indoor areas. Even though particulate matter concentrations in recent years have been below the standard, studies into solutions for this pollution should start as soon as possible and be continued intensively. It is predicted that in the year of 2010, the concentration of particulate matter in most Indonesian cities will be approximately ten times that of today [Kompas, 17 April 1997].

This study suggests that there is a practical solution using vertical building elements to reduce the indoor concentration of fine airborne particulate matter as well as to provide the required ventilation rates. However, as mentioned earlier, the relative performance of these vertical elements in relation to environmental factors could not be precisely determined. Based on the results of the CFD experiment, which was then confirmed by field trials, the proposed vertical building elements to be used for particulate matter reduction are:

1. Fencing: this is a common feature in Indonesian housing. A solid fence is proposed in place of traditional fencing. The suggested detailed design of the fence construction is described in Chapter 14.
2. Vegetation: this is also a common feature of Indonesian front courtyards. This study suggests using vegetation in conjunction with solid fences to provide more surface area and rougher surfaces for particulate matter deposition. Low-growing vegetation (shrubs or bushes) with dense foliage and furry leaves as specified in Chapter 12 planted in front and adjacent to the solid fence will provide more deposition surface areas due to its leaf type. Therefore more particulate matter is deposited. The use of climbing plants approximately 1 m in front of the windows is also suggested for a house which already has openings in close proximity to the noise sources. Climbing plants with less dense foliage as used in this study indicated that concentration of particulate matter is only slightly reduced, but it is expected that climbing plants with denser foliage would be able to provide greater reduction.
3. Even though there is no clear conclusion could be made related to the study of angled surfaces (i.e. jalousie windows) in reducing particulate matter. The use of windows with jalousie style is still proposed based on some indications showed by field trials that there were many occasions when jalousie windows offered more particulate matter reduction than casement windows. It was also considered that this type of openings might catch dirt (coarse particulate matter) and thus reduce the intrusion into the house. The detailed design of the proposed windows is described in Chapter 14.

The indoor particulate matter concentration and the progress of particulate matter reduction in the proposed housing design are shown in Figure 15.2. This Figure was drawn from the CFD experiment, as the CFD gave more stable predictions than the field experiment. However, the field experiment is also important as it shows that in real conditions these predictions may vary, being either much higher or much lower, due to unpredictable changes in the environmental conditions.

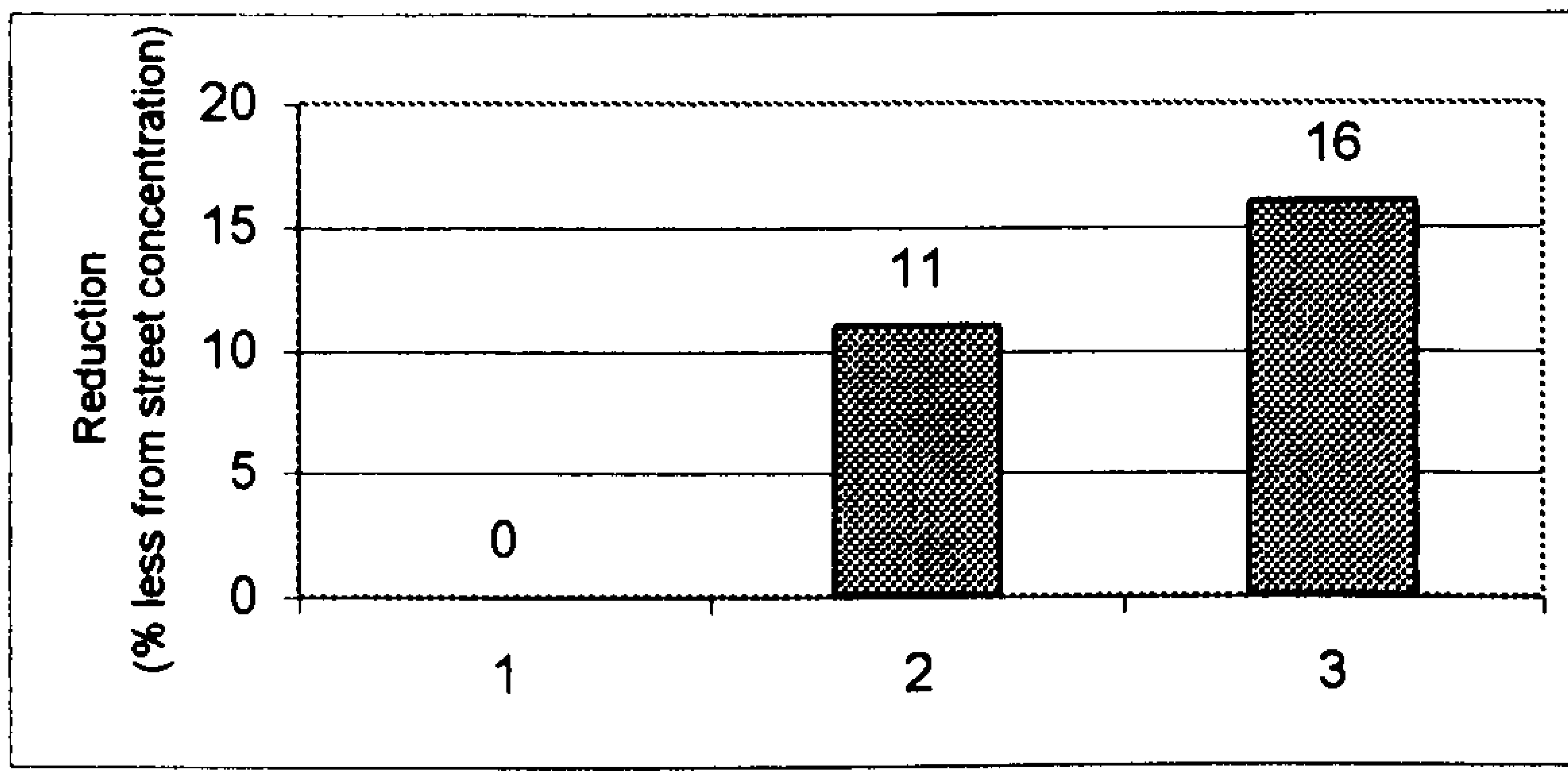


Figure 15.2. Prediction of indoor particulate matter concentrations compared to the street concentrations within a house with 1.3 m high solid fence and 4.5 m distance between the barrier and the opened windows, with mostly oblique wind.

Key:
1 average reduction adjacent to streets
2 average reduction offered by solid barriers
3 average reduction offered by configuration of solid fence, porous fence and windows (unspecified whether jalousie or full opened windows), and thus the total reduction to be achieved indoors

Other important conclusions from this study are:

1. It is mostly wind speed and wind direction that affect the particulate matter dispersion in the presence of such obstructions.
2. A narrower front courtyard (2.5 m wide) reduced more fine particulate matter by approximately 2 % compared to a wider front courtyard (4.5 m wide)
3. Porous barriers with parallel wind direction reduced more fine particulate matter by approximately 1% to 1.5 % more than solid barriers (regardless of the width of the front courtyard and the height of the barriers).
4. Solid barriers with oblique wind direction reduced fine particulate matter by approximately 3 % more than porous barriers (regardless of the width of the front courtyard and the height of the barriers).
5. A very porous frame (representing climbing plants) set 1 m in front of the windows helped to reduce fine particulate matter by approximately 1 % to 5%, while a less porous frame (representing less porous climbing plants) is expected to provide more reduction.

6. The overall reduction indoor concentration is approximately 16% less than the street concentration (Figure 15.2). There is no clear conclusion to be made in this study related to the capability of the proposed window style (i.e. jalousie windows) to reduce particulate matter. However, as was demonstrated by the field trials, it is expected that in real conditions, the use of jalousie windows will reduce more particulate matter.

15.1.3 Indoor noise levels

Sound pollution is another effect of street traffic. However, as air pollution has more obvious effects on everyday life, in most developing countries, noise attracts less attention than air pollution. As the effects of sound pollution develop very slowly, people tend to pay less attention until it is too late. Therefore, attempts to reduce this type of pollution at earlier stages, even when people feel it is unnecessary, will give many benefits in the future. Reducing noise early on will improve health levels and the social life of the occupants since noise also creates feeling of annoyance and anger [Nilsson, 1993].

Apart from considering the effect of fine airborne particulate matter on human life, this study has also tried to find how noise levels from adjacent street traffic could be attenuated by at least 10 dBA more than the reduction provided by existing designs. This would bring the indoor noise levels closer to the indoor standard for a house of 45 dBA (an international standard and an Indonesian proposal). This is more difficult for low-income families in hot humid developing countries. Fortunately the results of this study suggest strongly that noise can be attenuated by using vertical building elements. The suggested vertical building elements are as follows:

1. Fencing. A solid and massive fence is proposed in place of traditional fencing. The suggested detailed design of the fence construction is described in Chapter 14.
2. Specific design of window and other opening. There was no clear conclusion could be made related the ability of particular windows or openings type that might significantly reduce outdoor noise. However, the use of specific windows and openings consists of angled surfaces (louvre windows and louvre openings)

is still suggested considering that the combination between these windows and boundary fence offered noise reduction of approximately 25 dBA and considering that this type of openings may catch dirt (coarse particulate matter). The detailed design of these specific apertures is described in Chapter 14.

The indoor noise levels within conventionally designed housing are as follows:

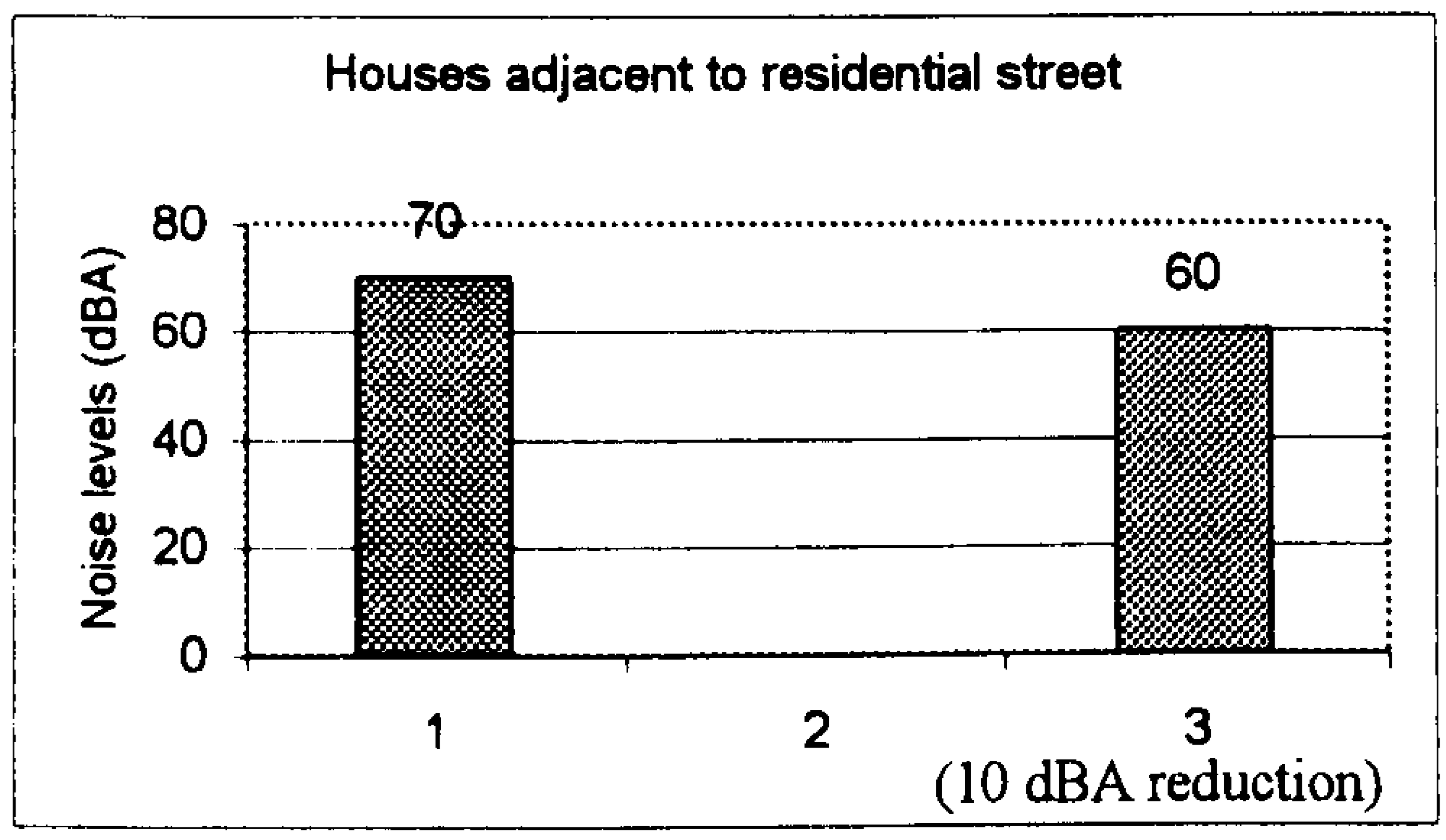


Figure 15.3. Noise conditions in typical, conventionally designed house

Key:
1 Average street noise levels ($L_{eq, 5\,min}$)
2 Average noise levels beyond the barrier/fence were not measured
3 Average of indoor noise levels ($L_{eq, 5min}$)

As a comparison, the indoor noise levels and the progress of noise reduction before reaching the indoor environments within the proposed housing designs are shown in the following figures:

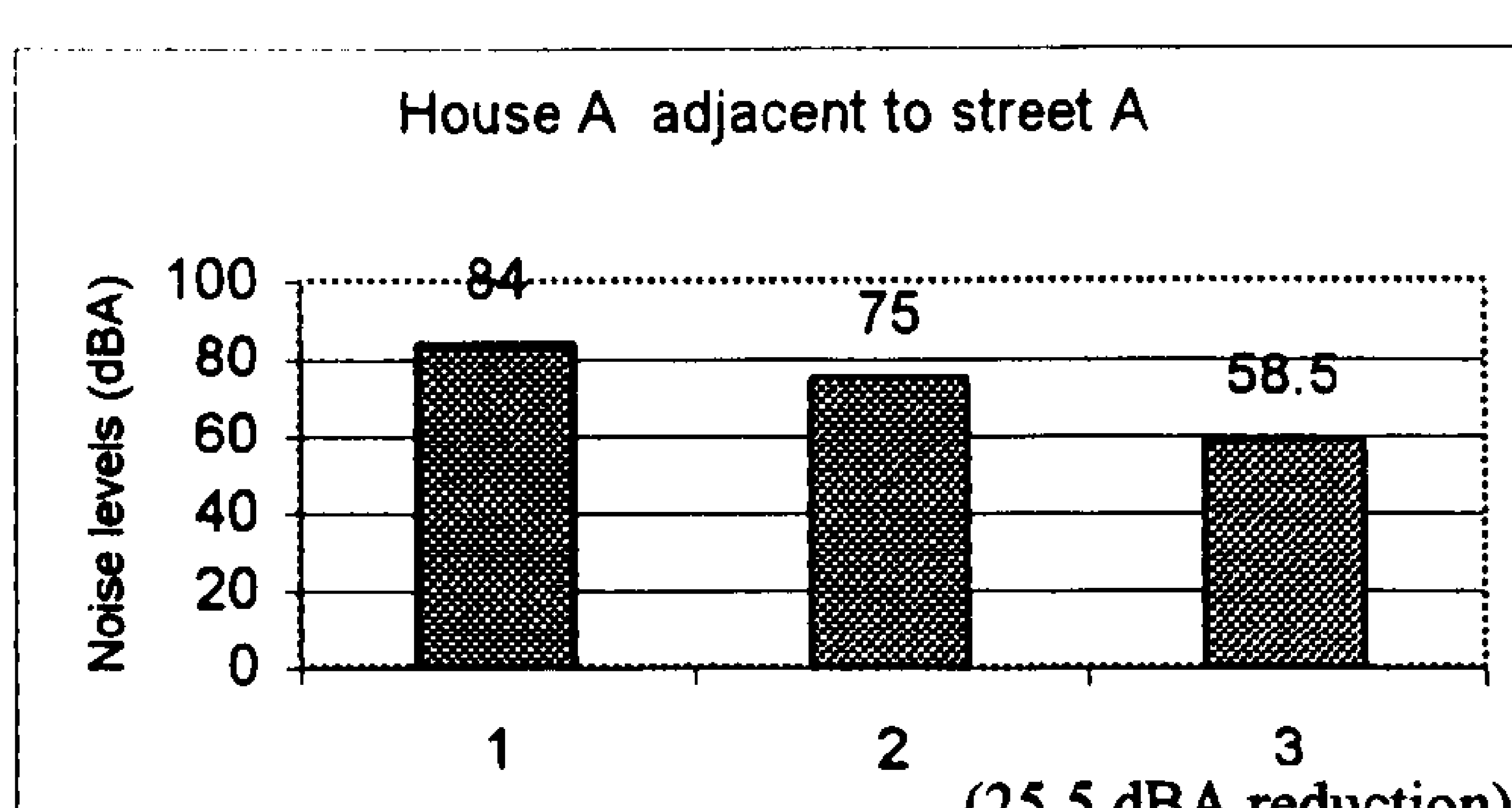


Figure 15.4. Progress of noise reduction in the proposed house type A adjacent to street type A

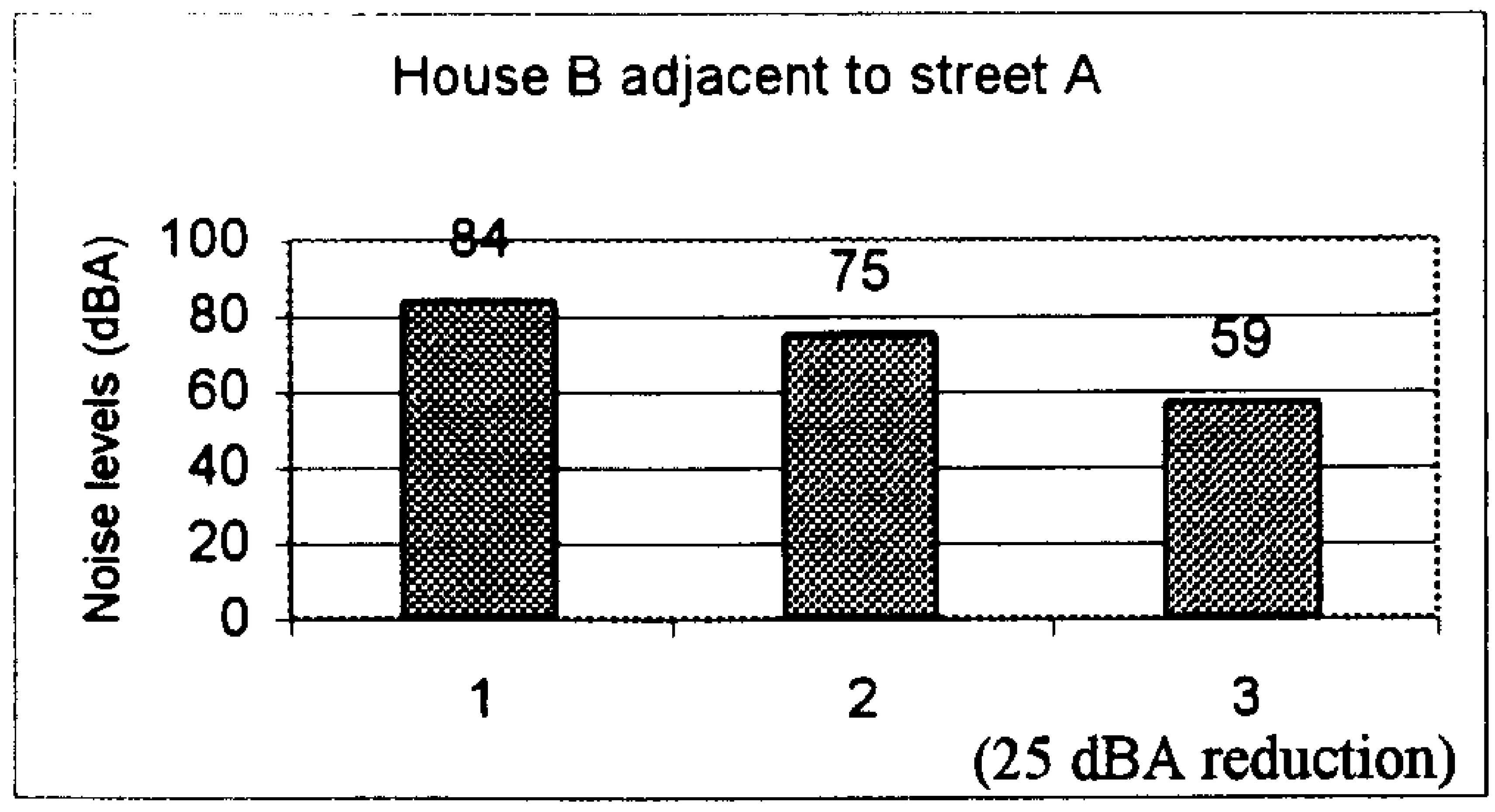


Figure 15.5. Progress of noise reduction in the proposed house type B adjacent to street type A

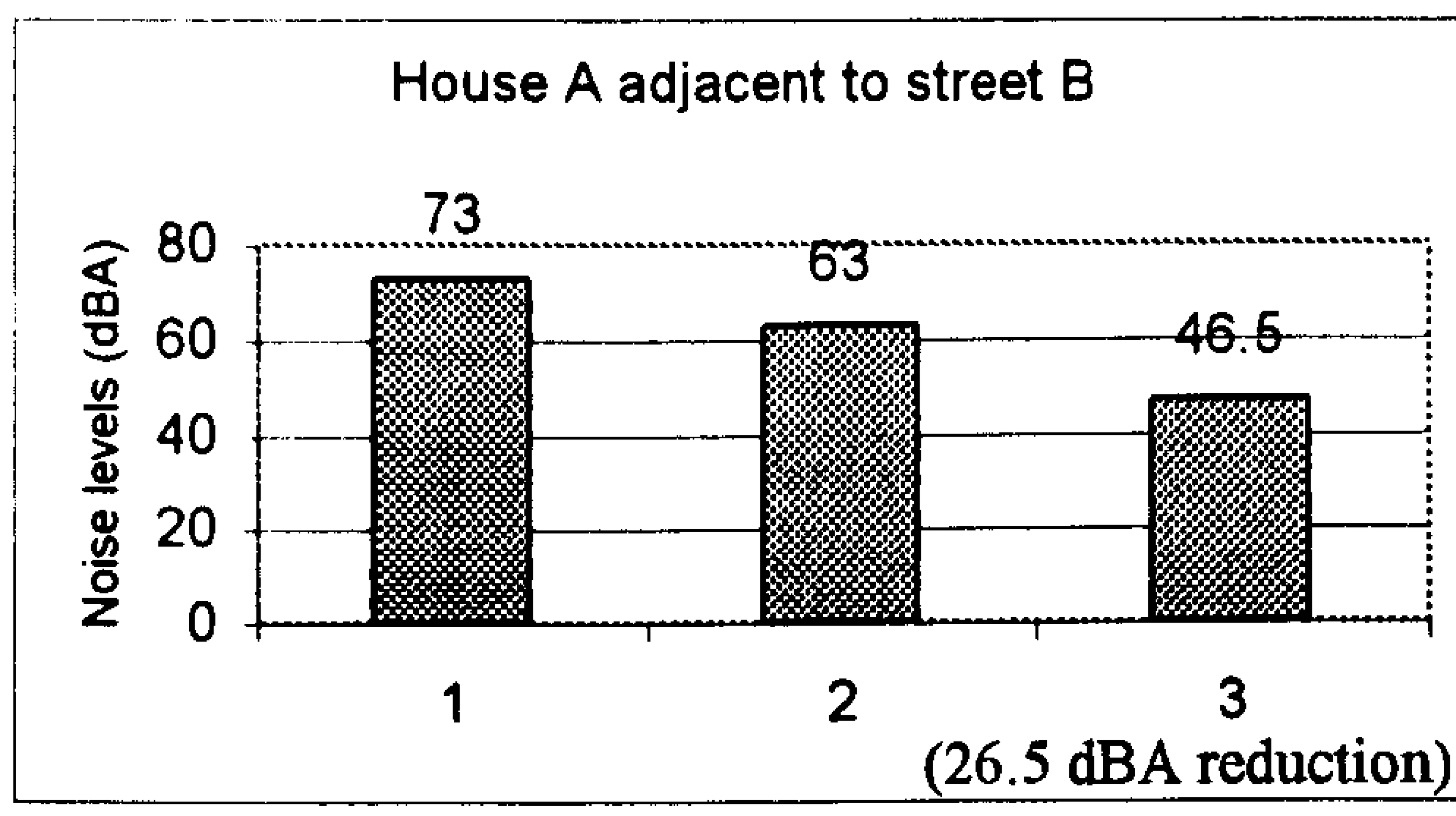


Figure 15.6. Progress of noise reduction in the proposed house type A adjacent to street type B

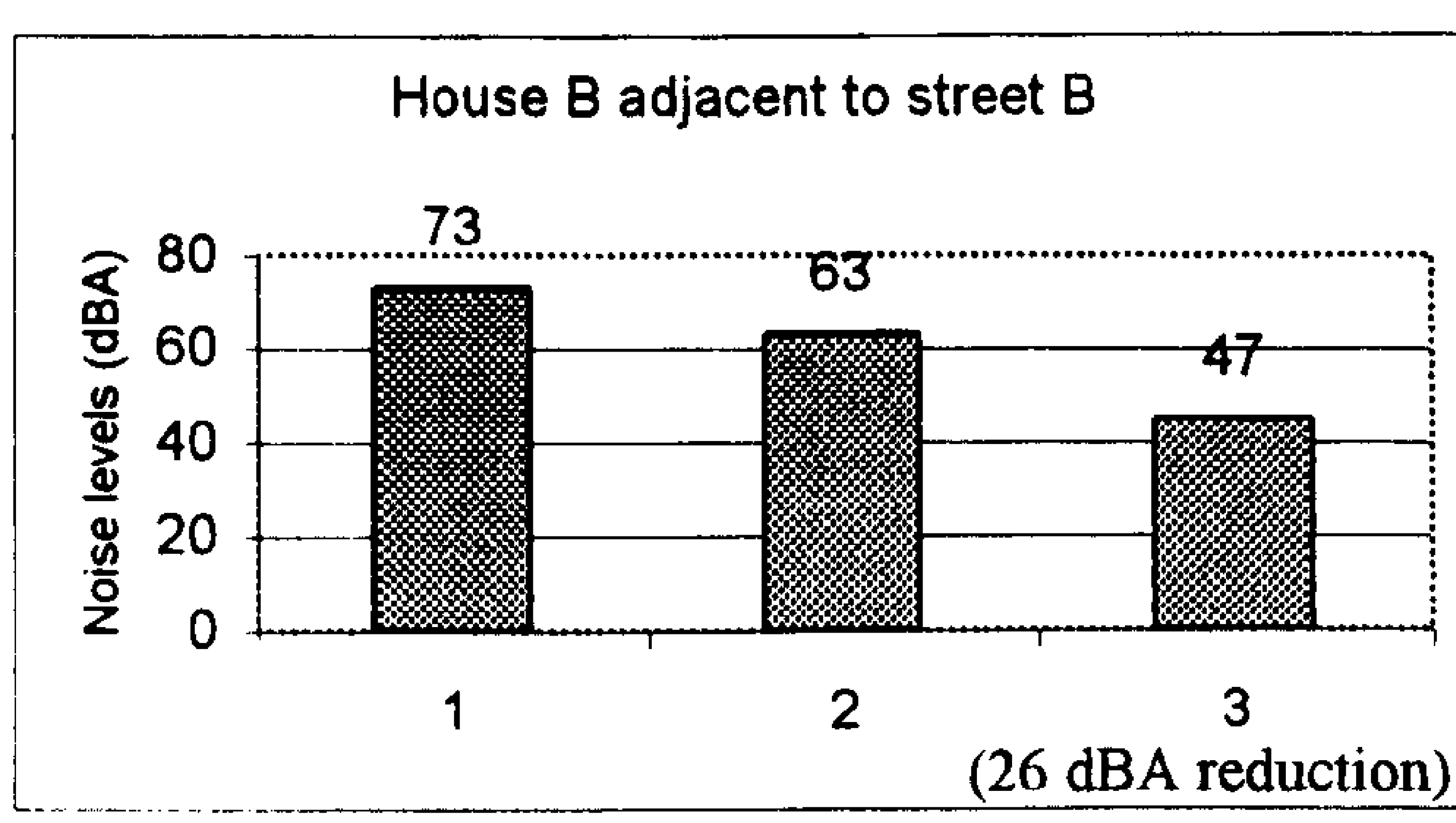


Figure 15.7. Progress of noise reduction in the proposed house type B adjacent to street type B

Key:
1 Street noise levels ($L_{eq,11h}$)
2 Average predicted noise levels in front of the courtyard due to solid barriers with 1.3 m height ($L_{eq,16h}$)
3 Average indoor noise levels with jalousie and closed glass windows positioned close to noise source (surfaces 1,2 and 4) (Tables 13.9 and 13.10)

From the above figures, it can be seen that the proposed design achieves significantly higher level of noise reduction compared to conventionally designed housing (approximately 60 dBA in conventional housing adjacent to residential street, refer to Table 13.12 and Figure 15.2). Within the proposed housing design, particularly within houses designed adjacent to street type B, the indoor noise levels are close to the standard.

15.2 Weaknesses

15.2.1 Weakness of the experimental method

There are clear practical advantages to the solutions proposed in this study. However, there is one weakness regarding the examination method of the design propositions. This weakness is explained below.

Resources available for this study meant that it was not possible to conduct sufficient field trials to fully validate the findings of the CFD study. The study indicated that solid fencing, vegetation with furry leaves and the use of jalousie windows would result in significantly greater particulate matter and noise reduction compared to other types of vertical element. However, since the relative performance of these three vertical elements in relation to the changes in microclimatic conditions, especially temperature and humidity, could not be studied in detail either by computational model or field trials. The precise performance of these building elements could not be determined. There are also discrepancies between the computational models and the field trials, which are caused by the limitation of the computational models to cover rapid changes of micro-environment as they occurred in the real conditions. Experiments carried out in more controlled environments (laboratory experiments using specific enclosures that are controlled similarly to the natural conditions) would be require to achieve this precision. More experiments are also necessary to enable more accurate analyses. Experiments carried out simultaneously with different housing conditions (different fence types, different window types, different length of front courtyards, etc.) each with a sufficient period of testing (minimum 3 days to fairly cover real weather conditions) would provide adequate data for further analyses.

15.2.2 Construction issues

There are some problematic issues regarding the construction of the proposed houses:

1. As the suggested housing design is more complex than the existing design, developers will need a longer period to construct the house.
2. The proposed housing design has extra costs for both the proposed features and the longer period of construction. The extra costs are for:

- Clay bricks or prefabricated concrete to construct the solid barrier (the vegetation is provided by the occupants).
- More timber to construct jalousie windows, fly/mosquito screens and jalousie roof openings.
- The use of special paints or varnishes that can create rough surfaces to enhance the durability of timber materials and to improve the ability of the surfaces to cause the deposit of particles [Schneider, et al, 1999].
- Metal for fly screen rails
- Metal mesh to construct fly screens
- More clay tiles to construct roof openings

As a rough guide, the extra cost will be approximately Rp 500,000 (£125), approximately 10% for the price for house type A (Rp 4,900,000 (£1225)) and 7% of that for house type B (Rp 6,900,000 (£1725)). These are the prices estimated before the economical turmoil in Indonesia, which started in the middle of 1997.
This extra cost is small compared to the improvement of indoor conditions, as the proposed design is capable to reduce particulate matter and noise from adjacent road traffic, while also capable to provide the required ventilation rates.

15.3 Further research

The progress of development and technology affects everyday life in many aspects. People experience both the good and the bad effects of this progress. An obvious bad effect is air pollution. Particular designs of vertical building elements are proposed in this study to improve the indoor environment within low cost housing from outdoor pollution. However, it is necessary to explore in more details how these vertical building elements will perform.

As is well known, low-income people living in low cost housing experience greater health problems, as pollution derives not only from the adjacent street traffic but also from the indoor environment and from the neighbourhood. Other indoor pollution is experienced by low income families from domestic activities, smoking [Harrison, 1997/1998] building materials [WHO/UNEP, 1985] and noise from neighbouring conditions [WHO/UNEP, 1985], particularly those who live in a very crowded area.

In confronting these complex pollutant sources, in the near future, architects need to develop more specific designs to provide both thermal comfort and pollution reduction. Further research is necessary to study more precise values of pollutant reduction offered by vertical building elements. Hence, the ability of these elements to reduce pollutants can be maximised. In particular, further research is necessary to explore the following:

1. The ability of vertical elements (fences, walls and windows) to reduce pollutant regarding specific environmental conditions (in other regions with their specific climatic conditions) temperature, humidity, wind speed and wind direction and rain levels. It is suggested that such research be done in controlled enclosures (laboratory) in order to do more precise analyses which covers all of the variables, especially the effect of rain, and thus allow more accurate conclusions to be drawn.
2. The ability of more specific types of vegetation to trap fine airborne particulates. As a first stage, experimentation within controlled enclosures is also suggested, which later may be carried out in the field given a sufficient period of time to provide adequate data.

Other research is also necessary for non-domestic buildings, such as schools, nursery homes or hospitals and other buildings where the young and elderly spend most of their time.

APPENDICES

Appendix 1:

Effect of Roof Shapes on Wind-Induced Air Motion Inside Buildings

(J. Kindangen, et al, 1997)

The effects of roof shape on wind induced air motion inside buildings were analysed by Kindangen by using a numerical simulation: computational fluid dynamics (CFD). In this study, Kindangen used FLUENT Software version 4.31, a product from Fluent Incorporation, New Hampshire. The standard k-ϵ turbulence model was implemented to account for turbulent flow. The flow and boundary conditions were isothermal. The reference wind velocity was 5.834m/s at a reference height of 4.25m with a reference turbulent intensity of 22%. The simulations were carried out with very rough mesh cells, as this is suitable for simulation with CFD. A coarse grid is sufficient to provide a good quantitative prediction of the fluid flow. Figure A1.1 shows a schematic view of the simulation and the cell dimension set; the building model was placed at the centre of the floor of the cube (31.20x31.20x12.00 (m^3)).

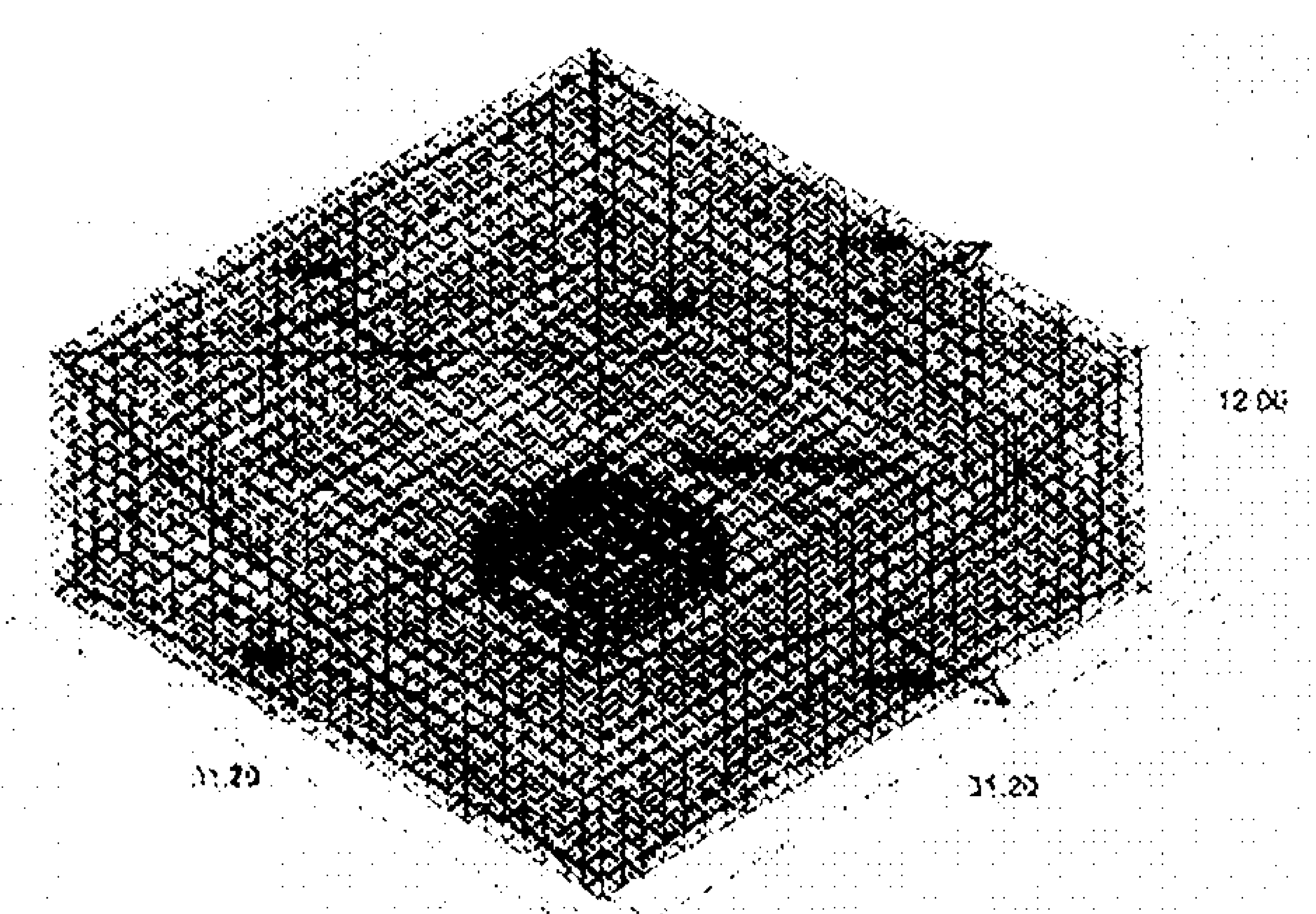


Figure A1.1. Schematic view of simulation with CFD
(After Kindangen, et al, 1997)

For this study, simulations were carried out on 10 tested models. Window sizes were identical at inlet and outlet, 1.50m high and 3.78m wide, corresponding to a wall porosity of 30%. This window size remained constant for all models. For this purpose, the tested models had the same dimensions: 7.20x7.20x2.70 (m^3), as can be seen in Figure A1.2.

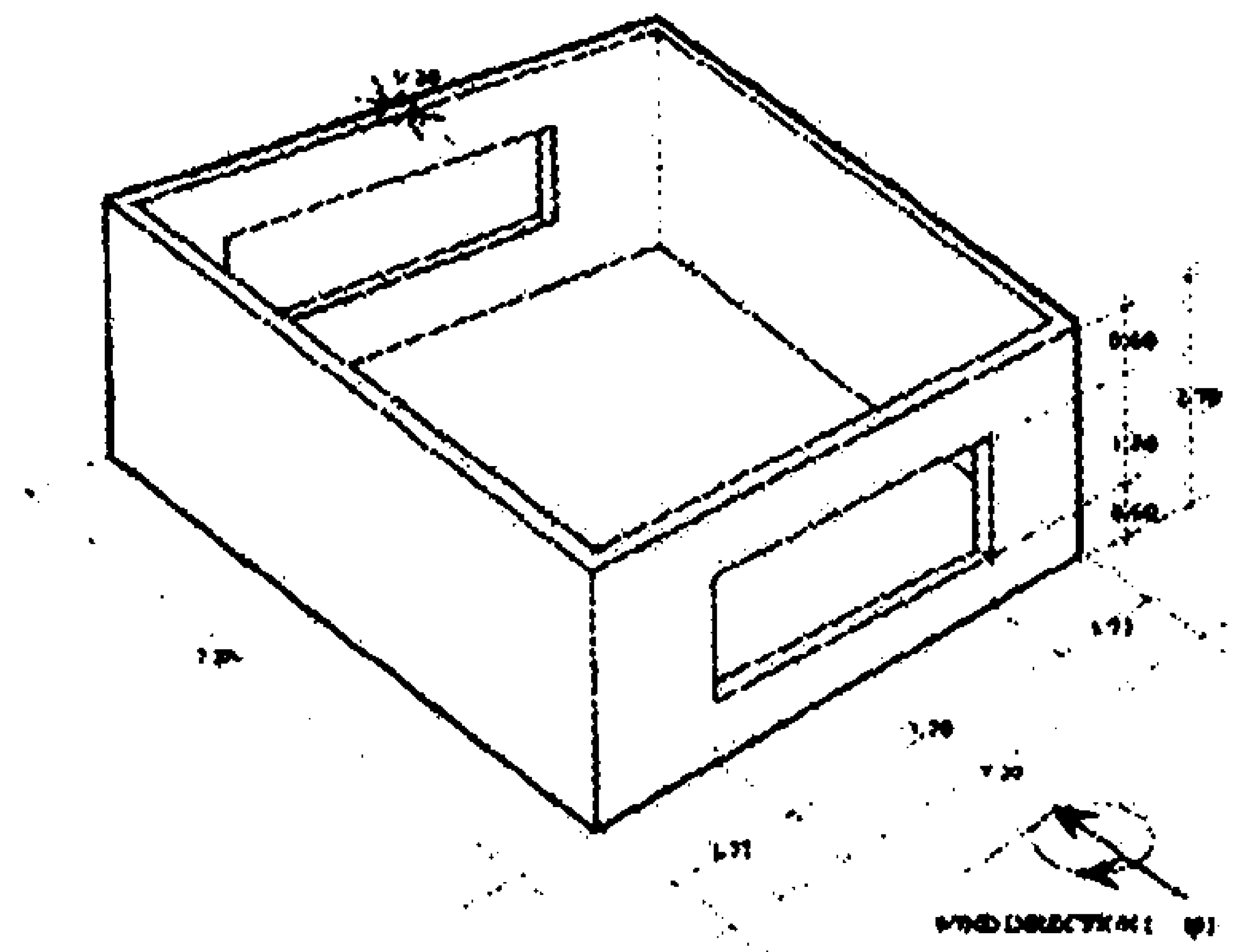


Figure A1.2. Dimension of basic model (in metre)
(After Kindangen, et al, 1997)

Ten roof shapes were selected to provide a representative sample of room shapes and architecture. The total height of each model is shown in Figure A1.3

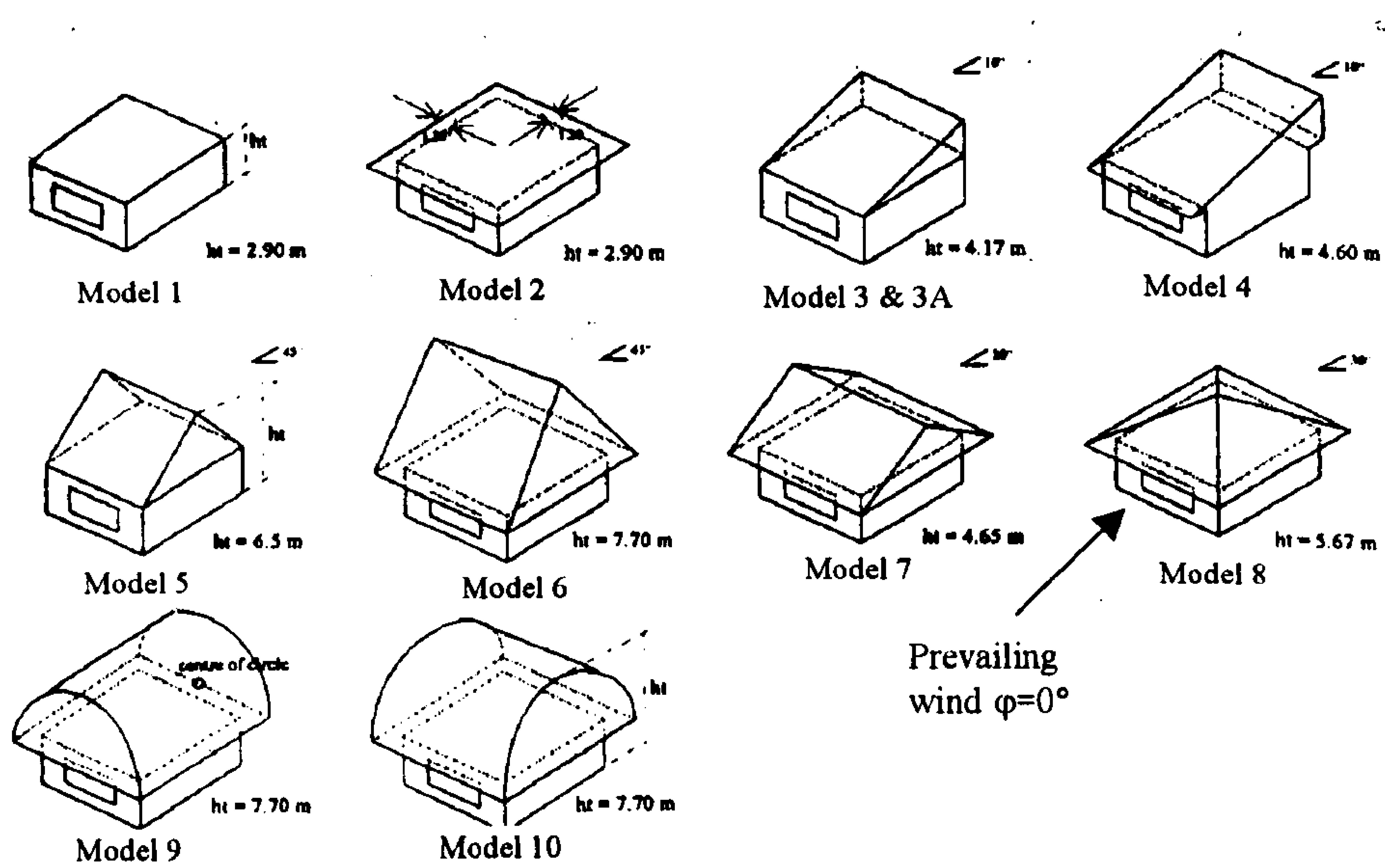


Figure A1.3. Roof types in Kindangen's research
(After Kindangen, et al, 1997)

For each model tested, the following three non-dimensional indoor air motion parameters were computed, based on the 36 points measured according to grid distribution (Figure A1.3.)

$$Cv = 1\frac{1}{n}\sum_{i=1}^{n}\left(\frac{V_i}{V_r}\right) \qquad (1)$$

$$C_{sv} = \sigma_s\left(\frac{V_i}{V_r}\right)/C_v \qquad (2)$$

$$C_{v_{max}} = \frac{V_{i_{max}}}{V_r} \qquad (3)$$

Where

C_v = average velocity coefficient

C_{sv} = coefficient of spatial variation

C_{vmax} = maximum local average velocity coefficient

V_I = mean velocity at interior location I (m/s)

V_r = mean outdoor reference free-stream velocity at the height of 4.25m (5.843 m/s)

$\sigma_s(V_i/V_r)$ = standard deviation of C_v

n = number of points measured in the model (36)

C_v is the measurement of the relative force of the interior air movement in the horizontal plane, which is representative of the occupied space of the room, in this case 1.35m above floor level. Kindangen used the coefficient of spatial variation at the 36 measurement points to analyse the uniformity of indoor airflow, which is an indicator of air flow homogeneity, a low value of C_{sv} indicating a uniform flow, and a high value being indicative of a greater spatial unevenness for the interior velocity distribution.

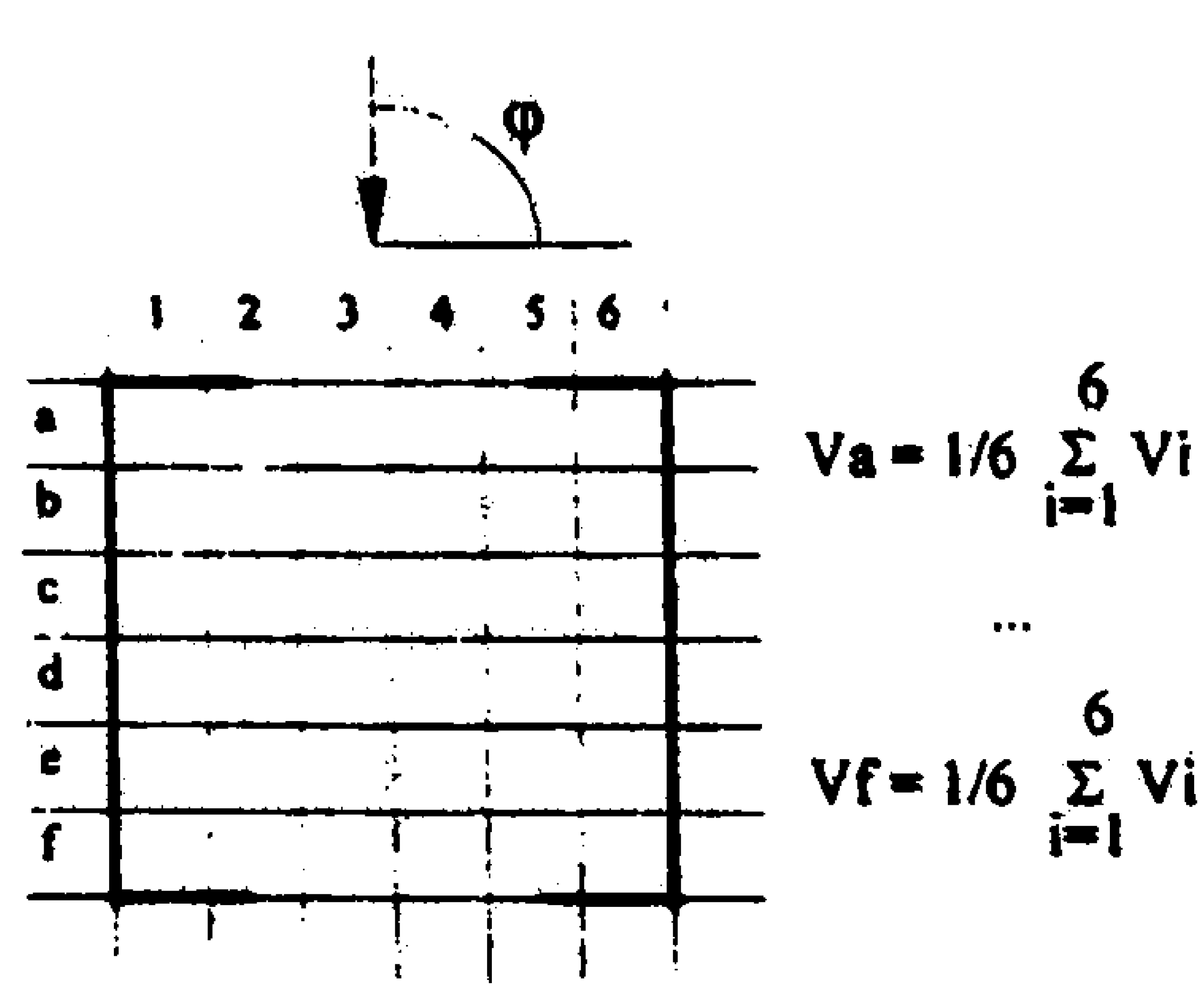


Figure A1.4. Plan of indoor air velocity at a height of 1.35m
(After Kindangen, et al, 1997)

For each model tested, Kindangen observed that wind direction had a great influence on the indoor airflow pattern, the highest C_v being generally found for the wind direction of 0° (ϕ = 0°). Except for models 1,3 and 3a, the highest velocity coefficient of these models was found for a wind angle of 0°, but for a wind incidence of 30°. The C_v of each model for ϕ =90°, of course, is the lowest of all wind direction.

The complete results of Kindangen's experiment were shown in Figure A1.5 and summarised in Table A1.1.

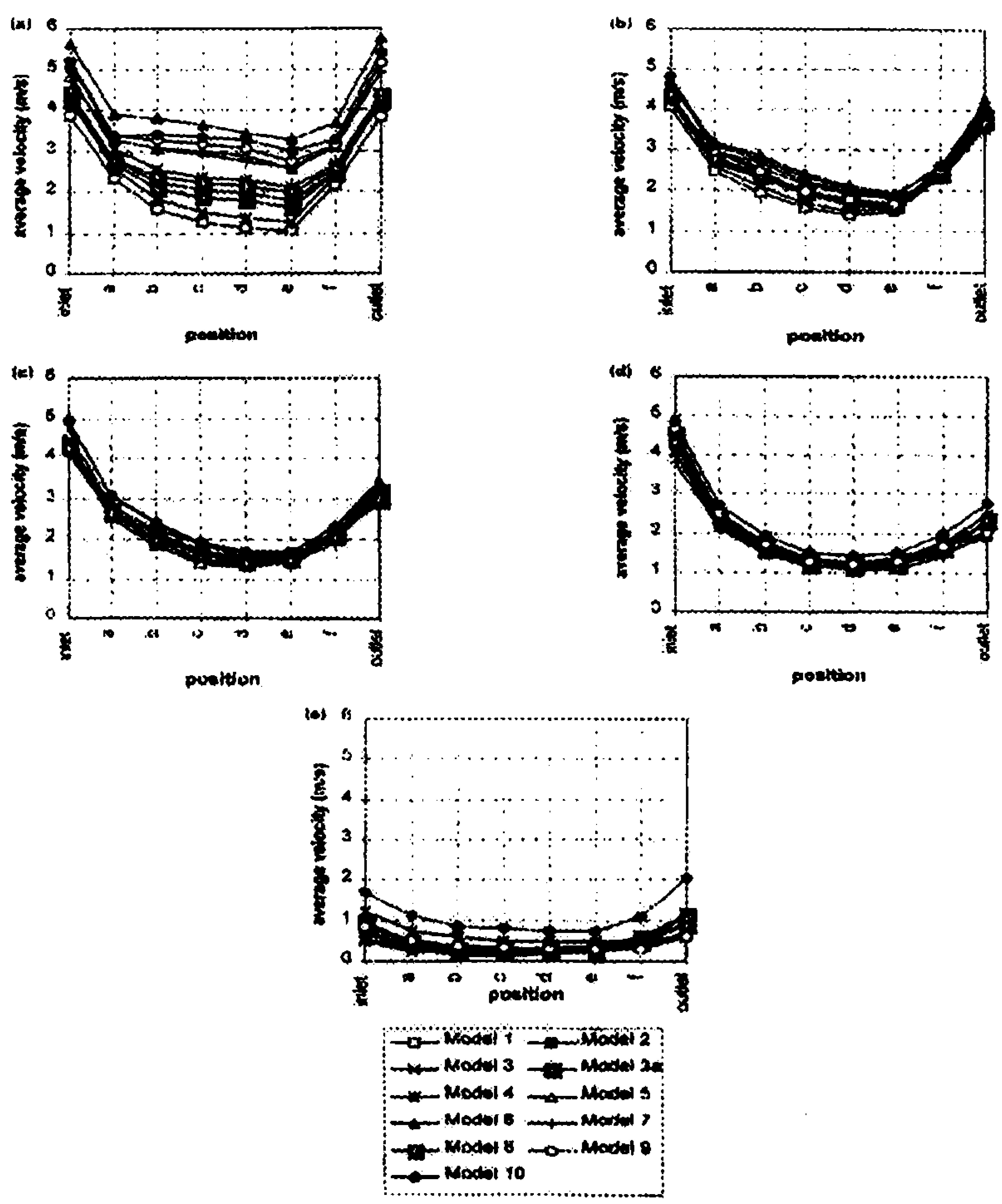


Figure A1.5. Distribution of indoor air velocity at a height of 1.35m in the centre section for (a) 0°, (b) 30°, (c) 45°, (d) 60°, (e) 90°
(After Kindangen, et al, 1997)

Roof shapes	Average velocity coefficient (Cv) in relation to wind direction						Average indoor air velocity m/s in relation to wind direction (in the centre of the room at height 1.35m)					
	0°	30°	45°	60°	90°	x*	0°	30°	45°	60°	90°	x**
1	0.28	0.32	0.30	0.27	0.06	0.25	1.2	1.5	1.4	1.3	0.3	1.14
2	0.38	0.35	0.32	0.27	0.06	0.28	2.3	1.8	1.6	1.3	0.3	1.46
3	0.32	0.34	0.31	0.27	0.06	0.26	1.5	1.6	1.5	1.3	0.3	1.24
3a	0.36	0.36	0.33	0.29	0.06	0.28	1.8	2.0	1.6	1.3	0.3	1.40
4	0.43	0.36	0.33	0.29	0.10	0.30	2.4	2.0	1.6	1.3	0.6	1.58
5	0.51	0.40	0.35	0.28	0.06	0.32	3.0	2.0	1.8	1.3	0.3	1.68
6	0.62	0.42	0.34	0.28	0.04	0.34	3.7	2.2	1.6	1.3	0.3	1.82
7	0.50	0.40	0.31	0.25	0.04	0.30	2.9	2.1	1.6	1.3	0.3	1.64
8	0.40	0.38	0.31	0.26	0.05	0.33	2.3	2.0	1.8	1.2	0.3	1.52
9	0.53	0.39	0.38	0.28	0.05	0.33	3.1	1.9	1.6	1.2	0.3	1.62
10	0.56	0.41	0.38	0.32	0.17	0.37	3.4	2.2	1.9	1.5	0.9	1.98

Table A1.1. Results of Kindangen's research
(After Kindangen, et al, 1997)

In general, Kindangen concluded the results of his experiments as follows:

- Roof shapes and wind directions

  Generally, roof shapes that are not flat such as sloping (triangular) or spherical induce greater indoor air motion. However, this also depends on wind direction. The greatest air motion can be gained at 0° and lowest at 90° and varied with roof shapes and wind direction of angles 30°, 45°, and 60°.

- Roof heights

  From the models, those with higher roof have greater velocity coefficient (C_v). Thus, height is one of the factors that can improve indoor airflow, especially for sloped roofs. However, these exclude a wind angle of 90° in certain roof shapes.

- Overhangs

  The use of roof overhangs in certain roof shapes with certain wind directions will induce indoor airflow. The presence of roof overhangs is adequate for protection against rain and glare, common natural conditions in hot humid regions.

- Inlet and outlet

  Position of inlet and outlet are important in relation to the roof itself. Roof shape induces indoor airflow, but has little influence on the pattern of inside airflow direction. In this case, configurations of the window or opening are entirely responsible for different indoor airflow patterns. This means that both roof shapes and configurations of inlet and outlet need to be considered in the same proportions.

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Appendix 2:

Window Dimension Calculations

(F. Moore)

This window ventilation calculation is adapted by F. Moore from the Florida Solar Energy Centre. This is a simplified worksheet procedure to determine the window size required producing the desired ventilation rate. Since it is a residence in a humid area, 24-hour ventilation is assumed. For security reason, assume that doors will not be depended on for ventilation. The required data for this calculation is primary weather and dimension data of the building in which it's located, and also a set secondary data that had been prepared for this purpose. The data required can be seen on the blank worksheet in the last page of this Appendix.

The secondary prepared data are as follows:

Wind Incidence Angle (deg)	Windspeed Ratios
0-40	0.35
50	0.30
60	0.25
70	0.20
80	0.14
90	0.08

Table A2.1. Inlet to site 10 meter windspeed ratios

Terrain Type	24 h ventilation (humid)	Night-only ventilation (arid)
oceanfront	1.30	0.98
airports or flatland	1.00	0.75
rural	0.85	0.64
suburban or industrial	0.67	0.50
centre of large city	0.47	0.35

Table A2.2. Terrain correction factors

Window type (based on Figure A2.1)	Effective open area
single hung	45 %
double hung	45 %
sliding	45 %
awning	75 %
casement	90 %
jalousie	75 %
hopper	45 %

Table A2.3. Effective open area of windows

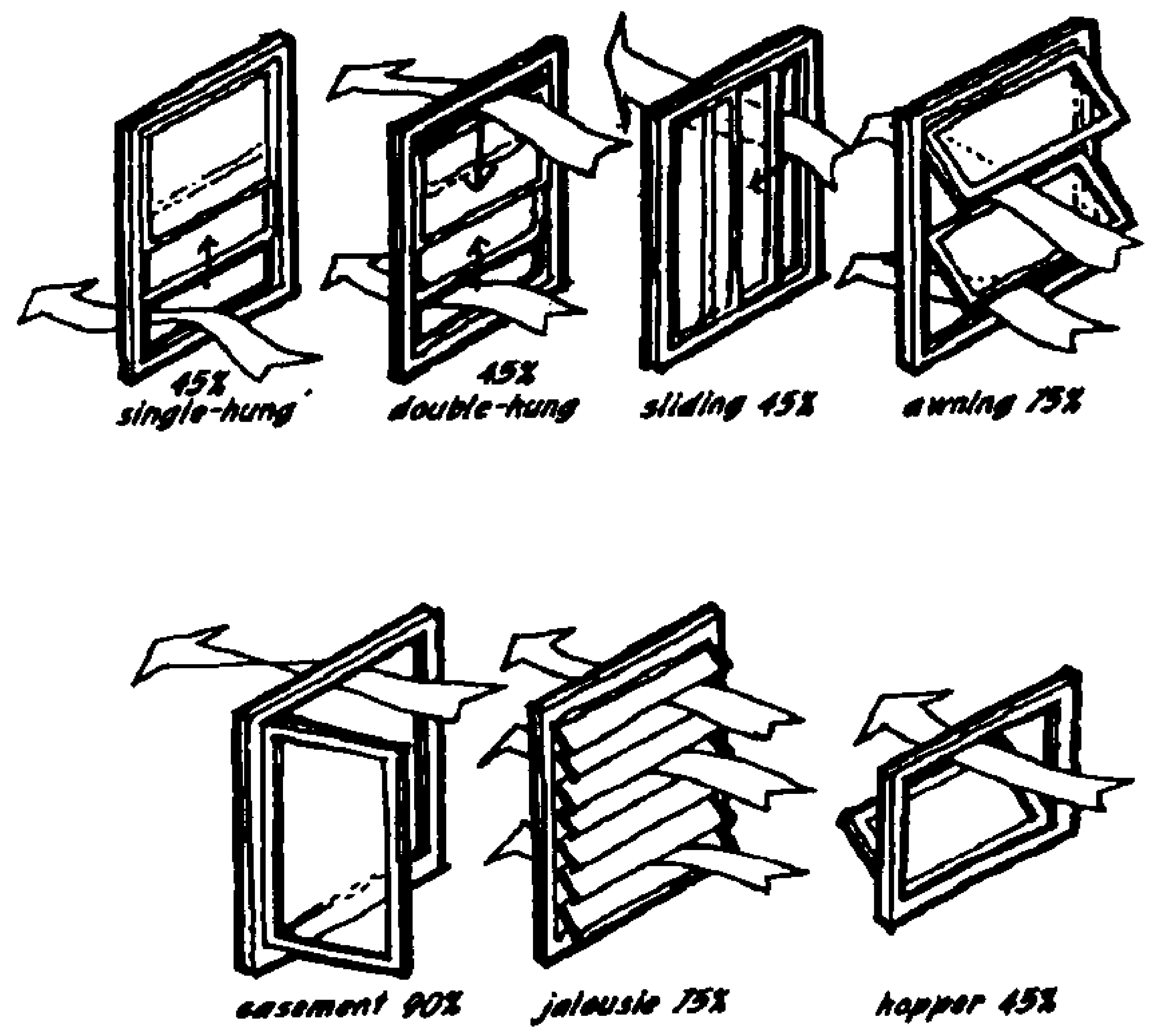

Figure A2.1. Porosity of various types of windows
(After F.Moore, 1993)

An example of the above calculation is applied to Yogyakarta conditions as follows:

No	Specification	Formula	House type A	House type B
1	building conditioned floor area		189 ft²	324 ft²
2	average ceiling height		8 ft	8 ft
3	house volume	step 1 x step 2	1,512 ft³	2,592 ft³
4	design air change rate/hour (rec.30)		30 ach	30 ach
5	required air flow rate (cfm)	(step 3 x step 4) : 60	756 cfm	1,296 cfm
6	design month (recommended: June)		June	June
7	name of nearest city		Surakarta	Surakarta
8a	wind speed	on June	2.3 mph	2.3 mph
8b	wind direction		SE	SE
9	wind angle to wall with largest window		30°and 60°	30°and 60°
10	inlet-to-site 10 m windspeed ratio	table 10.3	average = 0.30	average = 0.30
11a	terrain correction factor	table 10.4	0.67	0.67
11b	neighbouring buildings	Neighbourhood = 0.77 no surrounding = 1.0	0.77	0.77
11c	correction factor	second floor window = 1.15 otherwise = 1.0	1.0	1.0
12	windspeed correction factor	step11a x step11b x step11c	0.52	0.52
13	site windspeed (ft/min)	step 8a x step 12 x 88	155.6 ft/min	155.6 ft/min
14	window inlet airspeed	step 13 x step 10	47.6 ft/min	47.6 ft/min
15	net aperture inlet area	step 5 : step 14	16 ft²	28 ft²
16	total effective inlet+outlet area (screened)	3.33 x step 15	53 ft²	93 ft²
17	total effective area as % of floor area	(step 16 : step 1) x 100	29 %	29 %
18	effective openings of window type	table 10.5	Jalousie & casement	Jalousie & casement
19	calculate total effective area of each window : frame opening area (ft²) x effective opening factor x number of opening = (about equal or exceed step 16) **type 21 :** jalousie : 9 ft² x 0.75 x 5 = 33.75 ft² casement : 9 ft² x 0.90 x 3 = 24.3 ft² total : 58 ft²	**type 36 :** jalousie : 9 ft² x 0.75 x 6 = 405 ft² casement : 9 ft² x 0.90 x 7 = 56.7 ft² total : 97 ft²		

Table A2.4. Manual calculation for using natural ventilation based on Fuller Moore's formulae

Worksheet for Calculating Window Areas of Naturally Ventilated Houses

Project ______________________ Analyst ______________________

1. Building conditioned floor area = ________ (1) ft^2
2. Average ceiling height = ________ (2) ft
3. House volume = (step 1) x (step 2) = ________ (3) ft^3
4. Design air change rate / hour (recommended value is 30) = ________ (4) ACH
5. Required airflow rate, cfm = (step 3) x (step 4) ÷ 60 = ________ (5) cfm
6. Design month (recommended: May for Florida and Gulf Coast; June elsewhere) ________ (6)
7. Name of nearest city ________ (7)
8. determine windspeed (WS) and direction (WD) for the design month: WS = ________ (8a); WD = ________ (8b) mph
9. From prevailing direction, determine the incidence angle on the *windward* wall having the *largest* area of window (0° = perpendicular to wall) ________ (9) deg.
10. determine inlet-to-site 10-meter windspeed ratio = ________ (10)
11. Determine windspeed correction factors:
    - 11a. For house location and ventilation strategy, determine terrain correction factor ________ (11a)
    - 11b. For neighboring buildings, assume neighborhood convection factor = 0.77; no surrounding buildings = 1.0 ________ (11b)
    - 11c. For windows for the second floor (or for house on stilts), use a correction factor of 1.15 (otherwise, use 1.0). Correction factor = ________ (11c)
12. Calculate windspeed correction factor = (step 11a) x (step 11b) x (step 11c) = ________ (12)
13. Calculate site windspeed in ft/min = (step 8a) x (step 12) x 88 = ________ (13) ft/min
14. Calculate window inlet airspeed = (step 13) x (step 10) = ________ (14) ft/min
15. Calculate net aperture inlet area = (step 5) ÷ (step 14) = ________ (15) ft^2
16. Determine total effective inlet + outlet area (screened) = 3.33 x (step 15) = ________ (16) ft^2
17. Determine total effective area as % of floor area = (step 16) ÷ (step 1) x 100 = ________ (17) %
18. This total effective area requirement can be met by the same area of net opening. If windows or doors are used, then this area must be increased to allow for their effective area by applying the following effective opening factor: single- or double-hung window = 0.45; single- or double-sliding window = 0.45; hopper = 0.45; awning window = 0.75; casement window = 0.9; jalousie windows = 0.75; sliding door = 0.45; hinged door = 0.95.
19. Select openings and calculate their total effective area:

Opening type:	frame opening area (ft^2) x	effective opening factor (step 18) x	no. of this opening type =	
________:	________ x	________ x	________ =	________ ft^2
________:	________ x	________ x	________ =	________ ft^2
________:	________ x	________ x	________ =	________ ft^2
________:	________ x	________ x	________ =	________ ft^2
________:	________ x	________ x	________ =	________ ft^2
________:	________ x	________ x	________ =	________ ft^2

20. Total effective area as designed and installed (should equal or exceed step 16) = ________ ft^2

***

Appendix 3:

Ventilation Flow Rate Calculations by using Brevent

(Brevent Software Manual, BRE, UK, 1992)

The Brevent software was created by Andrew Cripps, CPhys and first launched in 1992 by the Building Research Establishment, UK. This is a model for predicting ventilation rates in dwellings. It is based on a set of equations that describe infiltration through building fabrics, and flow through discrete elements such as openings (e.g. trickle ventilators and air bricks, etc.), windows, extract fans, combustion appliances (flues), and passive stack ventilation devices (vertical ducts). This is a single-zone model but becomes two-zone when a ventilated subfloor space is included.

Brevent has already been used on a number of different projects at the Building Research Station (now BRE), UK. These have included investigating the performance of Passive Stack Ventilation (PSV) systems, the Ventilation of a sub-floor void, the development of the UK Building regulations for Ventilation in houses, and work on the developing CEN standard for ventilation calculations across Europe. It can also be used to enable people to understand the effect of changes to the ventilation of a building, for example by changing the position of a window or adding another ventilation device.

Brevent is a mass balance model that iterates on static internal pressures in order to find the flow rates for any given weather conditions. Pressures outside the dwellings are calculated from weather data and the pressure coefficients are experimentally determined by assuming constant wind speeds. Pressurisation testing does not indicate the location of the leakage paths but a useful approximation is to distribute the total leakage (multiply the designed ach value by the volume of the dwelling) around the walls, floors and ceilings of the dwelling on an area weighted basis. Then by choosing an initial floor level internal pressure (P_I), the flow rates into the dwellings via user-defined routes can be calculated. Flows into the dwellings are defined as positive and out from the dwellings are defined as negative. Detailed formulae for the Brevent calculations are as follows:

Formula for small openings

The volume flow rate through a small opening (e.g. air-bricks, grilles, trickle vents, etc.) is given as:

$$Q = F.A\left(\frac{2.|\Delta P|}{\rho}\right).\text{sign}(\Delta P) \qquad (1)$$

Where:

ΔP	= P(ISURF)-PI-bh/H pressure different across opening, derived as for equation ΔP(z)= P(ISURF)-PI-(Δρ.g.z)
b	= Δρ.g.H (stack effect term)
h	= height of the opening above ground level (m)
F	= F (Re, geometry of opening)
Re	= Reynolds number
A	= area of opening (m^2)
ρ	= density of air flowing; ρo or ρI depending on the sign of ΔP

The value of ΔP will depend on the height of the opening above ground because of the stack effect (equation ΔP(z)= P(ISURF)-PI-(Δρ.g.z)), but the area is assumed to be small so that no variation in ΔP over the opening is considered.

The function F can be taken as constant discharge coefficient (C_d) for large enough openings and Reynolds number greater than 1000. For sharp-edged openings it has the value of 0.61. Discussion of this and the variation of the flow exponent n may be found elsewhere.

The area used should be the 'equivalent' area of the opening being considered. This is defined as the area of sharp-edged circular orifice producing the same flow as the opening, at the same applied pressure difference. It is approximately equal to the geometrical area of the opening for large openings such as windows.

Formula for windows or large openings

The volume flow rate through a large opening is given as:

$$Q = \frac{WIN}{b}\left[\frac{|X_2|^{1.5}}{\rho_2^{1/2}} - \frac{|X_1|^{1.5}}{\rho_1^{1/2}}\right] \qquad (2)$$

Where:

X_1	= a-bZ_t	Z_l	= Z_l/H
X_2	= a-bZ_l	Z_l	= height of the bottom of the window (m)
A	= P(ISURF)-PI	H	= height of the window (m)
B	= Δρ.g.H	F	= opening factor (0 closed to 1 fully open)
Z_t	= (Z_l+h)/H	ρ_1, ρ_2	= density of air flowing (kg/m³)
Z_t, Z_l	= normalised top and bottom window heights		

$$WIN = \frac{2\sqrt{2}}{3}(f.H.w.C_d) \qquad (3)$$

Where:
w = width of window (m), i.e. h.w = area of window
C_d = discharge coefficient

If the neutral level falls within the window there will be flows in opposite directions through different parts of the window. The first term in Equation 2 therefore gives the flow below the neural layer, the second term the flow above it. If this occurs, the density of air flowing will be slightly different in the upper and lower flows. If this is thought to be significant, ρ_1 and ρ_2 must be set differently for each part of the flow, ρ_i for outflow, ρ_o for inflow.

When the neutral level falls outside, all of the flow is in the same direction through it. Hence both ρ_1 and ρ_2 will be the same, equal to ρ_i for outflow, ρ_o for inflow.

Where there is zero temperature difference between internal and external air, the density term (b) goes to zero ($\rho_i = \rho_o$). In this case, equation 2 cannot be valid (division by zero). Use of L'Hospital rule, however, gives an expression for Q at ΔT=0.

$$Q(\Delta T = 0) = WIN \Big/ \left[\rho.1.5.|a|^{0.5}.(Z_t - Z_1).sign(a)\right. \qquad (4)$$

Note that this result can be obtained by integrating equation 1 directly. This is easy since ΔP is not dependent on height because ΔT=0.

Data Needed for Brevent Calculation

Users must specify the required weather conditions (i.e. wind speeds, wind directions, and temperatures) and dwelling dimensions for running the Brevent. Element dimensions and flow coefficients are needed for each discrete flow. These weather data (i.e. temperature, wind speed and wind angle) was to be varied by using step of difference to provide more data for analysis. For example the lowest given internal temperature of 24°C was increased to 26°C for the next run. Within Brevent, stepping for temperature ranges from 0.5 to 2 and stepping for wind direction ranges from 10° to 90°. Temperature stepping for this experiment is 2°C and wind direction stepping is 30°, considering that stepping lower than these values will not give significant differences. Below is all specification needed for Brevent.

SPECIFICATIONS	DETAILED DESCRIPTIONS
House type	Brevent offers three types of houses that can be used for: Detached: house with all four walls exposed Semi detached : house with either side walls shared Terrace: house with both side walls shared, if it is in the centre of a terrace or, if it is at the end of a terrace, just one of them
Length of front face	Brevent offers the length of front face from 1 m to 50 m
Length of side face	Brevent offers the length of front face from 1 m to 50 m
Envelope height	Brevent offers the envelope height (walls height from the ground) from 1 m to 60 m
Dwelling height	Brevent offers the dwelling height (from the ground to the top of the roof) from 2.4 m to 60 m. If the dwelling has a pitch roof, its overall height is from the ground to the roof ridge levels. This number is required to scale wind speeds
Orientation of the front face	This orientation related to prevailing wind direction, which can be specified starting at angle of 0, 30°, 60°, etc. to 330°
Lowest internal temperature	Brevent offers the internal temperature from -50°C to 50°C
Highest internal temperature	Brevent offers the internal temperature from 24°C to 50°C
Internal temperature step	Stepping to increase or decrease the specified internal temperatures to provide sufficient data for variation of the running is limited from 0.1°C to 8°C
Lowest external temperature	Brevent offers the internal temperature from -50°C to 50°C
Highest external temperature	Brevent offers the internal temperature from 18°C to 50°C
External temperature step	Stepping to increase or decrease the specified external temperatures to provide sufficient data for variation of the running is limited from 0.1°C to 8°C
Lowest wind speed	The wind direction should be the prevailing wind. This is usually measured using an anemometer at 10 m height. Brevent offers the lowest wind speed from 0 to 20 m/s.
Highest wind speed	The wind direction should be the prevailing wind. This is usually measured using an anemometer at 10 m height. Brevent offers the highest wind speed from 0 to 20 m/s.
Wind speed step	Stepping to increase or decrease the specified wind speed to provide sufficient data. Brevent offers the stepping from 0.1 m/s to 2 m/s
Starting wind angle	This is the starting angle of a range of prevailing wind and can be specified from 0, 30°, 60°, etc. to 330°
Final Wind angle	This is the final angle of a range of prevailing wind and can be specified from 0, 30°, 60°, etc. to 330°
Wind angle step	Stepping to increase or decrease the range of prevailing wind direction from the starting angle to the final angle. Brevent offers the stepping by 30°
Anemometer height	An ordinary position of 10 m height is suggested by Brevent
Wind profile exponent	Guidance to choose the wind profile exponent is as follows: Open flat country: 0.17 Country with scattered wind breaks: 0.2 Urban: 0.25 City: 0.33
Pressure difference	To measure the overall leakiness of its fabric (or envelope), a dwelling can be pressurised and depressurised using a large fan fixed in place of an external door. The total leakage of the fabric is then quoted at a reference pressure difference, following International convention this is 50 Pa, although the model allows for other values.
Leakage exponent	A flow exponent is also derived from pressurisation measurements and it will be in the range of 0.5 (turbulent flow) to 1.0 (laminar flow, but a common value is about 0.6. In the model it is assumed to apply to all leakage paths.
Leaky value	Guidance to choose the leaky value is as follows: 20 ach: leaky house 15 ach: ordinary UK house 10 ach: airtight house
Housing density	The housing density should be self-specify by the user, but as a guidance, the Brevent offers the housing density from 0% (housing density of an isolated house) to 35% (a house in a very crowded area, i.e. within a city)

Table A3.1. Detailed descriptions of Brevent specifications

Output: Total ventilation Flow Rates

Total ventilation flow rate for dwellings is the sum of the moduli of all flows into and out of the dwellings divided by two, because flow in equals flow out. Air change rate is measured in air changes per hour, i.e. the ventilation flow rate divided by volume of the dwellings.

As windows and walls can have flow in both directions, these components must be treated separately and their moduli added to give the total ventilation figures. This differs from the net flow rate required to achieve the mass balance when initially calculating the internal pressure difference at floor levels.

The output of the Brevent simulation can be obtained in a figure and a list of results as follows:

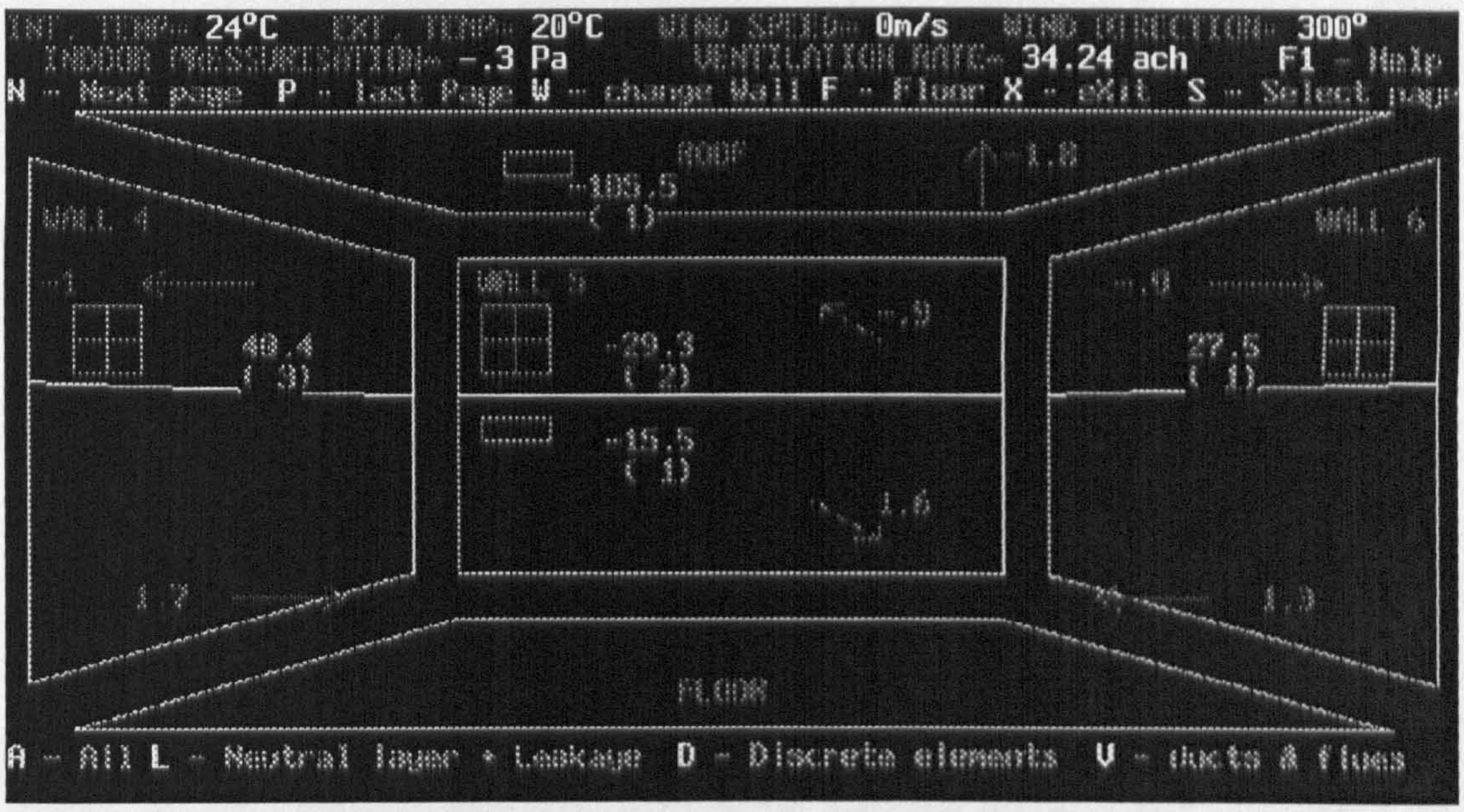

Figure A3.1. An example of an exploded view result from the Brevent calculation

Keys:
At the top of the screen, the basic weather data for the particular run loop is given, followed by the predicted indoor pressure at ground level (relative to outside) and the total dwelling ventilation rate. The green values show airflow in each surface (m^3/h) followed by number of the discrete elements (windows or openings). The yellow horizontal line shows the neutral layer, completed with red values of flows below and above the neutral layer on each surface (m^3/h). Positive values show flows into the dwelling and negative values show flows out of the dwelling.

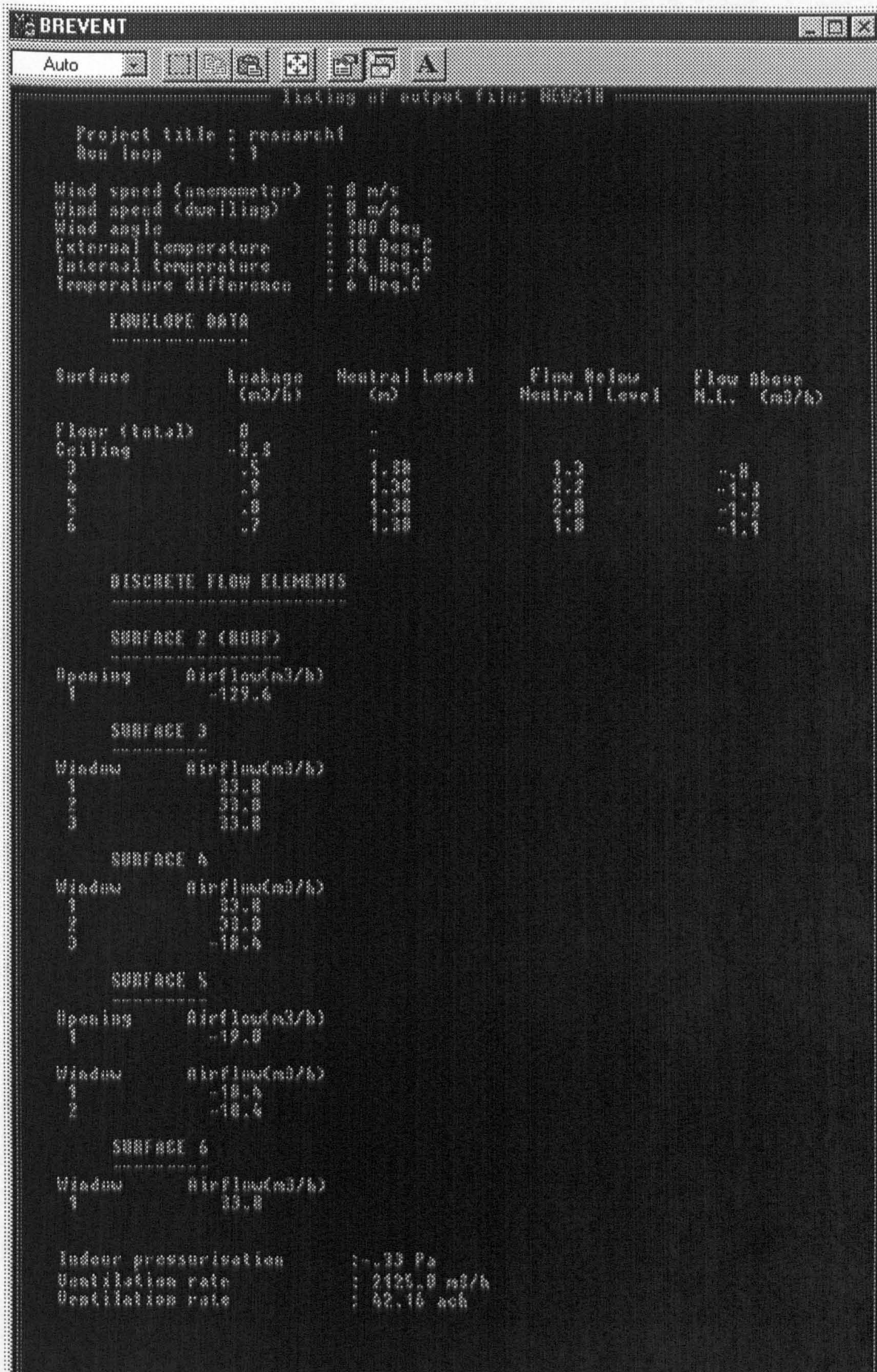

Figure A3.4. An example of the list result after running the Brevent simulation

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Appendix 4:

The Prediction of Particulate Matter Dispersion by using CFD

(C. Mediastika and TJ. Scanlon, based on the CFD experiments, 1998)

The CFD experiment was developed to provide more accurate data and thus give results on the dispersion of particulate matter in particular environmental conditions, in this case referring to Yogyakarta. The CFD prediction was used to study the phenomena of particulate matter dispersion in a certain environmental condition due to the presence of some vertical building elements. As field and CFD experiments have their specific advantages, both of these experiments are of importance in drawing more comprehensive analyses of this study.

The theories behind the CFD experiment are as follows:

Governing equations

The fluid flow was modelled by partial differential equations describing the conservation of mass, momentum and species concentration in three rectangular Cartesian co-ordinate directions for steady, incompressible flow which, after Reynolds averaging become:

Conservation of mass

$$\frac{\partial U_i}{\partial x_i} = 0 \qquad (1)$$

Conservation of momentum

$$\frac{\partial U_i U_j}{\partial x_j} = -\frac{\partial}{\partial x_i}\left(\frac{P}{\rho} + \frac{2}{3}k\right) + \frac{\partial}{\partial x_j}\left\{\nu_t\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\right\} \qquad (2)$$

Conservation of scalar species

$$\frac{\partial C U_t}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\frac{\nu_t}{\sigma_{c,j}}\frac{\partial C}{\partial x_j}\right\} \qquad (3)$$

Transport equation for k

$$\frac{\partial k U_i}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\frac{\nu_t}{\sigma_1}\frac{\partial k}{\partial x_j}\right\} + \nu_t S - \varepsilon \qquad (4)$$

Transport equation for ε

$$\frac{\partial \varepsilon U_i}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\frac{\nu_t}{\sigma_2}\frac{\partial \varepsilon}{\partial x_j}\right\} + C_1\frac{\varepsilon}{k}\nu_t S - C_2\frac{\varepsilon^2}{k} \qquad (5)$$

Where:

$$\nu_t = C_\mu \frac{k^2}{\varepsilon}$$

$$S = \left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right)\frac{\partial U_i}{\partial x_j}, \quad \sigma_1 = 1.0 \quad \sigma_2 = 1.3, \quad C_\mu = 0.09, \quad C_1 = 1.44$$

$$C_2 = 1.92, \quad \sigma_{c,j} = 1.0$$

It should be noted that $\sigma_{c,j}$ is the direction-dependent turbulent Schmidt number for the species equation, which may be varied according to pollutant dispersion observations within the atmospheric boundary layer.

Solution algorithm

The CFD code used was the commercially-available finite volume based package PHOENICS. For the discretisation of convective transport the QUICK was used. For the pressure-velocity coupling the code employs a global solver based on the SIMPLE algorithm.

Boundary conditions

All boundary conditions were implemented by the inclusion of additional source and/or sink terms in the finite volume equations for the computational cells at the domain boundaries. At the upwind free boundary a uniform inlet velocity profile was assumed.

Inlet values of the turbulence parameters k and ε were also prescribed pertaining to typical values within an atmospheric boundary layer.

At the downwind and upper free boundaries a constant pressure boundary condition was applied. For the cube surfaces the standard form of the log-law wall function was applied while at ground level a roughness height $z_0 = 0.0022l$, where l is the building height, is introduced such that at ground level:

$$U = \frac{u_*}{\kappa} ln \frac{z}{z_o} \qquad (6)$$

For the turbulence quantities k and ε the following relationships were applied at solid regions

$$k = \frac{u_*^2}{\sqrt{C_\mu}}, \quad \varepsilon = \frac{u_*^3}{\kappa z} \qquad (7)$$

Convergence criteria

The solution was declared converged when the sum of the mass, momentum and species residues were less than a residual factor of 0.01 times the incoming mass flow. It was found that the total solution time was of the order of 6 hours using a Pentium 266 computer.

Nomenclature

C	pollutant concentration
k	turbulence kinetic energy
ε	dissipation rate of k
Γ	diffusion coefficient
l	building height
p	static pressure
u, v, w, U	velocity
u_*	shear velocity
ν	kinematic viscosity

Subscripts

t	turbulent

Examples of the view results from the CFD simulation can be seen Figures A4.1. and A4.2:

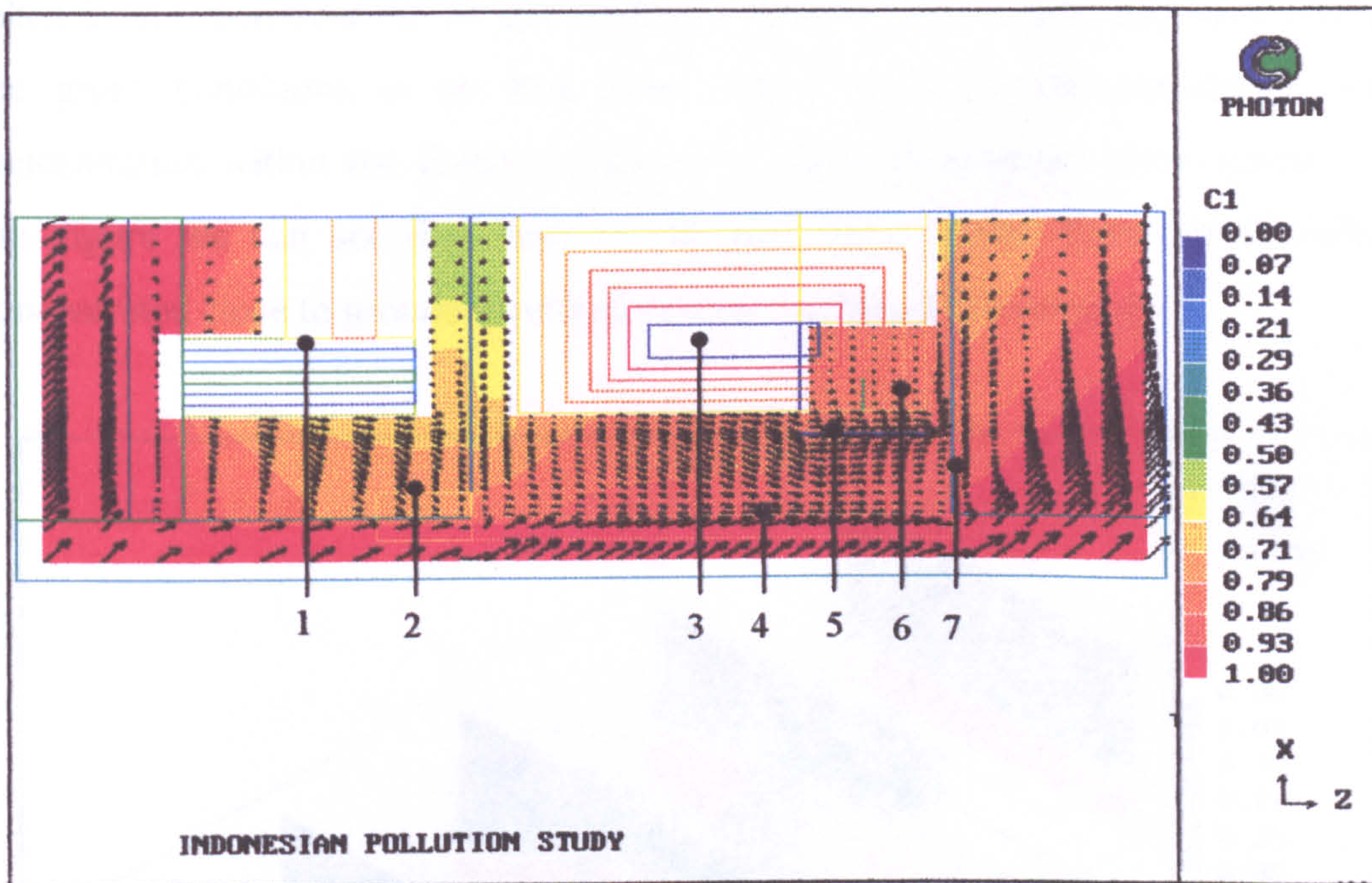

Figure A4.1. Two-dimensional presentation result after running a set of input, based on experiment no.15 as specified in Chapter 11.

Figure A4.1 describes the dispersion of the particulate matter in a given situation as defined in this experiment. Detailed notations are as follows:

1 = a neighbouring house.

2 = an obstruction as a representation of a large neighbouring tree

3 = the reference house

4 = the first fencing

5 = the second porous fence in front of the windows

6 = the room within the house where the concentrations after certain window types were measured

7 = a high side neighbouring wall

In this experiment (see Figure 11.4), the wind was set to move either parallel to the fence (i.e. the street) or at an oblique angle carrying the particulate matter with it. As can be seen in this figure, the wind slowed down when approaching a short obstruction (1m-2 m), but gathered, accelerated and deflected toward rooms with openings when approaching a high obstruction. The different colours show the distribution of particulate matter concentrations.

Figure A4.3 shows an example of the three-dimensional view results which is also taken from experiment no. 15 specified in Chapter 11. This view divided the area of the given conditions in to four areas (cells) to show the particulate matter concentration within the given conditions in three-dimensional presentation. From this figure we can see that most of the particulate matter from street traffic is concentrated close to ground level and decrease in height accordingly.

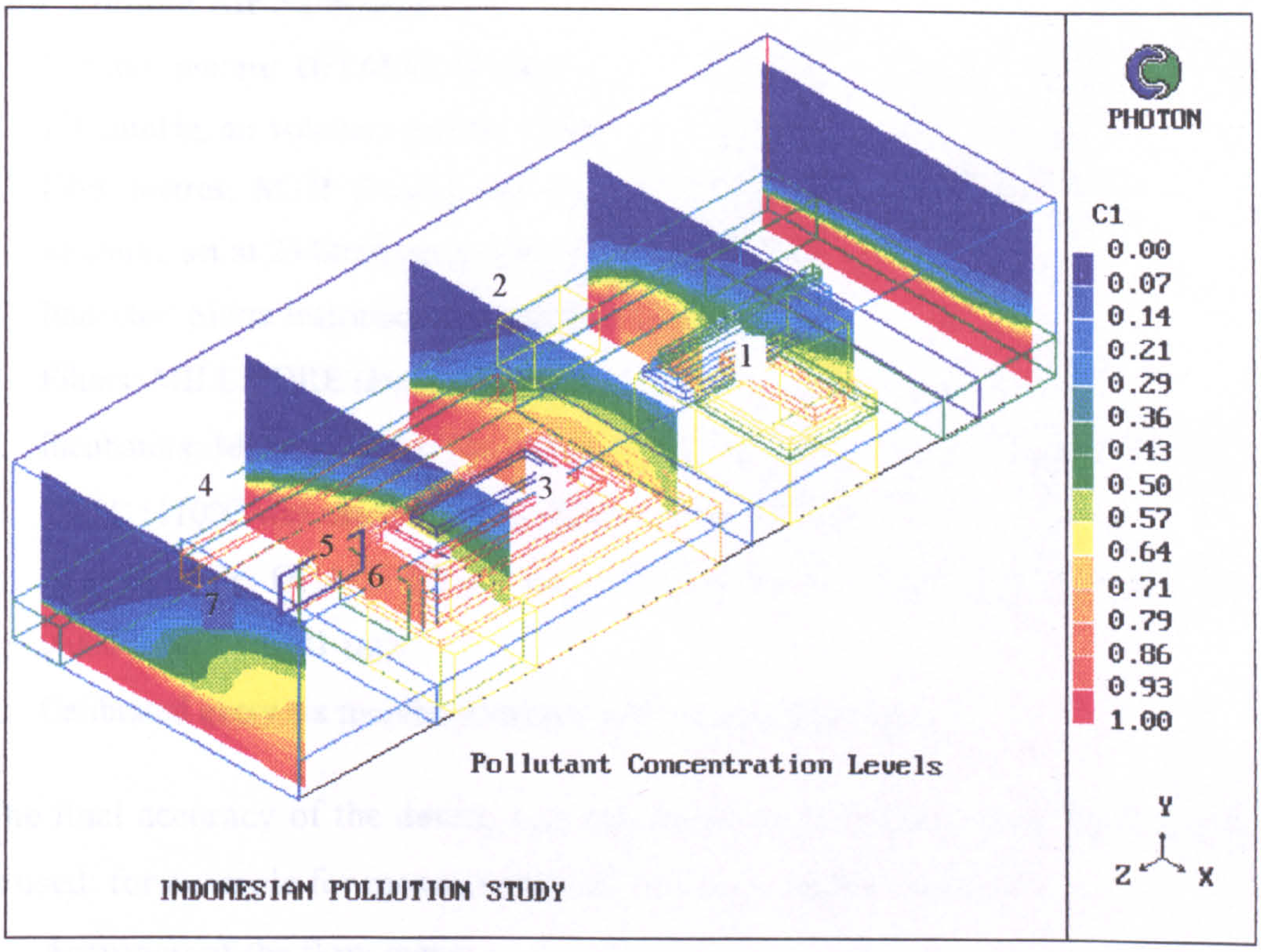

Figure A4.3. Three-dimensional presentation result after running a set of input, the concentration of the particulate matter is also shown with different colour

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Appendix 5:

The Field Experiments

The detailed specifications of the devices used in the field experiments and the results of these experiments are specified in this appendix.

The device specifications:

Low Volume Air Samplers

1. Vacuum pumps: HITACHI (Japan), type 35RC-20SD5, pressure 0.2 kgf/cm^2 (vacuum 150 mmHg, air volume capacity: (vacuum) 0.6 litre/min.
2. Flow metres: MTB (Japan), debit capacity 5 litre/min to 32 litre/min, accuracy 0.1 litre/min, set at 25 litre/men for this measurement.
3. Impactor: Sierra Instruments, Model 234 cascade impactor.
4. Filters: MILLIPORE (Japan); type AP, pore size: prefilter (∅ 55 mm)
5. Incubators: MEMMERT (West Germany), type TV150, range of temperatures 25°C to 120°C (110°C was used to dry the filters), 110V, 600 watt.
6. Analytic scale: OHAUS (USA), type AP250D, maximum capacity 200 gram, accuracy 0.00001 gram (0.01 μg).
7. Calibrated every six months (February and August each year)

The final accuracy of the device was calculated according to the following principal is used: for example for measurement of 24 hours (86400 second) =

- Accuracy of the flow meter

$$\frac{(0.1\text{x}100\%)}{25 \text{ (capacity that is used in the measurements)}} = 0.4\ \%$$

- Accuracy of the analytic scale

$$\frac{(\pm\ 0.01\text{x } 100\ \%)}{100 \text{ (average result from the measurements, i.e. } 100\mu g/m^3)} = 0.01\%$$

- Time accuracy

$$\frac{60 \text{ (60 second device adjustment) x}100\%}{86400} = 0.07\%$$

The final accuracy is the sum of the above three, i.e. 0.48%, or simply 0.5 %.

Devices for measuring weather conditions:

1. Thermometer: CASELLA, Type BS2842/66 UB6316 (wet), Type BS2842 48844 (dry)
2. Anemometer: ISC
3. Stop Watch: HERWINS (Switzerland), accuracy: 0.1 second

Analytic scale for weighting particulate matter on the leaf surface:
SARTORIUS (Germany), Type 2842, maximum capacity 160 g, accuracy: 0.0001 g.

Sound Level Meters for noise measurement in Chapter 5:

1. TECHNIKA, type 84005
2. Measurement range: 35 to 80 dB and 75 to 120 dB
3. Microphone: capacitance
4. Power supply: two 9V batteries
5. Accuracy ± 3 dB

Sound Level Meters for noise measurement in Chapter 12 and 13:

1. RION (Japan); type NL-10A,
2. Measurement range 33 –145 dB (L_{Aeq}),
3. Sensitivity –32 dBA, power: 4xAA size 6 V batteries,
4. Ambient condition for operation -10°C to 50°C (10% RH to 90% RH),
5. Accuracy 1.5 dBA,

SHEETS OF THE FIRST FIELD EXPERIMENTS

(PARTICULATE MATTER DISPERSIONS IN VARIOUS FENCING TYPES)

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel Debu selama 24 jam
di Sagan, Gondokusuman, Yogyakarta.
(Permintaan : Ir. Christina Eviutami. Fak.Teknik UAJ, Yogyakarta.)

Petugas : **Jumiya.**
Ponirah Hayu.

Tanggal. 2 s/d 3 Maret 1998.

No.	Parameter.	Satuan	No.Lab :1516. Jalan (I a) jam : 08.40	No.Lab : 1517. Pagar (II a) jam : 08.40	No.Lab : 1518. Rumah Model (III a) jam : 08.40	No.Lab : 1519. Rumah Asli (IV a) jam : 08.40
1.	Partikel debu	mg/m^3	0,128	0,122	0,097	0,087

Yogyakarta, 9 Maret 1998.

Mengetahui
Kepala Balai Teknik Kesehatan
Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium
Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

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di Sagan, Gondokusuman, Yogyakarta.
(Permintaan : Ir. Christina Eviutami. Fak.Teknik UAJ, Yogyakarta.)

Petugas : **Hartono.**
Damianus Budi Wibowo.

Tanggal. 4 s/d 5 Maret 1998.

No.	Parameter.	Satuan	No.Lab :1500. Jalan (I) jam : 08.55	No.Lab : 1501. Pagar (II) jam : 08.55	No.Lab : 1502. Rumah Model (III) jam : 08.55	No.Lab : 1503. Rumah Asli (IV) jam : 08.55
1.	Partikel debu	mg/m^3	0,158	0,109	0,093	0,075

Yogyakarta, 9 Maret 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel debu selama 24 jam
di Wirobrajan, Yogyakarta.
(Permintaan : Ir. Christina Eviutami. Fak.Teknik UAJ, Yogyakarta.)

Petugas : **Saridjo.**
Paripurno Pilihanto.

Tanggal. 6 s/d 7 Maret 1998.

No.	Parameter.	Satuan	No.Lab :1531. Jalan (V) jam : 09.30	No.Lab : 1532. Pagar (VI) jam : 09.30	No.Lab : 1533. Rumah Model (VII) jam : 09.30	No.Lab : 1534. Rumah Asli (VIII) jam : 09.30
1.	Partikel debu	mg/m^3	0,123	0,093	0,092	0,076

Yogyakarta, 9 Maret 1998.

Mengetahui
Kepala Balai Teknik Kesehatan
Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium
Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
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JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel debu selama 24 jam
di Wirobrajan, Yogyakarta.
(Permintaan : Ir. Christina Eviutami. Fak.Teknik UAJ, Yogyakarta.)

Petugas : **Suhadi Broto.**
Sutoyo.

Tanggal. 9 s/d 10 Maret 1998.

No.	Parameter.	Satuan	No.Lab :1540. Jalan (V a) jam : 08.30	No.Lab : 1541. Pagar (VI a) jam : 08.30	No.Lab : 1542. Rumah Model (VII a) jam : 08.30	No.Lab : 1543. Rumah Asli (VIII a) jam : 08.30
1.	Partikel debu	mg/m^3	0,111	0,079	0,036	0,055

Yogyakarta, 11 Maret 1998.

Mengetahui
Kepala Balai Teknik Kesehatan
Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium
Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
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JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel debu selama 24 jam
di Jogokariyan, Yogyakarta.
(Permintaan : Ir. Christina Eviutami. Fak.Teknik UAJ, Yogyakarta.)

Petugas : **Suparno.**
Bambang Setiyono.

Tanggal. 11 s/d 12 Maret 1998.

No.	Parameter.	Satuan	No.Lab : 1548. Jalan (IX) jam : 08.40	No.Lab : 1549. Pagar (X) jam : 08.40	No.Lab : 1550. Rumah Model (XI) jam : 08.40	No.Lab : 1551. Rumah Asli (XII) jam : 08.40
1.	Partikel debu	mg/m^3	0,084	0,063	0,057	0,060

Yogyakarta, 12 Maret 1998.

Mengetahui
Kepala Balai Teknik Kesehatan
Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium
Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
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Hasil Pengukuran Partikel debu selama 24 jam
di Jogokariyan, Yogyakarta.
(Permintaan : Ir. Christina Eviutami. Fak.Teknik UAJ, Yogyakarta.)

Petugas : **Saridjo.**
Jumiyo.

Tanggal. 13 s/d 14 Maret 1998.

No.	Parameter.	Satuan	No.Lab : 1555 Jalan (IX a) jam : 08.25	No.Lab : 1556 Pagar (X a) jam : 08.25	No.Lab : 1557 Rumah Model (XI a) jam : 08.25	No.Lab : 1558 Rumah Asli (XII a) jam : 08.25
1.	Partikel debu	mg/m^3	0,089	0,062	0,053	0,051

Yogyakarta, 17 Maret 1998.

Mengetahui
Kepala Balai Teknik Kesehatan
Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium
Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
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JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Fisik Udara selama 24 jam
di Sagan, Gondokusuman, Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik UAJ, Yogyakarta.)

Petugas : **Jumiya.**
Ponirah Hayu.

Tanggal. 4 s/d 5 Maret 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1520	09.00	27,5	75,0	Barat (270°)	3,99
2	1521	11.00	29,5	87,0	Barat (270°)	3,27
3	1522	13.00	31,0	92,0	Barat (270°)	3,60
4	1523	15.00	33,5	90,0	Barat (270°)	5,77
5	1524	17.00	31,0	93,0	Barat Daya (225°)	2,99
6	1525	19.00	29,5	80,0	Barat (270°)	2,46
7	1526	21.00	27,5	80,0	Barat (270°)	1,97
8	1527	23.00	26,0	82,0	Barat (270°)	2,15
9	1528	01.00	26,0	85,0	Timur Laut (45°)	2,45
10	1529	03.00	26,0	80,0	Barat (270°)	3,00
11	1530	05.00	26,5	74,0	Barat (270°)	2,45
12	1535	07.00	26,5	68,0	Barat (270°)	2,20

Yogyakarta, 9 Maret 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Fisik Udara selama 24 jam
di Wirobrajan, Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik UAJ, Yogyakarta.)

Petugas : **Saridjo.**
Paripurno Pilihanto.

Tanggal. 6 s/d 7 Maret 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1536	09.00	31,0	82,0	Selatan (180°)	3,66
2	1537	11.00	32,5	79,0	Selatan (180°)	4,27
3	1538	13.00	32,5	70,0	Selatan (180°)	3,57
4	1539	15.00	33,0	68,0	Selatan (180°)	2,86
5	1544	17.00	32,0	70,0	Selatan (180°)	3,97
6	1545	19.00	31,0	65,0	Selatan (180°)	2,90
7	1546	21.00	29,5	67,0	Barat Daya (225°)	3,25
8	1547	23.00	29,5	72,0	Selatan (180°)	2,16
9	1552	01.00	29,0	71,0	Selatan (180°)	2,48
10	1553	03.00	27,0	71,0	Utara (360°)	2,79
11	1554	05.00	25,0	70,0	Utara (360°)	2,49
12	1559	07.00	27,0	70,0	Selatan (180°)	2,32

Yogyakarta, 9 Maret 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Fisik Udara selama 24 jam
di Wirobrajan, Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik UAJ, Yogyakarta.)

Petugas : **Suhadi Broto.**
Sutoyo.

Tanggal. 9 s/d 10 Maret 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1560	09.00	28,0	82,0	Selatan (180°)	2,11
2	1561	11.00	29,0	79,0	Barat Daya (225°)	1,09
3	1562	13.00	32,0	88,0	Selatan (180°)	2,20
4	1563	15.00	32,5	89,0	Selatan (180°)	2,59
5	1564	17.00	31,5	91,0	Barat (270°)	3,50
6	1565	19.00	29,5	85,0	Selatan (180°)	4,91
7	1566	21.00	27,0	80,0	Selatan (180°)	2,57
8	1567	23.00	26,5	82,0	Selatan (180°)	2,73
9	1568	01.00	26,0	75,0	Selatan (180°)	2,86
10	1569	03.00	25,5	76,0	Barat Daya (225°)	3,81
11	1570	05.00	26,0	78,0	Selatan (180°)	2,59
12	1571	07.00	26,5	76,0	Selatan (180°)	2,78

Yogyakarta, 11 Maret 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Fisik Udara selama 24 jam
di Jogokariyan, Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik UAJ, Yogyakarta.)

Petugas : **Suparno.**
Bambang Setiono.

Tanggal. 11 s/d 12 Maret 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1572	09.00	29,5	69,0	Barat Daya (225°)	1,57
2	1573	11.00	30,0	70,0	Barat (270°)	2,74
3	1574	13.00	33,0	75,0	Barat (270°)	2,84
4	1575	15.00	32,0	71,0	Timur (90°)	3,80
5	1576	17.00	33,5	78,0	Barat (270°)	2,24
6	1577	19.00	32,0	80,0	Barat (270°)	2,78
7	1578	21.00	29,0	74,0	Barat (270°)	2,10
8	1579	23.00	30,0	72,0	Barat (270°)	0,99
9	1580	01.00	27,0	64,0	Barat (270°)	2,14
10	1581	03.00	25,0	71,0	Barat (270°)	2,89
11	1582	05.00	25,0	70,0	Barat Daya (225°)	3,50
12	1583	07.00	27,0	64,0	Barat (270°)	4,81

Yogyakarta, 12 Maret 1998.

Mengetahui
Kepala Balai Teknik Kesehatan
Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium
Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Fisik Udara selama 24 jam
di Jogokariyan, Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik UAJ, Yogyakarta.)

Petugas : **Saridjo.**
Jumiya.

Tanggal. 13 s/d 14 Maret 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1584	09.00	30,5	72,0	Barat (270°)	2,89
2	1585	11.00	31,0	72,0	Timur (90°)	2,54
3	1586	13.00	34,5	79,0	Barat (270°)	3,70
4	1587	15.00	33,5	70,0	Barat (270°)	2,91
5	1588	17.00	33,5	70,0	Barat (270°)	2,44
6	1589	19.00	32,0	70,0	Timur (90°)	3,79
7	1590	21.00	32,5	68,0	Barat (270°)	2,97
8	1591	23.00	30,0	67,0	Timur (90°)	3,51
9	1592	01.00	30,0	72,0	Barat (270°)	2,45
10	1593	03.00	25,0	71,0	Barat Laut (315°)	2,55
11	1594	05.00	27,0	70,0	Barat Laut (315°)	1,45
12	1595	07.00	30,0	70,0	Barat (270°)	1,20

Yogyakarta, 17 Maret 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

SHEETS OF THE SECOND FIELD EXPERIMENTS

(PARTICULATE MATTER DISPERSIONS IN THE PRESENCE OF VEGETATION)

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel Debu
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Suhadi Broto.**
Ngatidjan.

Tanggal, 2 Nopember 1998.

NO	Parameter	Satuan	No.Lab: 1221 Code : A (1) Jam : 08.15	No.Lab: 1222 Code : B1 (1) Jam : 08.15	No.Lab: 1223 Code : B2 (1) Jam : 08.15	No.Lab: 1224 Code : P1(1)	No.Lab: 1225 Code : P2 (1)
1.	Partikel debu.	mg/m^3	0,054	0,048	0,040	-	-
2.	Debu di Daun.	mg	-	-	-	0,20	0,50

Mengetahui :
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Yogyakarta, 7 Nopember 1998.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel Debu
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Hartono.**
Sutoyo.

Tanggal, 3 Nopember 1998.

NO	Parameter	Satuan	No.Lab: 1234 Code : A (2) Jam : 08.30	No.Lab: 1235 Code : B1 (2) Jam : 08.30	No.Lab: 1236 Code : B2 (2) Jam : 08.30	No.Lab: 1237 Code : P1(2)	No.Lab: 1238 Code : P2 (2)
1.	Partikel debu.	mg/m^3	0,089	0,067	0,056	-	-
2.	Debu di Daun.	mg	-	-	-	0,70	0,90

Mengetahui :
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Yogyakarta, 7 Nopember 1998.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel Debu
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Jumiya.**
Parjono.

Tanggal, 4 Nopember 1998.

NO	Parameter	Satuan	No.Lab: 1247 Code : A (3) Jam : 08.15	No.Lab: 1248 Code : B1 (3) Jam : 08.15	No.Lab: 1249 Code : B2 (3) Jam : 08.15	No.Lab: 1250 Code : P1(3)	No.Lab: 1251 Code : P2 (3)
1.	Partikel debu.	mg/m^3	0,100	0,071	0,044	-	-
2.	Debu di Daun.	mg	-	-	-	0,30	0,50

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Yogyakarta, 7 Nopember 1998.

Koordinator Laboratorium
Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel Debu
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Hartono.**
Ngatidjan.

Tanggal, 5 Nopember 1998.

NO	Parameter	Satuan	No.Lab: 1260 Code : A (4) Jam : 08.15	No.Lab: 1261 Code : C1 (4) Jam : 08.15	No.Lab: 1262 Code : C2 (4) Jam : 08.15	No.Lab: 1263 Code : R1(4)	No.Lab: 1264 Code : R2 (4)
1.	Partikel debu.	mg/m^3	0,050	0,045	0,041	-	-
2.	Debu di Daun.	mg	-	-	-	7,21	1,68

Yogyakarta, 7 Nopember 1998.

Mengetahui :
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN

BALAI TEKNIK KESEHATAN LINGKUNGAN

JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel Debu
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Saridjo.**
Ponirah Hayu.

Tanggal, 6 Nopember 1998.

NO	Parameter	Satuan	No.Lab: 1273 Code : A (5) Jam : 08.30	No.Lab: 1274 Code : C1 (5) Jam : 08.30	No.Lab: 1275 Code : C2 (5) Jam : 08.30	No.Lab: 1276 Code : R1(5)	No.Lab: 1277 Code : R2 (5)
1.	Partikel debu.	mg/m^3	0,088	0,043	0,035	-	-
2.	Debu di Daun.	mg	-	-	-	1,36	1,38

Yogyakarta, 7 Nopember 1998.

Mengetahui :
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel Debu
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Jumiya.**
Suparno.

Tanggal, 7 Nopember 1998.

NO	Parameter	Satuan	No.Lab: 1286 Code : A (6) Jam : 08.15	No.Lab: 1287 Code : C1 (6) Jam : 08.15	No.Lab: 1288 Code : C2 (6) Jam : 08.15	No.Lab: 1289 Code : R1(6)	No.Lab: 1290 Code : R2 (6)
1.	Partikel debu.	mg/m^3	0,073	0,059	0,065	-	-
2.	Debu di Daun.	mg	-	-	-	2,06	2,37

Yogyakarta, 7 Nopember 1998.

Mengetahui :
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel Debu
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Saridjo.**
Paripurno P.

Tanggal, 10 Nopember 1998.

NO	Parameter	Satuan	No.Lab: 1309 Code : A $_{(0)}$ Jam : 08.30	No.Lab: 1310 Code : B$_{(0)}$ Jam : 08.30	No.Lab: 1311 Code : C $_{(0)}$ Jam : 08.30	No.Lab: 1312 Code : D$_{(0)}$ Jam : 08.30
1.	Partikel debu.	mg/m³	0,057	0,055	0,053	0,068

Yogyakarta, 17 Nopember 1998.

Mengetahui :
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN
PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel Debu
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Suhadi Broto.**
Suzana.

Tanggal, 11 Nopember 1998.

NO	Parameter	Satuan	No.Lab: 1321 Code : A (7) Jam : 08.15	No.Lab: 1322 Code : D1(7) Jam : 08.15	No.Lab: 1323 Code : D2 (7) Jam : 08.15
1.	Partikel debu.	mg/m^3	0,055	0,056	0,053

Yogyakarta, 17 Nopember 1998.

Mengetahui :
Kepala Balai Teknik Kesehatan
Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium
Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel Debu
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Jumiya.**
Ponirah Hayu.

Tanggal, 12 Nopember 1998.

NO	Parameter	Satuan	No.Lab: 1347 Code : A (8) Jam : 08.15	No.Lab: 1348 Code : D1(8) Jam : 08.15	No.Lab: 1349 Code : D2 (8) Jam : 08.15
1.	Partikel debu.	mg/m^3	0,125	0,106	0,097

Yogyakarta, 17 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
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JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Partikel Debu
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Saridjo.**
Paripurno P.

Tanggal, 13 Nopember 1998.

NO	Parameter	Satuan	No.Lab: 1365 Code : A (9) Jam : 08.15	No.Lab: 1366 Code : D1(9) Jam : 08.15	No.Lab: 1367 Code : D2 (9) Jam : 08.15
1.	Partikel debu.	mg/m^3	0,053	0,047	0,037

Yogyakarta, 17 Nopember 1998.

Mengetahui :
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Fisik Udara
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Suhadi Broto.**
Ngatidjan.

Tanggal, 2 Nopember 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1226	08.30	27,5	86,0	Barat (270°)	3,60
2	1227	09.30	28,5	82,0	Barat (270°)	3,43
3	1228	10.30	29,0	75,0	Barat (270°)	3,03
4	1229	11.30	28,5	79,0	Barat (270°)	5,14
5	1230	12.30	29,0	79,0	Barat (270°)	5,30
6	1231	13.30	28,0	78,0	Timur (90°)	5,14
7	1232	14.30	27,5	82,0	Barat (270°)	4,50
8	1233	15.30	27,0	82,0	Barat (270°)	3,30

Yogyakarta, 7 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Fisik Udara
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Hartono.**
Sutoyo.

Tanggal, 3 Nopember 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1239	08.30	26,0	92,0	Barat (270°)	3,30
2	1240	09.30	28,0	82,0	Barat (270°)	1,99
3	1241	10.30	29,0	79,0	Timur (90°)	1,16
4	1242	11.30	29,0	75,0	Barat Laut (315°)	2,99
5	1243	12.30	29,0	80,0	Barat Laut (315°)	1,19
6	1244	13.30	28,5	79,0	Barat (270°)	2,07
7	1245	14.30	28,0	85,0	Barat Laut (315°)	1,49
8	1246	15.30	28,0	82,0	Barat (270°)	2,39

Yogyakarta, 7 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Fisik Udara
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Jumiya.**
Parjono.

Tanggal, 4 Nopember 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1252	08.30	30,0	73,0	Timur (90°)	4,24
2	1253	09.30	30,5	67,0	Barat (270°)	3,60
3	1254	10.30	31,0	70,0	Barat (270°)	3,98
4	1255	11.30	31,0	67,0	Barat (270°)	3,86
5	1256	12.30	30,0	69,0	Barat (270°)	6,95
6	1257	13.30	31,5	67,0	Barat (270°)	6,93
7	1258	14.30	29,0	72,0	Barat (270°)	4,15
8	1259	15.30	27,0	85,0	Barat (270°)	5,14

Yogyakarta, 7 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan
Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium
Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
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Hasil Pengukuran Fisik Udara
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Hartono.**
Ngatidjan.

Tanggal, 5 Nopember 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1265	08.30	39,0	72,0	Timur (90°)	3,79
2	1266	09.30	29,5	69,0	Barat (270°)	4,50
3	1267	10.30	30,0	79,0	Barat (270°)	3,79
4	1268	11.30	30,5	70,0	Barat (270°)	3,91
5	1269	12.30	31,5	68,0	Barat (270°)	4,50
6	1270	13.30	29,0	75,0	Barat (270°)	3,21
7	1271	14.30	27,5	82,0	Barat (270°)	1,89
8	1272	15.30	27,0	89,0	Barat (270°)	2,39

Yogyakarta, 7 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
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(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Saridjo.**
Ponirah Hayu.

Tanggal, 6 Nopember 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1278	08.30	27,5	82,0	Barat Daya (225°)	3,60
2	1279	09.30	30,0	69,0	Barat (270°)	2,32
3	1280	10.30	30,0	73,0	Barat Laut (315°)	2,77
4	1281	11.30	28,5	85,0	Barat (270°)	2,06
5	1282	12.30	29,0	85,0	Barat Daya (225°)	1,81
6	1283	13.30	29,5	73,0	Barat (270°)	2,82
7	1284	14.30	30,5	70,0	Barat (270°)	3,35
8	1285	15.30	30,0	73,0	Barat (270°)	2,88

Yogyakarta, 7 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan
Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

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Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Jumiya.**
Suparno.

Tanggal, 7 Nopember 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1291	08.30	28,0	78,0	Barat (270°)	4,79
2	1292	09.30	29,5	75,0	Barat (270°)	3,60
3	1293	10.30	30,5	75,0	Barat (270°)	4,28
4	1294	11.30	30,0	66,0	Barat (270°)	4,34
5	1295	12.30	31,0	67,0	Barat (270°)	4,24
6	1296	13.30	28,0	78,0	Barat (270°)	3,86
7	1297	14.30	29,5	75,0	Barat Daya (225°)	4,09
8	1298	15.30	29,5	66,0	Barat (270°)	5,51

Yogyakarta, 7 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
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Petugas : **Saridjo.**
Paripurno P.

Tanggal, 10 Nopember 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1313	08.30	29,5	69,0	Timur Laut (45°)	2,46
2	1314	09.30	31,0	70,0	Timur Laut (45°)	3,27
3	1315	10.30	31,5	65,0	Timur (90°)	3,60
4	1316	11.30	29,0	72,0	Timur Laut (45°)	3,99
5	1317	12.30	31,0	67,0	Barat Daya (225°)	5,78
6	1318	13.30	29,5	66,0	Barat (270°)	2,99
7	1319	14.30	26,5	88,0	Timur Laut (45°)	0,67
8	1320	15.30	27,0	85,0	Timur (90°)	1,96

Yogyakarta, 17 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
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JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Fisik Udara
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Suhadi Broto.**
Suzana.

Tanggal, 11 Nopember 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1324	08.30	27,5	86,0	Barat (270°)	2,30
2	1325	09.30	29,0	75,0	Barat (270°)	3,50
3	1326	10.30	29,5	73,0	Barat (270°)	3,00
4	1327	11.30	29,5	79,0	Barat (270°)	2,10
5	1328	12.30	29,5	80,0	Barat (270°)	3,50
6	1329	13.30	31,5	73,0	Barat (270°)	4,00
7	1330	14.30	31,0	70,0	Barat (270°)	4,00
8	1331	15.30	30,0	73,0	Barat (270°)	5,00

Yogyakarta, 17 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
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Hasil Pengukuran Fisik Udara
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(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Jumiya.**
Ponirah Hayu.

Tanggal, 12 Nopember 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1350	08.30	30,5	70,0	Barat Laut (315°)	3,00
2	1351	09.30	30,5	64,0	Timur (90°)	4,16
3	1352	10.30	32,5	57,0	Barat (270°)	4,73
4	1353	11.30	32,0	62,0	Barat (270°)	6,92
5	1354	12.30	31,5	63,0	Timur (90°)	2,25
6	1355	13.30	31,5	63,0	Barat Daya (225°)	4,72
7	1356	14.30	32,0	62,0	Barat (270°)	6,39
8	1357	15.30	30,5	64,0	Barat (270°)	4,27

Yogyakarta, 17 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Fisik Udara
Di Sagan, Kotamadia *Yogyakarta*.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, *Yogyakarta*)

Petugas : **Saridjo.**
Paripurno P.

Tanggal, 13 Nopember 1998.

No	No. Lab	Jam	Suhu udara (C°)	Kelembaban (% RH)	Arah angin (X°)	Kecepatan angin (km/jam)
1	1368	08.30	28,0	78,0	Barat Daya (225°)	1,80
2	1369	09.30	29,5	69,0	Barat (270°)	3,20
3	1370	10.30	30,0	66,0	Barat (270°)	2,10
4	1371	11.30	30,0	63,0	Barat (270°)	3,30
5	1372	12.30	30,0	66,0	Barat (270°)	2,80
6	1373	13.30	29,5	69,0	Barat (270°)	2,90
7	1374	14.30	29,5	63,0	Barat (270°)	2,60
8	1375	15.30	29,0	66,0	Barat (270°)	2,30

Yogyakarta, 17 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

SHEETS OF THE SOUND INSULATION EXPERIMENTS

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
BALAI TEKNIK KESEHATAN LINGKUNGAN
JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Kebisingan
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Saridjo.**
Paripurno P.

Tanggal, 13 Nopember 1998.

No	Jam	Kebisingan dB(A)	
		Luar Code : X (8)	Dalam Code : Y (8)
1	08.30 – 08.35	69,1	59,8
2	09.00 – 09.05	67,6	58,8
3	09.30 – 09.35	65,7	54,4
4	10.00 – 10.05	69,5	59,5
5	10.30 – 10.35	68,0	57,8
6	11.00 – 11.05	69,5	58,1
7	11.30 – 11.35	69,4	58,2
8	12.00 – 12.05	67,4	56,3
9	12.30 – 12.35	68,1	57,8
10	13.00 – 13.05	74,4	61,4
11	13.30 – 13.35	69,5	59,3
12	14.00 – 14.05	68,5	58,0
13	14.30 – 14.35	69,2	58,3
14	15.00 – 15.05	68,1	58,3
15	15.30 – 15.35	70,4	60,1

Yogyakarta, 17 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

DEPARTEMEN KESEHATAN R.I.
DIREKTORAT JENDERAL PEMBERANTASAN PENYAKIT MENULAR DAN PENYEHATAN LINGKUNGAN PEMUKIMAN
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JALAN POLOWIJAN No. 11 TELP. (0274) 376288 FAX. 384637 YOGYAKARTA 55133

Hasil Pengukuran Kebisingan
Di Sagan, Kotamadia Yogyakarta.
(Permintaan : Ir. Christina Eviutami, Fak. Teknik, Univ. Atmajaya, Yogyakarta)

Petugas : **Hartono.**
Suzana.

Tanggal, 16 Nopember 1998.

No	Jam	Kebisingan dB(A)			
		Luar Code : X (10)	Dalam 1 Code : Y1(10)	Dalam 2 Code : Y2(10)	Dalam 3 Code : Y3(10)
1	08.30 – 08.35	69,1	58,7	59,8	57,4
2	09.00 – 09.05	65,7	65,7	54,4	54,3
3	09.30 – 09.35	69,5	59,3	59,5	58,6
4	10.00 – 10.05	68,0	57,9	57,8	58,1
5	10.30 – 10.35	69,5	59,5	58,1	56,4
6	11.00 – 11.05	69,4	59,1	58,2	57,7
7	11.30 – 11.35	67,4	56,5	56,3	57,5
8	12.00 – 12.05	68,1	57,9	57,8	55,3
9	12.30 – 12.35	69,5	59,9	59,3	56,0
10	13.00 – 13.05	68,5	58,1	58,0	56,6
11	13.30 – 13.35	69,2	58,7	58,3	57,8
12	14.00 – 14.05	68,1	57,8	58,3	57,2
13	14.30 – 14.35	70,4	60,0	60,1	59,2

Yogyakarta, 17 Nopember 1998.

Mengetahui
Kepala Balai Teknik Kesehatan Lingkungan Yogyakarta.

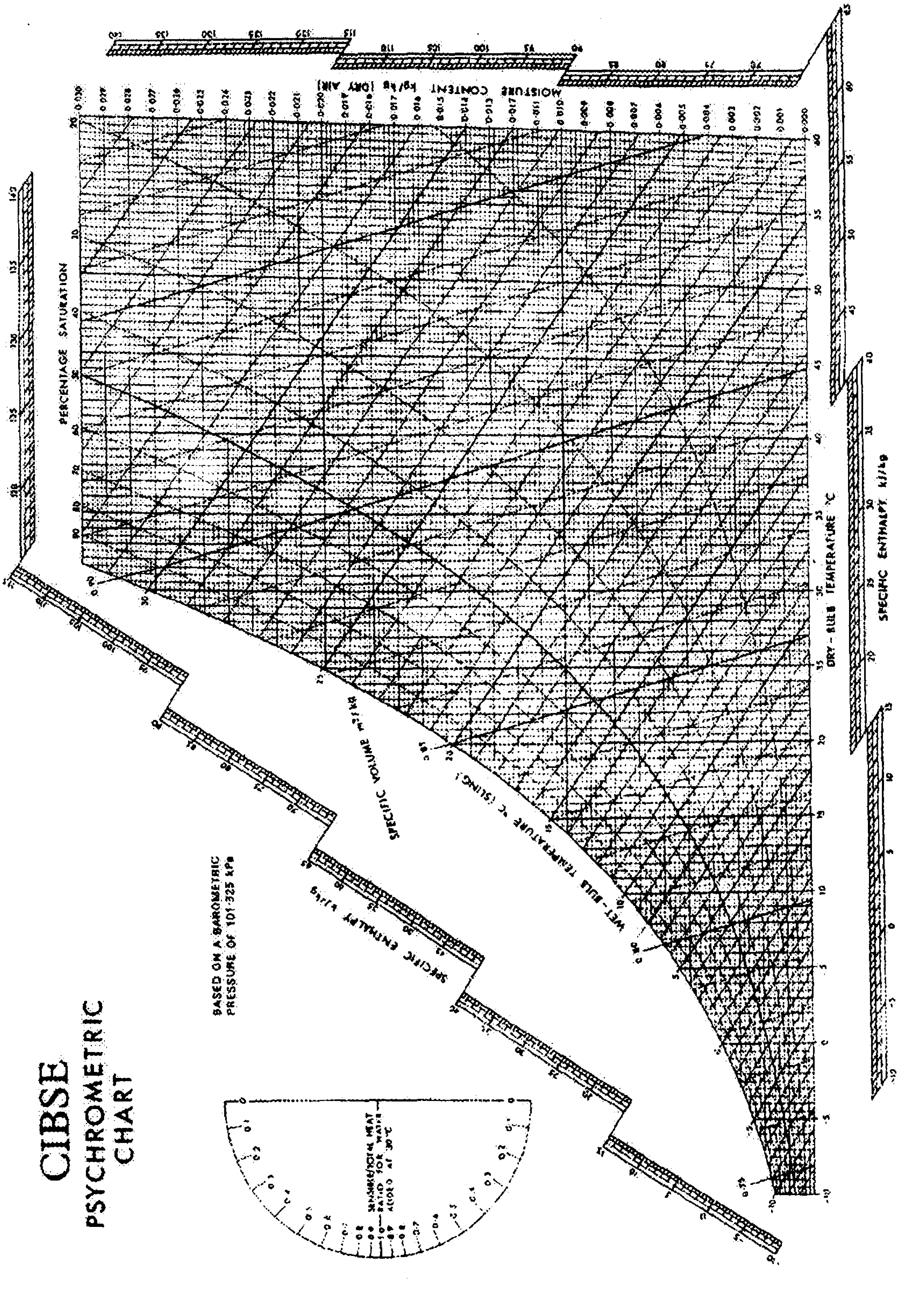
Ir. JB. BUDI HARSANTO.
NIP. 140 098 823.

Koordinator Laboratorium Kimia Fisika Gas.

Ir. SIGIT HERNOWO.
NIP. 140 129 859.

Appendix 6:

Psychometric Charts



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