COMPUTER SIMULATION OF BUILDINGS WITH PASSIVE ELEMENTS FOR ENERGY EFFICIENCY

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ABSTRACT: Conservation of energy used for thermal and visual comfort in the building sector using passive techniques has both short and long term benefits. In short term, passive solar buildings can mean lower capital cost due to smaller equipment and in the longer run, the life cycle cost of the buildings would be lower. Since major decisions that affect the thermal performance are taken by the architect at the pre- design stage, it is essential to provide him with a set of tools on passive techniques that can be integrated to his design. These tools can be as important as detailed computer simulations since those can be adopted only when the architectural design of the structure is completed to a considerable extent. Therefore, detailed computer simulations are better suited to optimise a building where the architect has already incorporated some of the energy conservation options. This paper explains the development of a set of graphical aids for hot humid climates using the results of computer simulations. The possibility of developing artificial neural networks with such results also has been highlighted.

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INTRODUCTION

The building industry is one of the largest industrial sectors world-wide. In Europe, it is the second largest industry accounting for around 12% of gross domestic product. However, little progress has been made towards the improvements of energy efficiency of buildings. According to Kennington & Monaghan (1993), the main reasons for this is as follows:

1. The design of energy efficient buildings is a complex task involving many different design disciplines requiring expertise that takes many years of study and practice to acquire.

2. There is little communication between professionals involved in the different design domains especially in the early stages of a project where the decisions taken have the greatest impact on future energy usage in the building. For example, architects and HVAC engineers may not interact at the very early stages of the design. In many instances, many design professionals are not recruited until the later stages of the project, resulting in major decisions being made without full knowledge of their consequences.

3. Software tools currently available may not provide sufficient information in a readily usable form at appropriate times in the design process, particularly in the early stages of a project.

Due to its vast usage of energy, energy conservation in the building sector can be identified as one of the major sources for the reduction of the fossil and nuclear fuel. Building designs with passive techniques has an important potential for energy conservation by reducing the heating and cooling needs in both residential and commercial buildings (Wouters et al., 1993). Generally, the architects work on the basis of whole to detail while the computer simulations for the thermal performance need information from detail to the complete building. Therefore, it is necessary for the architect to have a set of simple graphical tools that can be used in the pre-design stage when integrating the passive solar concepts. This will allow the inclusion of as many passive concepts as possible to conserve energy from the pre-design stage.

The development of graphical tools could be done by carrying out a large number of computer simulations on typical buildings. This paper explains one such simulation and the associated analysis to develop the graphical tools for hot humid climates prevailing in tropical countries. The use of Perimeter Annual Value concept in preference to Overall Thermal Transmission Value for hot humid climates is also highlighted.

These graphical tools also can be used to develop Artificial Neural Networks as well. The use of neural networks for this purpose will have certain advantages over representing the computer simulations in graphical form.

1. The graphical tools can be prepared only for selected cases. In the case of intermediate values of parameters, it would be necessary to resort to linear interpolation between two graphs, where the relationship may not be linear. In such situations, the neural network could be a better tool to predict an approximate annual air conditioning load.

2. The results from the neural network can be checked approximately with available graphical tools to determine the validity of the answers. It they are acceptable, those results also can be incorporated to further improve the neural network.

It will be possible to carryout similar simulations for a large number of buildings with different dimensions and these data can be used to train the neural network. Once trained, the neural network will be able to predict the energy consumption for a wide variety of buildings, which would be difficult to cover with graphical tools. This will be another application of computer simulations that can be carried out on proposed buildings.

ENERGY SAVINGS IN BUILDINGS

It is a primary requirement in buildings to provide visual, thermal and acoustic comfort together with other services. The desirable levels of these comforts are generally achieved by using energy, where there would be only a few buildings where the usage of energy is optimised without constraining the function of the building. In Western Europe, a massive 52% of energy delivered is consumed to maintain acceptable environmental conditions within buildings (Clark and Maver, 1991). In Taiwan, more than 30% of the total electrical power of the country is consumed by residential and commercial sectors. Of this, 40% is for providing lighting, 40% for air-conditioning and 20% for other functions (Yang and Hwang, 1993).

In Sri Lanka, the commercial sector consumes about 20% of the total energy demand at present, and this is expected to grow up to about 28% by 2013. Of this energy, 20% is for lighting, 5% for ventilation and 55% for air-conditioning (Attalage and Wijetunga, 1997).

Studies on possible energy savings have shown that in United States, a sum of US $ 100 billion a year can be saved by doubling the energy efficiency by the year 2010 (Bevington & Rosenfeld, 1990). The United Kingdom Department of Energy suggests that better design of new buildings could result in 50% reduction in energy consumption and that appropriate design intervention could yield reductions of 25% (Mathews & Richards, 1993). It is shown by Attalage and Wijetunga (1997) that in Sri Lanka, the commercial sector has a total energy conservation potential of 20% - 40% of the total consumption by the year 2013 if state of the art energy efficient equipment gradually replaces the existing equipment. Of this saving, air conditioning accounts for 14.4%-26.5%. It would be possible to make further savings if future buildings incorporate more and more passive solar techniques. This clearly shows that there is a considerable potential for saving energy by adopting appropriate techniques, specially of passive nature for buildings.

There is another important reason to seek energy savings in buildings in the context of preserving the environment. A major cause responsible for the global environmental degradation is the release of refrigeration gases and combustion products of fossil fuel into the atmosphere. These gases are primarily responsible for the depletion of the atmospheric ozone layer, global warming and acid rains, which can have serious effects on humans, animals and plant if left to progress unchecked.

Therefore, determination of methods that ensure thermal efficiency to limit the refrigeration loads in buildings are thus of paramount importance for the future. Achieving indoor thermal comfort with small capital investment is another subject area requiring earnest attention in the future.

When designing, architects follow the whole concept and proceed towards detailed design. Therefore, the main decisions are taken in the pre-design stage. Those decisions will generally determine the major thermal characteristics of the building. When computer simulations are used for buildings, those are performed starting from details, leading step by step to the complete design. Therefore, the procedure moves from the constituent parts towards the whole. This is in the opposite direction to the architectural design approach. Thus, for a proper simulation, the architectural design should run a full course (Holm, 1993). Usually towards the end of the architectural design, the building owner and the architect may have been inspired by the design in which case any extra energy cost may be of little significance.

Therefore, it is essential that the concepts that give the thermal efficiency are available to the architect in simple terms so that he can integrate at least some of the concepts into his design. One way to develop these concepts is to carry out computer simulations for typical buildings with the adoption of various energy conservation concepts, especially adopting passive techniques. The results of these computer simulations can be presented as graphical tools for the use of architects at the pre-design stage.

Since the climates and perceptions of thermal comfort can vary from one country to another or even within a country, it is very important to carry out detailed studies and then to produce these rules for various local climatic conditions.

USE OF PERIMETER ANNUAL LOAD VALUE FOR COMPARISONS

In hot humid environments, shading devices are far more effective than thermal insulation (Yang and Hwang, 1993). One of the parameters available for evaluating the thermal performance of building envelope is Overall Thermal Transmission Value (OTTV). This is of particular application to temperate climates where insulation is important in minimising the building energy use, which primarily comes from the conductive heating load.

As described by Yang and Hwang (1993), for hot humid climates, the use of Perimeter Annual Load value (PAL value) is more appropriate and offers more flexibility for the architect in adopting passive concepts. PAL value evaluates the heat gain per floor area, taking account of all external and internal heat gains including those from the building envelope. Thus, the architects have the option of adopting some features such as large glass facades that may not be the optimum, but to adopt some other concepts like adequate shading which will give a PAL value that is low enough.

PAL value also can be used as an indicator of the efficiency of the passive concepts adopted and also to compare the results of computer thermal simulations.

COMPUTER SIMULATIONS

In this study, the computer simulations have been carried out using the software package CASAMO developed as part of Ademe-AIT RUE Project at Asian Institute of Technology. It is a tool for designing buildings with one of the following objectives. It could be used to design buildings with comfortable thermal conditions, determine the methods available for reducing the energy consumed for air conditioning or calculating the air-conditioning loads of proposed or existing buildings. In hot humid tropical climates, the main sources of heat gains are due to effects of radiation transmitted through glazed areas and absorbed by roofing and exposed facades. The conduction component is not very dominant due to low temperature difference. In commercial buildings, considerable heat gains are also possible due to occupants, lighting and appliances (casual gains).

In this research work, CASAMO has been used to determine the air conditioning loads for different facade conditions, indoor temperatures throughout the year at an interval of two months. The annual air conditioning loads are calculated without considering the casual gains due to occupants and usage since the idea is to determine the effects of the facade on the thermal performance of the building. The air conditioning loads have been calculated for every two months since the sun path varies throughout the year. Although an interval of one month is preferable, it was not considered in order to keep the number of computer simulations at a manageable level.

Thermal gains in an air conditioned building can be due to reasons such as thermal gains due to direct solar irradiance through external glass facade, indirect solar irradiance through shaded or unshaded glass facades, solar gains through the solid walls, etc. Some of these have been considered in more detail.

Thermal Gains due to Direct Irradiance

This is specially applicable for facades facing east and west since solar altitude angle changes from about 0° at 0600 hours to 60° - 90° at noon depending on the day under consideration and then to about 0° at 1800 hours. Thus, it is quite difficult to control the direct solar irradiance gains by having large glass facades facing east or west.

Therefore, it is desirable to use solid walls for facades facing east and west. When solid walls are used, those are useful in maximising the time lag taken by any heat absorbed by the external facade reaching the interior face. Generally, a wall thickness of 200 mm with solid materials is sufficient to provide a time lag of about 6 hours when no insulation is used (Szololay, 1991). This thickness is also would be able to provide sufficient resistance against rainwater penetration and also could be cast either with bricks or precast concrete. Therefore, a wall thickness of 200 mm was used for the computer simulations, when no glass panels were provided. The effects of having glass facades of different window to wall ratios (WWR) without any shading were evaluated in the case studies.

Due to location of Sri Lanka, it is possible to control the direct solar radiation gains through windows facing north or south by providing appropriate shading devices. It has been shown by Jayasinghe et al (1997) that horizontal shading devices on north and south facades should subtend an angle, ϕ (see Figure 1), less than or equals to 50° to provide sufficient shading from 0800 hours until 1600 hours.

In many buildings in Sri Lanka, the present trend is to have large glass facades without any shading devices. When such a facade faces north or south, each of them will receive direct irradiance for nearly 10 hours from 0700 hours until 1700 hours for nearly six months of the year. However, it is possible to provide the external glass facades of these buildings with shading by using shading devices arranged horizontally and vertically as shown in Figure 2 a and b. In large glass facades, the projection required from the face of the building can be minimised by forming recessed windows where a large window will be formed by a large number of small windows as shown in Figure 2 c. Thus, for modelling, glass facades that have been shaded and unshaded were considered.

CASAMO does not allow the simulation of shaded windows consisting of large number of small windows. It allows only one horizontal shading device to be assigned for a given window. Therefore, a horizontal shading device has been specified where the projection of it was calculated by considering the full height of the glass facade between two consecutive floors. For example, the overhang of a shading device used in computer simulations for a window of height 1.8 m was 1.5 m.

Thermal Gains due to Indirect Solar Irradiance

Indirect solar irradiance on a building consist of diffused irradiance and ground reflected irradiance. The intensity of these irradiances are lower than the direct irradiance. When large glass facades are provided for buildings, irrespective of the presence of shading devices, heat gains due to indirect solar irradiance will take place. The heat gains due to indirect irradiance can be minimised when solid facades are used without windows.

Case Studies

Two case studies that have been carried out to model two different buildings are presented here. The details of the case studies are as follows.

1. Building details: Two building shapes have been considered. A square building of 24 m x 24 m and a rectangular building of approximately the same area of 20 m x 30 m. These two cases were considered to check the shape that is thermally more efficient. Both buildings were of ten storeys. The floor to floor height was 3.6 m. The square building was denoted as X and rectangular as Y. These are shown in Figures 3 & 4. The core area of the square building is of 12 m x 12 m. Thus the effective rentable area was 432 m^2 per floor. The core area of the rectangular building was 8 m x 18 m. Thus the effective rentable area was 456 m^2. The air conditioning load was calculated considering that the core area will not be air conditioned.

2. Facade details: It is quite common to use large glass panels in building facades generally without shading. However, it is explained above that even in multi-storey buildings, the external facade can be provided with shading devices. Therefore, the possibility of providing shading is also considered. For the computer simulations, the cases with shading was denoted as S. However, these shading devices will be effective only for the glass facades facing north and south. Two types of glass facades have been considered where type of glass was *3 mm clear glass*. Those having a height of 3.0 m per floor (denoted as A) and those having a height of 1.8 m with the sill level at 1.2 m (denoted as B), thus giving a total height of 3.0 m as shown in Figure 5. The length of a facade has been the length between two grid lines, thus 6.0 m for both these cases. The floor to floor height was considered as 3.6 m. Thus, A gives a window to wall ratio of 0.83 and B gives a window to wall ratio of 0.5.

3. Glazed facades: For each building, it is considered that glass facades of Types A and B will be provided on sides facing north and south. The effects of providing

additional windows on east (denoted by E), west (denoted by W) and east and west (denoted by EW) also have been considered. The shading devices were not considered for these three cases since those would not be effective. When glass was not used, a wall thickness of 200 mm was provided.

4. Temperatures and humidities maintained indoors: The temperatures maintained indoors were 22, 24, 26, 28 and 29. The relative humidity has been maintained at 60%.

5. The outdoor temperature from March 21st to September 21st is considered to vary between 27°C at 0600 hours to 34°C at 1400 hours. It varies between 25°C at 0600 hours to 32°C at 1400 hours from September 21st to March 21st. The outdoor humidity varies between 90% at 0600 hours to 60% at 1400 hours. These values have been selected using the temperature and humidity variation charts given for few typical days in Jayasinghe and Attalage (1997) which indicated that the average temperature variation in a typical day is about 7°C and a humidity variation as given above for low altitudes in Sri Lanka.

The air conditioning loads calculated at two month intervals have been added up to determine the annual air conditioning load and this value has then been divided by the total air conditioned area of the building to determine the annual air conditioning load per square metre.

In this study, the annual air conditioning load is calculated instead of Perimeter Annual Load value (PAL value) since the calculation of annual air conditioning load helps the designer to evaluate the economic consequences of his decisions.

Determination of Annual Air Conditioning Load

The air conditioning load of the building was calculated for 21st day of January, March, May, July, September, November, thus representing the climatic variations and the movement of the sun with some degree of accuracy. Then, the total air conditioning load (kWh) of the building for a two month period was calculated by multiplying each value by sixty. Thus a total of six such values were obtained. These were added to obtain the annual air conditioning load of the building. This value was divided by the total area of the building excluding the core to obtain the air conditioning load per m^2 per year.

ANALYSIS OF RESULTS

The results of the computer simulations for square and rectangular buildings are give in Tables 1 and 2, respectively. These results have also been presented in graphical form in Charts 1 and 2, respectively. The following notations have been used.

X = square building with glass facade facing north and south
Y = rectangular building with longer axis in east west direction and glass facade as in X

A = glass facade of height 3.0 m
B = glass facade of height 1.8 m
S = glass facade provided with shading devices
E = glass facade facing east
W = glass facade facing west

Thus, XASEW means square building with window type A on north and south provided with shading. It also has unshaded windows on E and W.

Internal temperature °C	XA	XAS	XB	XBS	XASE	XASW	XASEW
22	308.75	261.0	281.29	263.10	295.97	294.0	307.34
24	218.16	198.62	225.10	180.61	208.20	207.21	235.81
26	169.63	116.31	143.98	123.09	141.21	140.05	164.73
28	105.56	53.98	89.28	56.11	80.88	76.34	109.55
29	80.29	35.41	73.21	42.58	51.90	48.52	80.26

Table 1: Annual air conditioning load values for a square building - notations as given above. The unit is kWh/m^2/year

Internal temperature °C	YA	YAS	YB	YBS	YASE	YASW	YASEW
22	308.16	243.0	263.16	257.76	280.44	264.24	306.36
24	214.52	182.88	208.80	178.56	208.08	207.00	234.00
26	165.85	106.56	144.52	107.28	133.56	131.76	162.36
28	99.36	47.52	82.10	47.88	75.96	74.52	107.64
29	73.8	24.84	56.29	25.20	48.60	48.24	77.40

Table 2: Annual air conditioning load values for a rectangular building - notations as given above. The unit is kWh/m^2/year

It can be seen from Tables 1 and 2 that the energy consumption of rectangular buildings with longer axis in east west direction is generally less than the energy consumption in square buildings with same window to wall ratios and approximately the same floor area. This stems from the fact that it is easier to control the external energy gains through the facades facing north and south than those facing east and west. Thus, it is advantageous to have rectangular buildings with minimum facade areas on east and west. It can also be seen that having shaded windows can always help to reduce the energy consumption for air conditioning.

The indoor temperature that is maintained for thermal comfort also has a significant effect on the energy consumption. For example, in the case of a rectangular building with shading, with indoor temperature being maintained at 27°C, the annual air conditioning load is about 75 kWh/m^2/year (from Chart 2) whereas when the same building is maintained at 24°C, the air conditioning load is about 180 kWh/m^2/year (from Chart 2). This indicates nearly 2.5 times increase. It should be noted that 27°C with 60% humidity and wind velocity less than 0.25 m/s can just provide thermally comfortable conditions for Sri Lankans as indicated by the comfort zones marked on psychrometric chart provided in Figure 6 (Jayasinghe et al., 1997).

These comfort zones have been suggested for Sri Lankans by Jayasinghe and Attalage (1997) on the basis of a comfort survey covering about 3000 subjects. Few modifications have been incorporated for the methods suggested in Szokolay (1991) to suit Sri Lankans. It was shown that when combined ventilation and air conditioning is used, it is possible to maintain buildings even at higher temperatures such 29°C with about 70% relative humidity and air velocity above 0.6 m/s while providing thermal comfort to a majority of people.

When the same building is provided with windows on east and west without shading in addition to shaded windows facing north and south, the air conditioning load is about 235 kWh/m^2/year at 24°C internal temperature, thus indicating a nearly three fold increase in the energy consumption.

Thus the annual air conditioning loads caused by thermal gains for the ten storey rectangular building shown in Figure 2 for maintaining 27°C and 24°C indoors are 342 MWh and 820.8 MWh respectively. If the coefficient of performance of the air conditioning system is 4.0, the total electrical energy consumptions will be 85.5 Mwh and 205.2 MWh. Thus, it would be possible to achieve an energy saving of 120.2 MWh by maintaining the building at 27° C instead of 24°C.

If an average size house consumes 1000 units of electricity per year (1 MW hour), these energy savings of a ten storey building will be sufficient to provide electricity to 120 households. It has been reported by Perera (1997) that the annual energy consumption of rural house holds will be below 350 units per house. These energy savings in a ten storey building will be able to provide electricity to 343 rural households.

It is possible to compare the case of a building maintained at 24°C with windows provided on east and west facades. The total air conditioning load of such a building due to the considered thermal gains is 1071.6 MWh. The corresponding electricity usage is 267.9 MWh with a coefficient of performance of 4.

These figures indicate the importance of proper design of buildings and the need to maintain the interior of the buildings at just the sufficient thermally comfortable conditions for a country like Sri Lanka which has already tapped most of its hydro-power potential and has to depend on fossil fuels for further increases in generation capacity.

CONCLUSIONS

In this paper, the application of computer simulations to buildings with passive solar elements to determine the air conditioning loads resulting from external thermal gains has been presented. This is of particular advantage at the preliminary design stage, since the designer has the ability to change and rearrange the passive elements that have already been adopted with minimum effort. In such instances, it is invaluable to be able to predict the effects of such decisions. The results of computer simulations that have been carried out using CASAMO were presented in graphical form for quick reference by architects and service engineers. Once the preliminary design is over, it will be possible to use a more sophisticated software for further improvements in energy efficiency. It will also be possible to further improve these charts by including the internal loads due to occupancy and also by using a more sophisticated package which can take account of the dynamic nature of the environment more precisely than CASAMO.

It was shown that due to the location of Sri Lanka, extensive use of shading devices on facades facing north and south can be of particular advantage in minimising the thermal gains due to solar irradiance. Avoiding windows on facades facing east and west also can be used. It was also shown that the energy usage can be minimised by maintaining the buildings at thermally comfortable, but at elevated temperatures that suits Sri Lankans, when air conditioning is used.

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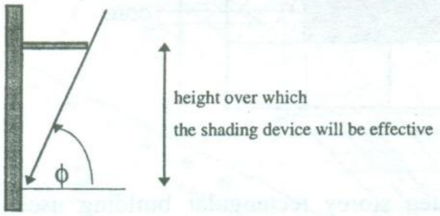


Figure 1: Effectiveness of shading devices

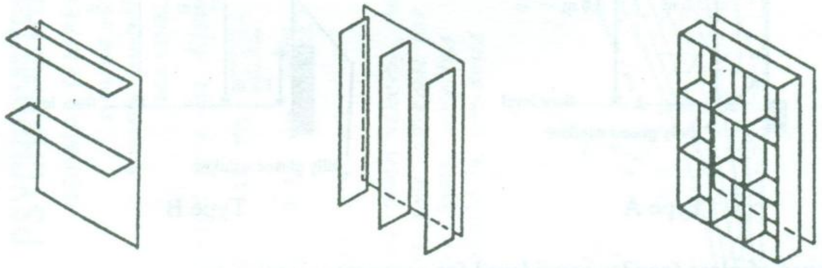


Figure 2: a. Horizontal shading devices; b. Vertical shading devices; c. A combination of horizontal and vertical shading devices

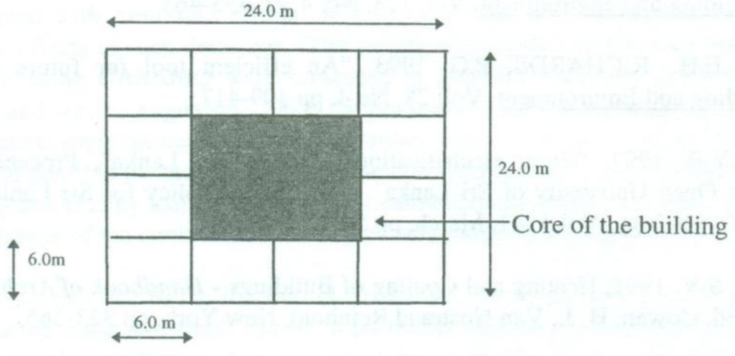


Figure 3: The plan view of the ten storey square building used for computer simulations

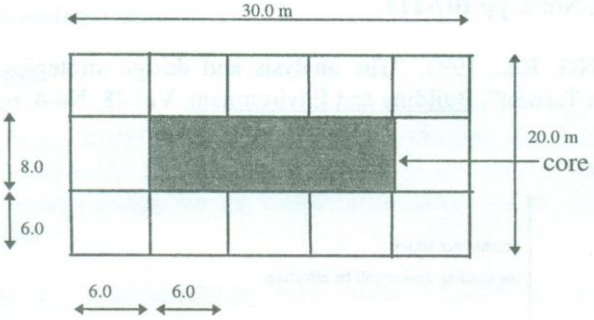
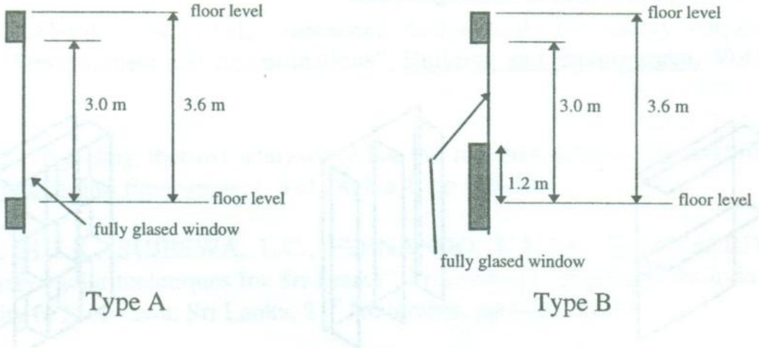


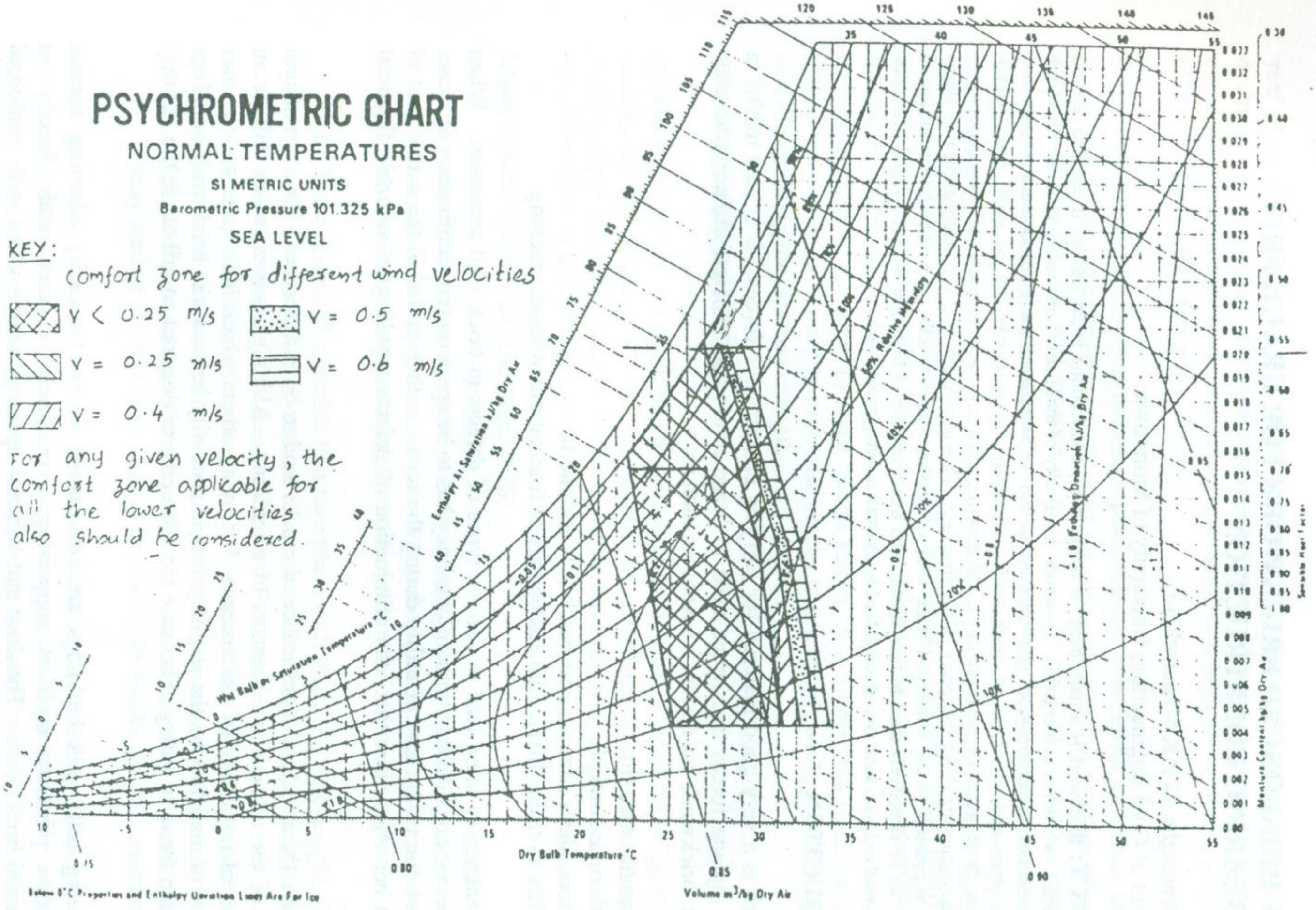
Figure 4: The plan view of the ten storey rectangular building used for computer simulations



Type A

Type B

Figure 5: Types of glass facades considered for computer simulations



Psychrometric chart for normal temperatures, metric units.

Figure 6: Psychrometric chart showing the comfort zones obtained with different internal air velocities