Design guidelines for thermal comfort in row houses in Bangkok

Pattaranan Takkanon

Faculty of Architecture, Kasetsart University, Bangkok, Thailand

ABSTRACT: This work aims to establish appropriate design guidelines and recommendations to ensure thermal comfort in row houses in Bangkok where existing building regulations do not derive from climatic design approach. Affordable comfort is to be achieved by primarily passive means as far as possible and the design should also provide the flexibility for active means whenever they are required. Computer simulations have been carried out to investigate and compare thermal performance of design variables including orientation, zone location, roof and wall materials, aperture schedules, and shading devices. The design guidelines and recommendations are developed based on the results from the two series of simulations: naturally ventilated and air-conditioned cases. Thermal condition is a result of interaction of all variables. Row houses should be designed with respect to orientation and zone location. Aperture schedule has a great effect on indoor conditions. It is suggested to close windows during the day to keep the zone cool and open the windows at night. Adding insulation could improve the indoor condition better than changing the roof and wall materials. Guidelines for designing shading devices are proposed particularly for each orientation.

Keywords: design guidelines, thermal comfort, row houses, Bangkok

1. INTRODUCTION

In Bangkok, numbers of row houses are built instead of single dwelling units to minimise the building material usage, construction cost and time while providing as many units as possible.

However, recent studies show that their thermal performance is poor [1,2] and the current building regulations are not from climatic design approach for such a region.

In order to propose design guidelines, 7282 cases of computer simulations were conducted to study thermal performances of naturally ventilated and air-conditioned row houses under Bangkok's hot and humid conditions. Design parameters include orientation, zone location, roof and wall materials, aperture schedules, and shading devices.

2. BANGKOK CLIMATE

Bangkok is located at 13.44°N latitude. It experiences high air temperatures and relative humidity. The South East Asian monsoons cause small seasonal changes which distinguish summer (from March to April), rainy season (from May to October) and winter (from November to February). Monthly mean temperatures range from 26.8 to 30.7°C. The average monthly temperature is highest in April and lowest in December. The average humidity varies between 67.6 and 79.9%. The diurnal ranges of temperatures are below 10 K all year round. The average wind speed in Bangkok is moderate at 1.7 m/s. There are two predominant wind directions: south and southwest.

3. COMFORT LIMIT

Thermal comfort expectations of fully acclimatised people are different from those who are used to air-conditioning. As given by the ASHRAE Standard 55a-1995 on "Thermal Environmental Conditions for Human Occupancy", the upper limit of comfortable temperature is 26°C and the wet bulb temperature upper limit is 20°C [3]. However, many studies have concluded that in tropical regions where people are able to acclimatise and/or have physiological variation, the comfort temperature is higher, Lovins [4]. Results from a field study by Busch [5] show the discrepancies between thermal comfort requirements of the Thai and non-acclimatised people. Based on 80% of Thai workers being satisfied, the upper limit of the comfortable temperature can be as high as 28°C for people in air-conditioned buildings, and 31°C in naturally ventilated buildings.

Many research projects consider the adaptive model as a contributor to variable indoor temperature standards that develop more adaptive capabilities of building occupants. Therefore, this approach possibly enhances levels of occupant comfort and leads to more environmentally responsive building design. In this study, the comfort zone of Bangkok was established using adaptive model.

$$T_n = 17.6 + 0.31 \times T_{av} \quad (1)$$

Where T_{av} = mean monthly outdoor temperature

T_n = neutrality temperature

with the limitation that $18.5 < T_n < 28.5$°C and the comfort limits can be taken as $T_n \pm 2.5$°C.

When the upper limit in terms of absolute humidity (AH) is adopted as 12 g/kg and the mean temperature(T_{av}) of the warmest month (April) in

Bangkok is 30.7^{o}C (derived from the average of Bangkok meteorological data over the period of 1991-1998), the thermal neutrality (T_n) would be:

$$T_n = 17.6 + 0.31 \times 30.7 = 27.1^{o}C$$

and the upper limit of comfort temperature proposed by this method becomes: 27.1+2.5=29.6^{o}C. This comfort limit will be used to assess the indoor conditions of the simulated cases.

4. BANGKOK ROW HOUSES

Bangkok row houses combine living and business space in one place. The shop is on the ground floor while living room and bedrooms are on the upper floors. Typical row houses in Bangkok are of 4 storeys. The floor plan of one unit of row houses is 4×12 m. The floor height is 3.00 m except for the ground floor which is 5.5 m and 3.5 m for row houses with and without mezzanine floor, respectively. Each block of row houses has 10 units according to the Building Control Act 2000 that allows a block of not longer than 40 m.

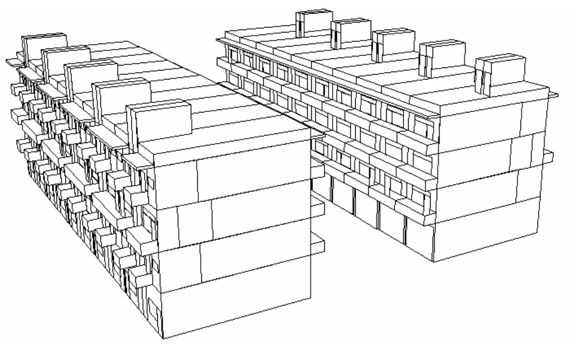

Figure 1: Typical row houses in Bangkok

5. COMPUTER SIMULATIONS

After the comparison of numerous software packages for environmentally responsive design, TAS simulation program was selected. It serves the purposes of the study in terms of available and editable input for thermal simulations, production of two and three-dimensional modelling using its own application, and its Window-based operating system which is readily available in Thailand. Its graphic interface also suits architectural design purposes.

TAS simulations require weather year data on an hourly basis. This includes dry bulb temperature (^{o}C), relative humidity (%), wind speed (m/s) and direction (degrees, E from N), global and diffuse solar radiation on horizontal (Wh/m^2), and cloud cover (0-0.1). Since there is no existing data set for Bangkok, ten-year weather data from Bangkok Meteorological Station were reviewed to generate a weather year for the simulations. The weather year was then converted to TMY2 which is a required format for TAS.

For naturally ventilated cases, the simulations have been carried out for the hot days to study the critical conditions. The hottest day (Day 94) and the average day (Day 101) are selected for the study.

To find one month and one year cooling load in air conditioned cases, the hot month (April) is chosen as well as the whole year (1999).

Two blocks of row houses facing each other were taken into consideration. Thermal performance of the end and intermediate units were examined. Urban terrain is set for the computer program to simulate the conditions of high density.

From the assumption that orientation in conjunction with other design variables affect thermal performance of buildings, models of row houses are rotated anti-clockwise to gain results from 8 different orientations.

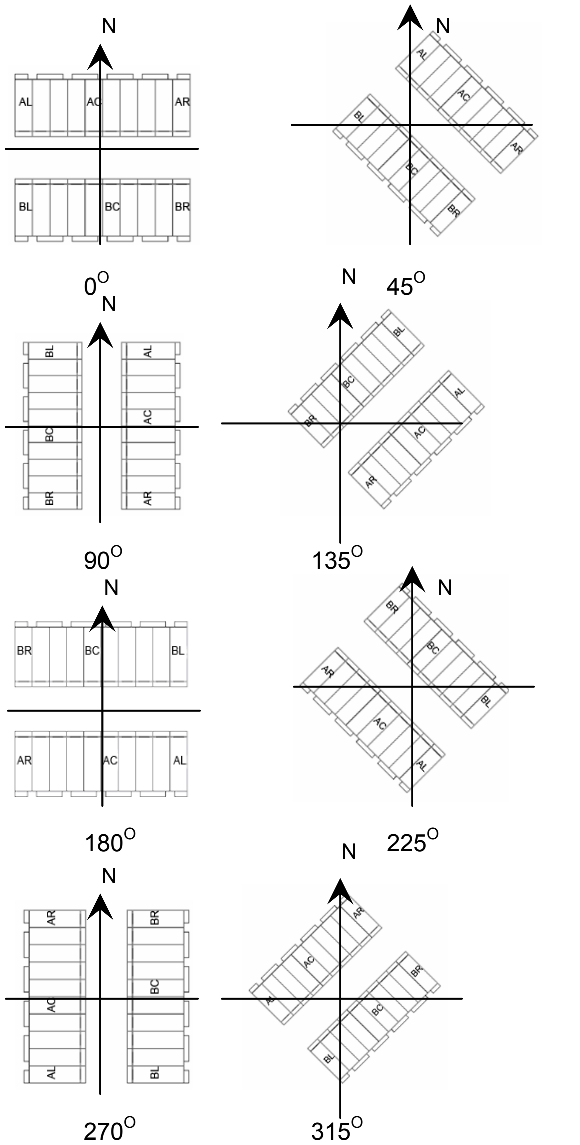

Figure 2: Building orientations

Design variables for this study consist of roof and wall materials, aperture schedule (schedule for window opening), and feature shading (fin and overhang type) as listed.

- Roofs

R1-flat roof with ceiling insulation
R2-15 degree fibrouscement with underroof insulation
R3-20 degree concrete tiles with underroof insulation
R4-20 degree concrete tiles with ceiling insulation

R5-15 degree metal sheet with underroof insulation
R6-15 degree fibrouscement with underroof insulation and stack

- Walls

W1-100 mm brick wall
W2-100 mm superblock (aerated concrete) wall
W3-2 layer brick with 100 mm air gap
W4-100 mm concrete block with acoustic board

- Aperture schedules

Win1-all opened all day
Win2-all closed during the day, all opened at night
Win3-all closed during the day except roof stack, all opened at night

-Shading devices

F1- partly shaded (distance limited by law)
F2-fully shaded

Details of internal gains calculated are based on demand of appliances for a small household of 4 members (2 at home during the day, the other two are out at work). The ground floor is a combined shop and kitchen. The first floor is a living room. These two floors are used during the day. The second and the third floors are bedrooms which are occupied at night. For naturally ventilated cases, infiltration air is set to 0.5 ACH and ventilation air is set as zero, and it will be calculated by the program using the weather data for the specified location.

6. DESIGN GUIDELINES

The following design guidelines for both naturally ventilated and air-conditioned row houses have been developed after analysing the simulation results. They are based on the combined effects of design variables on thermal performance of row houses.

6.1 Site planning

Site planning for row houses needs to serve the requirements of solar protection and natural ventilation.

In terms of solar orientation, a row house should face north, northeast, southeast, and south. Either north or south is the most desirable as long as the side wall of the end unit faces east at such an orientation. On the contrary, east, southwest and west facing front should be avoided. Preferably, at the land subdivision stage, the street should run east-west since north and south orientations are the best.

If any row house is allowed to be built facing east, southwest, northwest, and west, a provision of shading devices must meet the requirement of solar protection at the specified orientations.

The rows of houses can overshadow each other. The distance between the rows should be considered with respect to the shadow angles associated with the height of the row houses that provide shade. These factors vary depending on orientation. Table 1 shows the vertical (VSA) and horizontal (HSA) shadow angles selected for each orientation for buildings in Bangkok.

Table 1: Vertical and horizontal shadow angles at each orientation

Ori	0°	45°	90°	135°	180°	225°	270°	315°
VSA	77	35	24	21	35	21	17	36
HSA	67	-	32	-	58	43	-	40

Figures 3-8 show overshadowing provided from the opposite row houses at different orientations.

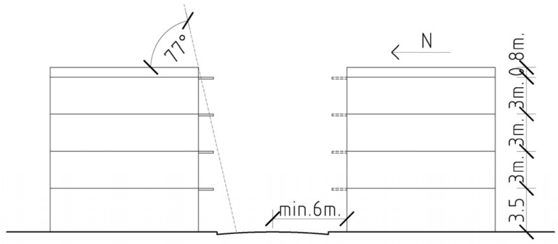

Figure 3: VSA = 77° Orientation 0° (the building on the right faces north)

When the row house considered faces north, the opposite building would not shade it. Self shading from overhang is enough for the building.

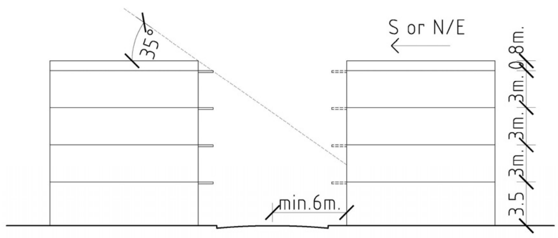

Figure 4: VSA = 35° Orientation 45° (the building on the right faces northeast) or 180° (the building on the right faces south)

When the row house faces northeast or south, overshadowing by the opposite building is up to half of the first floor (2nd level) façade.

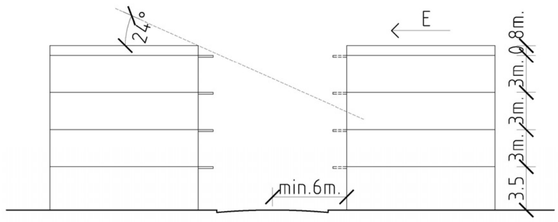

Figure 5: VSA = 24° Orientation 90° (the building on the right faces east)

When the row house faces east, overshadowing by the opposite building is up to about half of the second floor (3rd level) façade.

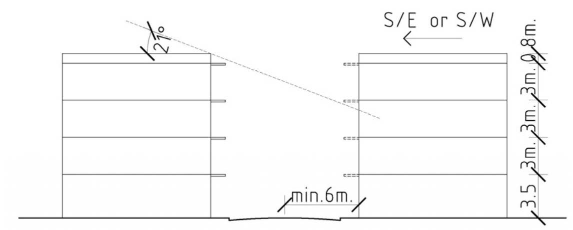

Figure 6: VSA = 21^o Orientation 135^o (the building on the right faces southeast) or 225^o (the building on the right faces southwest)

When the row house faces southeast or southwest, overshadowing by the opposite building is up to about half of the second floor (3rd level) façade.

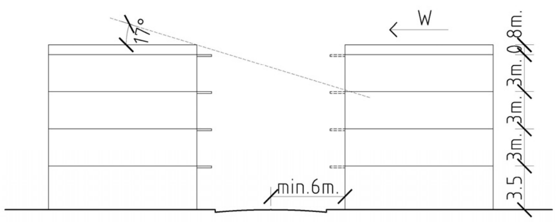

Figure 7: VSA = 17^o Orientation 270^o (the building on the right faces west)

When the row house faces west, overshadowing by the opposite building is up to cover the second floor (3rd level) façade.

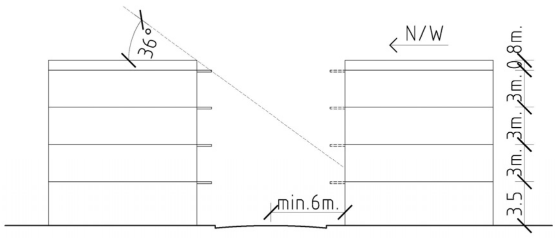

Figure 8: VSA = 36^o Orientation 315^o (the building on the right faces northwest)

When the row house faces northwest, overshadowing by the opposite building is up to about half of the first floor (2nd level) facade.

With wider road between the two blocks, the overshadowed area will be less. To get more accurate shaded area, it should also take into account the horizontal shadow angle (HSA) to gain the idea in 3 dimensions. The HSA is in relation to the length of the building block and the width of space between blocks on the same side of the road.

However, the distance for solar protection should be reconciled with that for natural ventilation. Narrow street can be an advantage for solar protection but become a disadvantage for natural ventilation since the larger distance would give more opportunities for prevailing wind to strike the building.

For wind orientation, the front and back openings of row houses are preferably perpendicular to the direction of the prevailing wind. Within 0 to 30, and potentially 45 degrees of wind incidence, it is possible to create accelerating flow from the windward to the leeward side. The opening should not be parallel to the wind since the indoor air velocity drops drastically. This is, therefore, relative to the circumstances such as local wind direction and surrounding. The requirements of solar protection and ventilation may be in conflict.

6.2 Zoning and layout

There is no subdivision for open plan row house even for the kitchen which is commonly placed on ground level at the back of the building. The row house of one or two rooms per floor needs careful consideration in locating its zones or designing layout of its interior in relation to orientation. Recommendations are as follows.

- The preferable orientation for commercial and living zones is either north or south with the side wall facing east. Northeast and southeast are also acceptable. At these orientations, zones at the back will assist in blocking the incoming solar heat from the opposite direction. If these back zones are for services, their locations in relation to these orientation may be acceptable. If the zones at the back are living zones exposed to the east, west, southeast, and southwest, a compromise should be made between the living zones at the front and at the back of the building. Otherwise, solar protection is required.
- For a commercial zone which is in use only during the daytime, the main door at the front facing the adjacent road needs to be open at all times or intermittently when a customer enters the shop. It would be difficult to keep the indoor temperature below outdoor temperature by closing the building in cases of naturally ventilated row houses while it is possible for air-conditioned ones.

However, the ground floor has an advantage of higher ceiling (larger opening) and earth contact. Ventilation can ensure thermal comfort. The wind induced into the building should be filtered out the dust from the adjacent road. Landscape design would assist this situation.

- Separation of heat sources from the living zone would improve the zone's thermal performance.

The study shows that heat produced by the kitchen area is transferred to adjacent areas and increases the indoor temperature in naturally ventilated buildings and the cooling load in air-conditioned ones. The space above the kitchen also receives heat by convection or conduction. The often-used living zone should not be located next to or at the same position as the kitchen. This area can be a buffer zone such as storage instead. Dividing the living and heat generating zones with partition and using fans to exhaust hot air at or near its source would also improve the conditions.

- Top floor zone needs to be well insulated. It receives extra heat from the roof. The living zone which is occupied during the day should not be on this floor. Most row houses keep it for a bedroom. Although it is purposely used at night, the heat stored during the day should be eliminated.

- Living zones should be located on the intermediate floors (the first and the second floor) since these floors are not affected by extra heat from the roof like the top floor and also gain higher wind speed in comparison to the ground level.
- Creating a buffer or transitional space could ameliorate the extreme conditions. Zones which are exposed to outdoor conditions can protect other zones from the unpleasant conditions such as high solar radiation. At the front or back of row houses, balcony, veranda, or colonnade extended out for the purpose of shading can act as a transitional space between outdoor and indoor. This would also affect the prevailing wind direction in relation to the openings shaded since the extended building components may create wind funnel.

Comparing zones on the same level, the intermediate unit performs better than the end units. For naturally ventilated row houses, end units with sidewalls exposed to the outdoor need more awareness on building material selection while the intermediate ones show only a slight difference caused by materials since it has only 2 external walls and is better protected from solar radiation by its adjacent units.

For air-conditioned row houses, intermediate units require less cooling but the top floor should be of cathedral roof type rather than that with attic space. It is advisable to improve the performance of the latter by ventilating its attic space.

6.3 Building components

The following recommendations were made regarding the design variables examined in the study.

- Roof

Heavyweight roof such as concrete slab is preferable. Roof insulation is crucial. Installing ceiling insulation would improve the indoor condition significantly.

For naturally ventilated row houses, a roof stack is recommended to be installed as another option for natural ventilation but the operational time is also important. It is required to be kept opened and its side walls need solar protection so that it would not be another exposure to the heat.

Roof with attic space is another choice. The attic space acts as a buffer zone to block the incoming heat.

For air-conditioned row houses, in addition to the roof types recommended above, the roof with attic space for the intermediate unit should be avoided if it is non-ventilated. Therefore, it is advisable to ventilate this attic space to improve its performance.

- Wall

For naturally ventilated row houses, although high mass and well insulated wall (concrete block with acoustic board) performs best at high temperature, the capacitive insulation of this wall type increases indoor temperature when the building is closed and indoor temperature is higher than outdoor. Even during the night, a wall with good resistance would keep the room warmer than the outside which is undesirable. When there is ventilation, wall materials make only slight differences which shows that insulation is not as necessary as when there is no ventilation. The material selection should be based also on the operation of the building.

For air-conditioned row houses, thermal mass and well insulated wall is recommended. Wall with good resistance is preferable.

It is suggested to add insulation since it improves the indoor conditions more effectively than changing wall material.

- Mezzanine

For naturally ventilated row houses, a mezzanine floor has insignificant effect on indoor thermal conditions whilst for air-conditioned row houses, its additional height increases the cooling load tremendously. Therefore, row house with mezzanine floor should not be air-conditioned. For an air-conditioned room, a limited size is preferable.

- Opening

Opening size can promote natural ventilation. The main wind breeze is assumed to come from the street direction since the front of the building faces the wider street compared to the smaller distance between its back and the building in the next plot. Designing larger window at the back would draw the air from the front and the plume would cover the bigger area in the room.

- Shading devices

Shading devices need to be designed particularly for each orientation. The distances required for the shading devices for building in Bangkok location are as shown in Table 1 and Fig 9. The meanings of abbreviations are as follows.

VSA= vertical shadow angle $=\tan^{-1}(h/O)$
HSA= horizontal shadow angle $=\tan^{-1}(w/F)$
O = overhang depth
F = fin depth
h = height of opening
w = width of opening
n = number of opening division

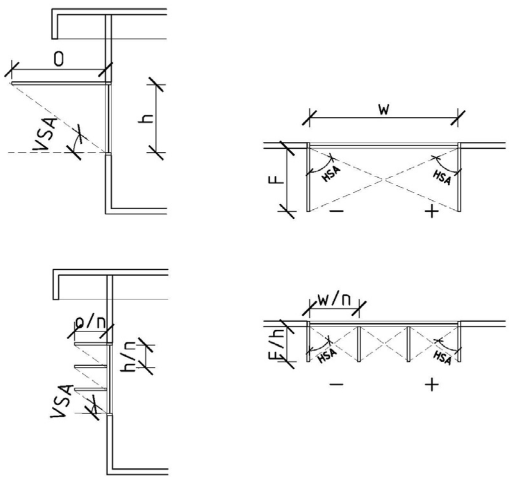

Figure 9: Shading devices for specified orientations

It is advisable to install adjustable shading device for the critical orientations including east, west, southeast, and southwest, as it is more flexible to close or open at desired angle.

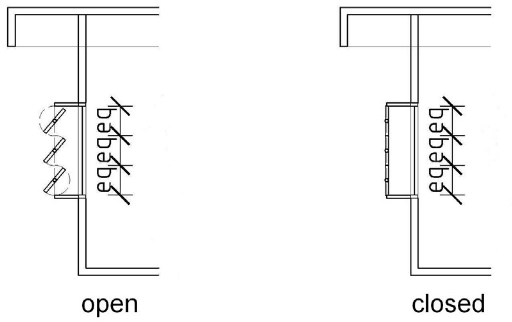

Figure 10: Adjustable shading devices

However, it should be kept in mind that although the solar radiation should be blocked out, indoor illuminance should be maintained at the required level. Installing light lamps in the dark area would increase the internal gain. Therefore, artificial light should be added only if necessary.

6.4 Operating building and occupants' adjustment

Operation of the building and the operational time are factors controlled by occupants. It is suggested that operating the building such as opening windows or using air-conditioner not only in regards to the room function and occupancy but also the changing outdoor conditions can make the building energy efficient.

Closing the building during the day would lower the indoor temperatures. It would also protect indoor space from outdoor air pollution (dust, smoke, etc.) especially during the day with more traffic on the adjacent road. With this operation, designing air tight space with insulation for noise control would become possible during the daytime.

During the night, opening windows for night ventilation is recommended. The noise problem caused by traffic will also be alleviated at night, supporting the idea of opening windows during this time. Apart from this strategy, indoor conditions could be improved by means of mechanical ventilation such as installing ceiling fans to enhance cooling effect. This will bring the indoor condition down to the comfort level. Since a provision of 1.5 m/s wind velocity from fans could give approximate 5 K apparent cooling effect [6], the upper comfort limit is therefore 34.6°C which covers the conditions all night and morning. Only hours in the afternoon are still slightly above the comfort limit. This duration of overheating varies with orientation and design materials.

The forced ventilation from fans that gives this air velocity could therefore improve the indoor thermal conditions and lessen hours of overheating. In addition to the night ventilation, an attic or whole house fan can be installed to reduce the room temperature by drawing the heat out through the attic. It is operated when Ti > To to assist in mitigating heat that has been stored during the day. Even though it may not provide a physiological cooling effect, it accelerates the process of heat dissipation [7].

The design guidelines can be used as a basis, however, may be adjusted in practice when other factors besides those for climate-sensitive design come to play. These may include views, preference of the occupants on space organizing, etc.

REFERENCES

[1] P.Takkanon, Proc. 37th ANZAZcA Australian and New Zealand Architectural Science Association Conference, Sydney – Australia (2003), 596-606.
[2] P.Takkanon, Proc. 1st iNTA International Network for Tropical Architecture Conference, Singapore, 2004.
[3] ASHRAE, Thermal Environmental Conditions for Human Occupancy, ASHRAE Standard 55a-1995, ASHRAE, Atlanta, 1995.
[4] A.B.Lovins, Air Conditioning Comfort: Behavioral and Cultural Issues, Esource Strategic Issues Paper, Boulder, Co., E-Source, 1992.
[5] J.F.Busch, A tale of two populations: thermal comfort in air-conditioned and naturally ventilated offices in Thailand, Energy Buildings, 18 (1992) 235-249.
[6] S.V.Szokolay, The cooling effect of air movement, Proc. 17th PLEA Passive and Low Energy Architecture Conference, Cambridge – UK, 2000.
[7] S.V.Szokolay, House for Townsville, a discussion paper, Brisbane, 2005.