Title: **Environmental Performance of the TTDI**

Authors: Joana Goncalves, University of São Paulo
Suraksha Bhatla, University of São Paulo

Subject: Sustainability/Green/Energy

Keywords: Energy Consumption
MEP
Sustainability

Publication Date: 2012

Original Publication: CTBUH Journal, 2012 Issue II

The Environmental Performance of the TTDI

Suraksha Bhatla

Joana Gonçalves

Authors

Suraksha Bhatla

t: +91 98400 94314
e: Suraksha4@gmail.com

Joana Gonçalves

Laboratório de Conforto Ambiental e Eficiência Energética, Universidade de São Paulo
Rua do Lago 876, Cidade Universitária
São Paulo-SP, CEP 05508-080
Brazil

t: +55 11 30914538
f: +55 11 30914539
e: jocarch@usp.br

Suraksha Bhatla
Suraksha graduated with honors from the School of Architecture and Planning, Anna University, Chennai in 2007 and went on to practice at T.R Hamzah and Yeang Sdn, Bhd in Kuala Lumpur. She was closely involved with the design phase of several large scale mixed-use, residential and commercial tower projects in Asia that were driven by sustainable concerns, including the Fusionopolis Office Tower, Singapore and PutraJaya Commercial Development, Kuala Lumpur, Malaysia. In 2009 she chose to return to academica and pursued her Masters in Sustainable Environmental Design at the Architectural Association, London. Her research at the AA, "Tall Communities: Passive Urban Housing for the Tropics" focused on the analytic exploration of basic bioclimatic strategies for hot humid climates and its consequent social impacts through passive design, with an emphasis on residential towers in keeping with the Asian mass housing market.

Joana Gonçalves
Joanna is an architect and urbanist from the faculty of Architecture and Urbanism of the Federal University of Rio de Janeiro, where she graduated in 1993. She practiced as an architect in Ana Maria Niemeyer SA, in Rio de Janeiro between 1992 and 1995. In 1996 she moved to London to study environmental design in the Architectural Association Graduate School, obtaining a MA degree from the Environment and Energy Studies Program in 1997. In the same year she moved to Sao Paulo to engage in teaching and research in the Faculty of Architecture and Urbanism at the University of Sao Paulo, where she received a PhD in 2003 with the thesis entitled, "The Sustainability of the Tall Building." Since 1998 she has been involved in teaching, research and consulting related to environmental design, collaborating with institutions in Brazil and in the U.K. Since 2009 she has been part of the teaching staff of the Masters Programme in Sustainable Environmental Design of the Architectural Association, London. In 2011 she was a visiting lecturer in the Harvard Graduate School of Design. Main research projects include the recent publication of the book *The Environmental Performance of Tall Buildings.*

> "Through detailed analysis of occupant behavior, the predicted energy consumption patterns shown in modeling and performance assessment techniques can be further improved, challenging the preconceived theoretical notion of comfort and behavioral patterns."

Tropical Asia is accelerating towards vertical densification of its urban communities. With this movement comes an increase in the cooling demand in the building sector. Currently, it is estimated that 60% of the world's electricity consumption, usually affiliated with high CO_2 emissions, is attributable to residential and commercial buildings, creating the need to look at ways of reducing energy consumption in these buildings (Laustsen 2008). Although commonly classified as a typology of high-energy demand, tall buildings can be beneficial in hot, humid climates. Considering both urban and building scales, the typology enhances the exposure of the built form to wind flow, generates more wind at the ground level and provides desirable shadows upon the immediate surroundings.

Introduction

Across southeast Asia several proclaimed "bioclimatic towers" stand as examples of the contemporary environmental approach to tall buildings in the tropics, including the two residential towers of the Taman Tun Dr. Ismail (TTDI) condominiums in Kuala Lumpur (see Figure 1). Completed in 2006, the 21- and 28-story towers were designed by T.R Hamzah & Yeang, who is widely known for advocating his ideas on ecological architecture for the tropics. Ken Yeang's buildings are designed to encourage the inhabitants to connect with the natural environment through semi-outdoor transitional spaces and other elements which help reduce energy use. His design approach incorporates shading elements such as balconies, sky lobbies and *brise-soleil,* with shafts and structural cores often strategically positioned to buffer the interior spaces from solar exposure. Wind catchers are also commonly used to enhance natural ventilation and vertical landscaping is claimed to act as a means of facilitating micro climatic mediation (Yeang 1996).

To evaluate the effectiveness of these different strategies, including shading devices and wing walls, a review of the environmental performance of the TTDI tower was based on the outcomes of a post-occupancy evaluation (POE). This included real time data measurements of internal environmental conditions, namely temperature and humidity, interviews with the occupants and the assessment of energy bills. While the field work brings insight into the reality behind the various energy and thermal comfort demands of residents, it also sheds light on their adaptive behavioral response to environmental conditions and architectural features offered by principles of

Figure 1. Taman Tun Dr. Ismail (TTDI) condominiums, Kuala Lumpur © T.R Hamzah and Yeang

Base Case - Thermal Analysis Simulation (TAS) inputs		
Floor Area	100 m² (10 x 10 m)	
Floor Height	3 m	
W/F Ratio	25%	
Internal Gains	5562 kwh year	
Thermostat	Upper Limit 30 C	
	Lower Limit 18 C	
U-value	0.3 / 0.8 / 3.0 W/m²K	
Aperture Type	Natural Ventilation	partially open - 20C
		fully open - 28 C
Infiltration	0.5 ach	
Ventilation Rate	0 ach	

Table 1. Inputs for Base Case TAS model

bioclimatic design. Findings from the study, as well as a technical review, revealed the method and extent by which the annual cooling demand in residential tall buildings located in the tropical region can be curtailed. Figures as low as 5–7 kWh/m² per year in the best case scenario were found, mainly due to the occupants' behavior, which had a fundamental role to play in achieving strong environmental performance.

The Study

The POE was carried out in two phases: the first phase included a general survey in a group of flats, which in turn, informed a more detailed study of three residential units in the second phase of the evaluation. Prior to the case study, basic practices of environmental design for the tropics were tested in a series of analytical studies with the support of advanced simulation tools. The studies were carried out for the climatic context of Kuala Lumpur and supported the subsequent technical critical assessment of the TTDI residential complex.

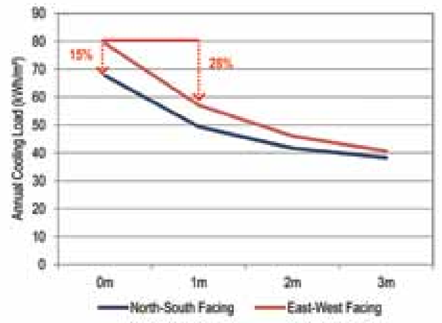

Figure 2. Relationship of annual cooling load and horizontal shading depth in different orientations, based on thermal dynamic simulations using EDSL, 2010 (TAS v 9.1)

The main aim when dealing with warm humid climates is to keep the building envelope protected from the typically high solar radiation, both direct and diffused, while ensuring effective heat dissipation by means of controllable ventilation. The tropical city of Kuala Lumpur (3.1˚N, 101.5˚E), has a warm, humid climate throughout the year with average hourly temperatures remaining at 27˚C for 76% of the year and humidity levels ranging between 60 to 80%. During the hottest period of the year, between February and April, external temperatures exceed 30˚C. In this context, the diurnal temperature differences range between 8 and 12 K, indicating the potential of night time cooling by means of natural ventilation (ASHRAE 2009a). Due to the proximity to the equator, Kuala Lumpur receives high levels of solar radiation (170–200 W/m² per day on the horizontal plane), highlighting the importance of shading. Apart from the direct component, the diffuse radiation is also high (>100 W/m²), as a consequence of high cloud cover that occurs for 80% of the year. Given the average monthly temperatures, based on Auliciems adaptive model (1981), a theoretical comfort zone was established as 22.9 –29.9˚C [1]. It is important to note that the prevailing winds in Kuala Lumpur blow mainly from west and southwest for most of the year, with an average speed below 2 m/s for 70% of the time.

Bioclimatic Strategies

In order to demonstrate the energy saving potential of passive strategies for tall buildings in the tropical context, the efficiency of shading was tested through computer simulation techniques using thermal analysis software [2]. Parametric studies were carried out using a base-case of a 10 x 10 meter residential unit positioned in an intermediate floor of a hypothetical tall building in Kuala Lumpur. Considering the limit of 29.9˚C established by the theoretical comfort zone, the annual cooling loads for the base case was simulated with the thermostat set point at 30˚C for a continuous occupation period of 24 hours (see Table 1). This set point was also determined based on research precedents [3] and findings from the fieldwork survey of TTDI residents, which identified the threshold temperature varying between 29˚C and 30˚C.

The performance of varying shading depths was analyzed for a 25% window to floor ratio[4], using north-south and east-west orientations. Looking at orientation only, 15% reduction of annual cooling loads was found when comparing the east-west to the north-south orientations. With the introduction of a one-meter horizontal shading device, the loads reduced further by nearly 28% (see Figure 2). With three-meter deep shading, the cooling loads reduce further to become similar for windows facing either north-south or east-west, making orientation a non-differentiating parameter for the environmental performance of the residential unit. In addition, simulations verified that there is no negative impact [5] on the internal daylight distribution for the given base case, even with a three-meter deep shading device (see Figure 3 and Table 2).

Insulation produced a perhaps surprising initial reduction of 42% in annual cooling loads by improving the U-value of the external walls from 3.0 W/m²K, which is ⇗

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[1] Auliciems, A.(1981). The comfort equation (Tn = 17.6 + 0.31To ± 2.5°C) was used as the neutral temperature found, was closest to the values accepted by tropical subjects in fieldwork survey.

[2] Environmental Design Solutions Limited 2010, (TAS v 9.1) Dynamic thermal simulation TAS model uses hourly values of incident solar radiation and outdoor temperature, to simulate internal temperatures and cooling energy requirements based on a given set of specific internal environmental, constructional and occupancy conditions for the entire year.

[3] BUSCH (1992) Bangkok, Thailand (1100 surveys) 28.5 ET (NV) 24.5 ET (A/C). DeDear (1991) Singapore (583 NV/ 235 A/C surveys) 28.5 ET (NV) 24.2 ET (A/C). Indraganti, M. (2010) Hyderabad, India (100 surveys) 29.23 (NV).

[4] The 25% window to floor ratio (WFR) was chosen for the parametric studies, as simulation test results of different WFR and the consequent cooling load demand revealed that at this point the ventilation is effective, thereby causing a slight reduction in the cooling loads. Also mass housing schemes in the tropics usually use large glazing areas with WFR between 20–35%.

[5] Even with a 2.5-meter shading depth for 10x10 meter unit, double side lit, with a 25% window to floor ratio, it was found that the average daylight factors of 5% can be achieved above the recommended 1–1.5% for living spaces as per CIBSE 1999 (see Table 2).

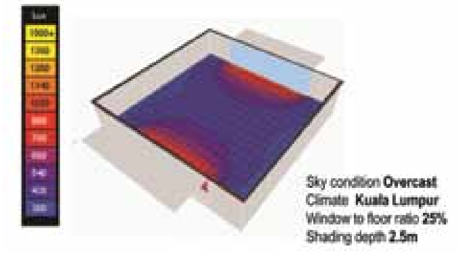

Figure 3. Performance of daylight distribution along the ten-meter-room depth of the base case, using Radiance (v3.5) and Ecotect 2010, (v 4)

conventional construction practice in concrete without insulation, to 0.8 W/m²K, when 400 millimeters of mineral wool insulation is applied to external walls (see Figure 4). Moreover, the cumulative positive impact of shading and insulation resulted in more than 50% reduction in annual cooling loads in comparison to the base case (no shading and no insulation), effectively decreasing from 100.3 kWh/m² to 49.4 kWh/m² per year. At this stage, the potential of cooling through natural ventilation had not yet been considered.

The findings from the first steps of the analytical work are summarized in Table 3, showing the reductions in cooling loads of different combinations, with various degrees of shading depths and U-values. The most cost-effective and optimum combination proved to be the one-meter overhang with the U-value of 0.8 W/m²K [6]. The further reductions in cooling loads were possible with increased shading depth from 1 to 3 meters and increased insulation. However, it must be said that the reduction was marginal, approximately 4 to 8%, in comparison to the optimum combination.

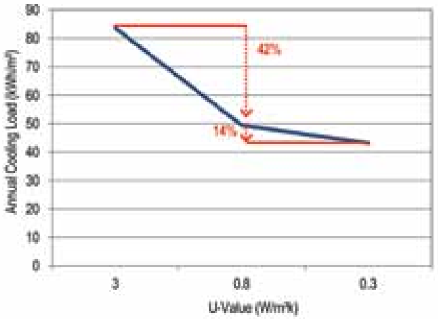

Figure 4. Annual loads of concrete building structure with different U-values in W/m²K oriented north south, based on thermal dynamic simulations using EDSL, 2010 (TAS v 9.1)

Once the envelope was made robust with shading and insulation, the analytic work focused on the study of different ventilation scenarios and its consequent effect on the reduction of annual cooling loads. At this point, size, form and layout of the theoretical base case were modified to represent a typical layout within the residential unit, commonly observed within the typology. This was done to explore if the differences in the performance was similar for the different ventilation conditions, and heights, owing to the various degrees of exposure to the outside (namely one, two, and three façades) (see Table 4 and Figure 5).

Expectedly, the overall performance is similar in different exposures and orientations, due to the solar protection optimization tactics. Results show some slight variations between the different ventilation strategies, as indicated in the cooling loads. The most problematic case was identified in the west-facing orientation, with single-sided ventilation. For this specific case, the analytical work showed that by providing opportunities for cross ventilation, including vertical floor voids (as seen in the TTDI project) and better aperture distribution, the thermal performance of the west-oriented and single exposed unit could be improved significantly. Annual cooling consumption dropped by 25% at typical intermediate floor levels (30 meters above ground) and by only 19% at top floor level (60 meters above ground). This difference in reduction is due to the impact of high horizontal solar radiation, despite the higher wind velocities at the top. With the addition of a double roof [7] painted white, the top floor units' performance could be further improved to 30% to emulate the typical units.

Case Study: The TTDI Tower, Kuala Lumpur

The TTDI residential complex consists of two towers, one oriented north-south and the other east-west. Due to the impact of solar radiation, in principle, the north-south oriented tower is likely to have a better environmental performance, which is why it was chosen for this study. The 21-story north facing tower includes 120 apartments, which house middle and upper middle class families with two- to four-people per household. Some of the signature bioclimatic features incorporated in this project are the continuous 1.2-meter deep shading device; white concrete façades to reflect solar radiation (see Figure 6); 0.6-meter-wide wing

	Window to floor ratio/shading depth			
	15%	20%	25%	30%
1 m	5.05	6.65	7.69	8.33
1.5 m	4.45	5.79	6.68	7.19
2 m	4.11	5.27	5.91	6.41
2.5 m	3.84	4.9	5.53	5.91

Table 2. Showing above 5% average daylight Factor for different Window to Floor Ratios and shading depths, based on simulations for Kuala Lumpur using Radiance (v3.5) and Ecotect 2010, (v 4)

	Insulation (U-Value, W/m²K)					
Shading (m)	3.0	-22.6%	0.8	-57.0%	0.3	-63.3%
1.0 -41.5%	83.6 -16.6%	40.0%	49.4 -50.8%	8.0%	43.2 -57.0%	
2.0 -49.0%	76.3 -23.9%		41.7 -58.4%		35.3 -64.8%	
3.0 -52.4%	73.1 -27.1%		38.3 -61.8%		31.9 -68.2%	

Table 3. Findings from the analytical work showing the combined contribution in reduction of cooling loads, with respect to degrees of shading and insulation. The percentage below is the amount of reduction

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[6] The U-value of 0.8 W/m²K can be achieved with 400 mm mineral wool added to the external concrete walls or simply with lightweight concrete blocks (hollow blocks) commonly found in the local construction sector, to which high-reflectance colors can be easily applied.

[7] A double roof is a non-structural exterior slab placed over the structural roof of a building, common in tropical buildings, it protects the top floor against horizontal solar radiation. The analytic work prescribes a Super insulated Inner roof slab of 0.3 W/m²K, shaded by outer roof both with a surface reflectance of 0.6 and U-value of 0.8 W/m²K

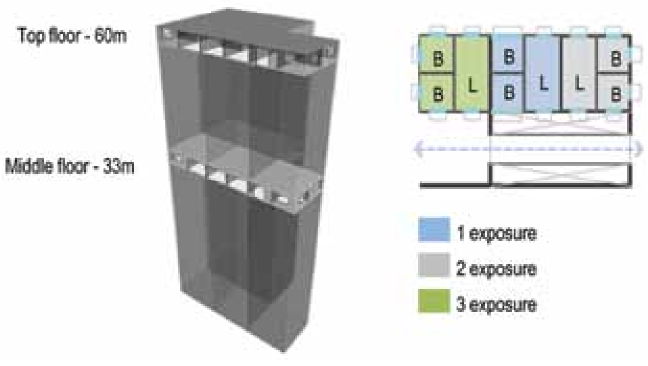

Figure 5. Modified base case for the TAS model EDSL 2010, (TAS v 9.1)

walls located on the east-west faces to capture wind and enhance air flow across the center of the building; and, finally, a double roof covering the top floor flats. The typical layout of the floor plate is divided by a six-meter wide corridor flanked by four flats on either side, each 10 meters deep. The floors are connected vertically by two-meter wide voids, which allow light and airflow, designed to serve the communal circulation areas of the flats (see Figure 7).

The fieldwork took place during the summer period, from June 30 to July 7, 2010. Of the 120 flats, 42 households responded to the general survey on their lifestyle and occupational pattern, as well as their thermal comfort expectations. This data revealed that the air-conditioning thermostat settings during summer varied from 22 to 26˚C for middle-aged people (<50 years) and 26 to 28˚C for elder residents (>50 years). Interestingly, 90% of inhabitants who were interviewed expressed their preference for natural ventilation to mechanical and declared that they exercised window control as their first response to dealing with higher indoor temperatures. However, the survey also showed that occupants' satisfaction levels varied based on occupant perception, floor height and window adaptability.

In this respect, residents in the west-facing corner flats, with three external façades in the plan Flats A and E, considered the bedrooms "hot" in the afternoons, while occupants of those facing east, in the plan Flats D and H, found bedrooms and kitchens "warm" in

Figure 6. TTDI tower, north-south orientation, white façades and shading devices to reflect incident solar radiation © T.R Hamzah and Yeang

Optimized Base Case with Internal Layout TAS inputs		
Mean height of surroundings - 40 m		
Floor Area	100 (10 x 10 m)	
	Living Room	50 m^2
	Bedrooms	25 m^2
Floor Height	3 m	
W/F Ratio	25%	
Internal Gains	5562 kwh year	
Thermostat	Upper Limit 30 C	
	Lower Limit 18 C	
U-value	External Walls	0.8 W/m^2K
	Glazing	5.6 W/m^2K
Aperture Type	Natural Ventilation	partially open: 20C
		fully open: 28 C
Infiltration	0.5 ach	
Ventilation Rate	0 ach	

Table 4. Inputs for TAS model of the Modified Base case EDSL 2010, (TAS v 9.1)

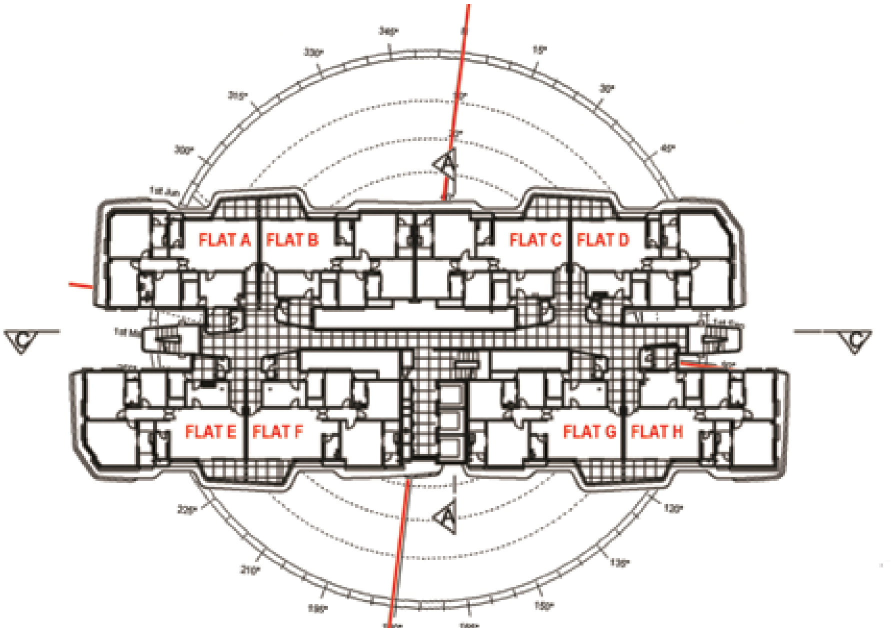

Figure 7. Typical floor plate with the naturally ventilated corridor and vertical floor voids to bring in daylight access and enhance air movement across the inner parts of the building (Source –T.R Hamzah and Yeang). © T.R Hamzah and Yeang

Figure 8. Shallow depth of floor voids

Figure 9. Detailed post occupancy evaluation of flats located at different heights facing north

late mornings. Such responses imply that the impact of solar radiation was experienced by occupants in those critical times as a consequence of the disproportionate shading depth, in relation to the considerably large window areas, with 30–35% of the window-to-floor-ratio, on the east and west façades. The rooms adjacent to the vertical floor voids, which should be the ones that benefit the most from the internal cross ventilation through the stack effect, also had an issue, but this time related to the restricted access to ventilation. The occupants kept the windows closed for privacy reasons, due to the perceived narrow depth of floor void of just under two meters (see Figure 8). On the other hand, the design of the open perforated wide corridors at all levels, allowed ample cross air movement that ameliorated the heat dissipation from the flats, when windows and/or doors were partially opened.

Getting Closer

Following the more generic survey, a more detailed post occupancy evaluation took place in three residential units located on three different floors, including Flat A located at the 13th floor, Flat B on the 7th and Flat C on the 18th floor, all facing north (see Figure 9). In this case, all three flats had two occupants of Indian origin over the age of 53. The differences in floor heights were crucial to demonstrate the impact of height on the effectiveness of ventilation and solar protection strategies, and ultimately, the resulting energy performance of the flats. Table 5 shows the occupancy pattern of the three flats, including time schedule, thermal comfort conditions, window operability and overall energy consumption.

The energy bills for the year of 2010 showed significant variations among the three flats with a range of 25 to 45%. Considering air-conditioning systems and fans account for 30 to 45% of the total consumption (CETDEM 2005) of the average electricity consumption breakdown by the end user of residential flats in Kuala Lumpur, it could be assumed that out of the 15 Kwh/m^2 per year consumed in Flat A, the energy for space cooling can be as low as 5 to 7 Kwh/m^2 per year based on varying occupancy patterns. This figure indicates that Flat A is not only the least dependent on air conditioning, but also probably the only one among the three which is naturally ventilated for most of the year. Given the similarities in the occupancy pattern, differences between flats can be narrowed down to two factors: the differences in comfort standards, and the degree of climatic adaptation. For instance, it was identified that during the summer nights, the residents of Flat A prefer the use of fans rather than air-conditioning, unlike the occupants in Flats B and C.

Cases	Energy Consumption year	Occupant Profile	Clothing Insulation (Clo)	Room Occupancy	Pattern of Occupation (hours)																						Metabolic Rate (Met)	Window/Door Operation Schedule			
					0:00–7:00							8:00–12:00				13:00–15:00			16:00–20:00				21:00–24:00					Morning	Noon	Evening	Night
Flat A	15 (kWh/m^2 per year)	Mother (age 74)	0.54–0.84	Living								▨	▨	▨	▨			▨	▨								1–1.7	open	close	open	close
												■								■	■	■									
				Kitchen												▨	▨										2	open	open	open	close
		Son (age 46)	0.29–0.36																												
				Bedroom	▨	▨	▨	▨	▨	▨	▨												▨	▨	▨	▨	0.8	close	close	close	close
					■	■	■	■	■	■	■												■	■	■	■					
Flat B	40 (kWh/m^2 per year)	Wife (age 57)	0.54–0.84	Living									▨	▨			▨	▨	▨	▨	▨			▨			1–1.7	open	close	open	close
																						■	■	■							
				Kitchen								▨			▨	▨						▨	▨				2	open	close	open	close
		Husband (age 60)	0.29–0.36																												
				Bedroom	▨	▨	▨	▨	▨	▨	▨														▨	▨	0.8	close	close	close	close
					■	■	■	■	■	■	■													■	■	■					
Flat C	25 (kWh/m^2 per year)	Mother (age 76)	0.54–0.84	Living														▨	▨	▨	▨	▨					1–1.7	close	close	close	close
																					■	■									
				Kitchen												▨	▨						▨	▨			2	open	open	open	close
		Son (age 53)	0.29–0.36										■	■																	
				Bedroom	▨	▨	▨	▨	▨	▨	▨														▨	▨	0.8	close	close	close	close
					■	■	■	■	■	■	■														■	■					

Table 5. Comparative data from the POE of the three flats (A, B & C) in the TTDI north-south residential tower

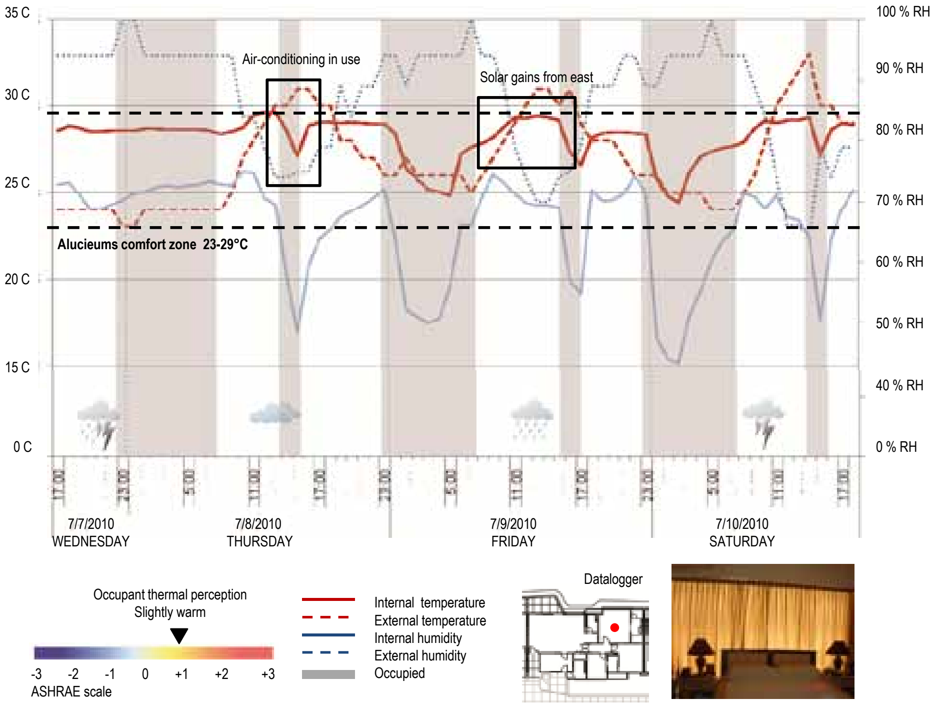

Figure 10. Flat B, air temperature and humidity measured in the master bedroom between July 7 and July 10, 2010, compared to the external climatic conditions

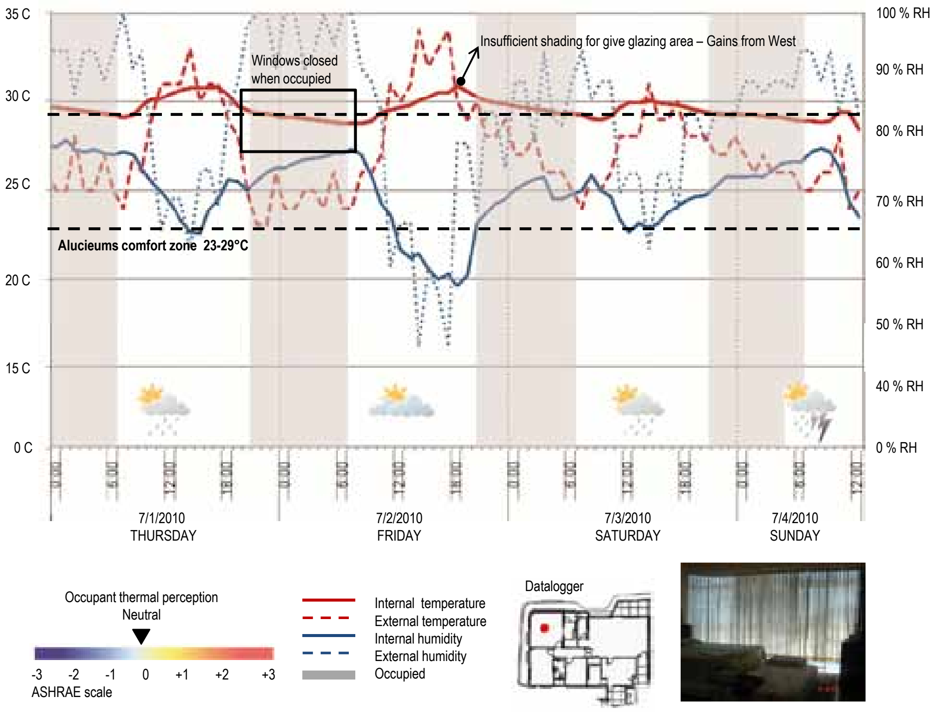

Figure 11. Flat A, air temperature and humidity measured in the master bedroom between June, 30 and July 7, 2010, compared to the external climatic conditions

In addition, in some particular rooms in Flats B and C, where natural ventilation was preferred, ergonomic issues such as improper room dimensions for furniture layout and privacy requirements inhibited more flexible use of windows, which was seen previously in the wider survey. As a result this caused poor ventilation, closure of the internal blinds and the inevitable increased dependency on artificial cooling, mechanical ventilation and artificial lighting (see Figure 10). In terms of solar exposure, Flat B on the 18th floor receives considerably more solar gains than the other two flats due to its position at a higher floor, despite the double roof. In addition, the architectural layout of the building floor plate, allowed direct solar radiation from the internal open corridor and adjacent voids in the central part of the building heating the service and secondary bedrooms of the flat. Furthermore, the kitchen was found to be "hot" in Flat B due to the closed plan layout.

In comparison to Flat B, Flat A has an advantageous position in the TTDI Tower. With the main orientation towards north and west, the exposure of three façades coupled with the proximity to the wing wall creates the appropriate conditions for good airflow within all rooms. The open-plan conversion created by the resident enhanced cross ventilation in the kitchen area where the most internal gains are concentrated. It also improved the daylight penetration from both sides, namely west and north, reducing the demand for artificial lighting. The west facing service areas were shaded in the direction of the prevailing winds and flanked with wing walls, enhancing the cross airflow. Data loggers measuring temperature and humidity were placed for four days in the living room, master and secondary bedrooms in Flat A. In all cases the air temperatures remained relatively stable and below 30°C, except in the west facing master bedroom due to overheating. Based on the findings from the simplified analytical studies, the overheating effect was presumably a consequence of the impinging afternoon sun on an uninsulated wall (see Figure 11). In this case, the surface temperatures recorded on the west facing walls were 2°C higher than external temperature at 7 p.m., after sunset.

Nevertheless, the overall thermal conditions of the rooms in Flat A indicated good thermal and energy performance.

Apart from the capacity of the architectural design to modulate the variable and sometimes undesirable indoor and outdoor conditions, the good environmental performance of Flat A is inextricably linked to the willingness of its residents to exercise adaptive behavior. These included opening and closing windows, controlling the internal blinds and curtains, as well as sleeping close to the ground or under the ceiling fans.

Considerations and Key Findings

The initial analytic work showed that shading of windows and walls is the most effective passive approach for the tropics. The base-case considered a window-to-floor ratio of 25%, which proved to have a good impact on daylight and ventilation, yet was still large enough for generous views of the scenery outside. For windows of such proportion, a shading solution between one to two meters deep, in principle, can be efficient. However precise shading devices need to be determined based on glazing area and orientation. Moreover, contrary to common belief, insulation has a huge potential to reduce the overall cooling load demand in warm-humid climates like Kuala Lumpur, while contributing to more stable internal temperatures throughout the day. The study recommends insulating concrete walls with U-values of 0.8 W/m^2K (400 millimeters mineral wool) to be beneficial when applied externally. Environmentally, shading and insulation improves energy performance by 50%, making the unit robust to climatic variations and, therefore, passively conditioned for longer periods.

...Pritzker

> “The fact that an architect from China has been selected by the jury represents a significant step in acknowledging the role that China will play in the development of architectural ideals.”
>
> *Thomas J. Pritzker, explaining the selection of Chinese architect Wang Shu for the 2012 Pritzker Prize. From “Chinese ‘Amateur’ Wins Prestigious Architecture Prize,” CNN, February 28, 2012.*

Apart from providing a comparative benchmark of 15 kWh/m^2 per year for electricity consumption for future residential units in tall buildings in the tropics, the fieldwork also provided some useful insights into the validity of previous analytical research simulations with regards to shading and natural ventilation. In fact, residents from the middle and upper middle class groups, where the use of air conditioning is a cultural trend, have actually proven to prefer to naturally ventilate their apartments, despite the warm humid climatic conditions of Kuala Lumpur. Constant air movement has proved to enhance the residents' perception of comfort, which is achieved by exercising adaptive mechanisms such as opening windows, doors and/or using low-powered ceiling fans. As a consequence, ambient air temperature around 30˚C was found acceptable. On a more critical observation, the fieldwork also showed the importance of the relationship between the internal furniture layout, position and size of windows. Equally important is the issue of privacy that must be addressed, especially when facing common corridors. By designing buildings with a range of adaptable options–primarily through smaller windows and blinds to address privacy, gusty winds and security–designers can influence occupants to utilize them and tolerate climatic variability in naturally ventilated apartments.

It is crucial to understand the way occupants of existing buildings contribute to overall energy performance, which provides a fundamental measure for the achievement of true environmentally responsive design. Through detailed analysis of occupant behavior, the predicted energy consumption patterns shown in modeling and performance assessment techniques can be further improved, challenging the preconceived theoretical notion of comfort and behavioral patterns.

The findings from the post-occupancy evaluation of the TTDI tower offers insight on the real potential of climate responsive design and the impact of the occupants' behavior and their thermal expectations from the building. A set of effective design guidelines for the tropics can be formulated for future projects by studying the real environmental performance of more existing tall buildings in a wider fieldwork study. With the help of more comprehensive measured data and detailed analytical investigations, specific design solutions can be found. ■

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