EVALUATING THE THERMAL PERFORMANCE OF LOW-INCOME HOUSING IN THAILAND

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Abstract: This research investigates potential areas for improving the thermal performance of low income, government-provided housing designs in Bangkok, Thailand. In a country that experiences hot and humid temperatures throughout the year, buildings need to be adaptable to the climate in order to improve the thermal comfort of inhabitants. The current housing typologies include a prevalence of high density, low-rise condominiums with a large brick and concrete composition. As an initial step, the performance of the building was determined according to adaptive comfort standards using IES (VE) software. The results from the baseline model were analysed according to the adaptive comfort CIBSE TM52 guidelines. The zones under consideration within the case study housing unit were observed to exceed the acceptable limits of what is deemed appropriate for naturally ventilated buildings. The critical zone of concern is the living room with this zone exceeding the upper limit for overheating by a maximum of 11 hours annually. The main sources of the low thermal performance were identified as resulting from: thermal storage effects, the lack of sufficient natural ventilation through the living zones and excessive heat gains through the roof. The internal operating temperatures of the apartment remain high throughout the day and night, ranging from a maximum of 38.5° to a minimum of 27.3°.

Keywords: Thermal Comfort, Low Income Housing, Thailand, Tropical Climates, Dynamic Thermal Simulations

1 Introduction

The consequences of rapid population growth and urbanization in the context of the limited availability of resources have exposed the immediate need to address underlying social circumstances which are attributed to the prosperity of both individuals and the natural world (Golubchikov & Badyina 2012; Hannula 2012). In the developing world the inadequacies of the current housing systems have been exposed. The accessibility of affordable housing is limited by the socio-economic status of those who need it (French et al. 2011) and the quality of the current stock of low income housing is characterised by technical inefficiencies and inappropriate design elements thus rendering it inadequate for day to day living. With concerns growing over urban liveability in these regions, priorities need to be placed on planned future development (Hannula 2012). This involves a shift towards the provision of housing that not only make use of environmentally sensitive construction materials, processes and technologies, but also considers how housing performs under the effects of both internal and external climatic factors (Golubchikov & Badyina 2012). This results in housing that promotes equity and social inclusion amongst communities and the poorest residents. Essentially advances need to be made in the supply of dwellings that reduce the vulnerabilities of inhabitants to future hazards and contribute to resilience, while remaining affordable (French et al. 2011).

In urban areas of Thailand, the adoption of western housing design standards and inadequate standards for thermal comfort assessment in tropical regions (Nicol 2004) means that affordable housing projects are planned and designed without climatic considerations. The inadequate adaptation of these buildings to the prevailing climate results in extreme indoor temperatures and reduced comfort. The Baan Ua-Arthorn programme is an example of a top-down governmental approach to providing housing for the lower income bracket of the population in Thailand (Kritayanavaj 2012; Usavagovitwong et al. 2013). The low cost housing development programme was implemented in 2003 as a means to enhance economic growth in the country, with the intention of constructing 600 000 homes (Kritayanavaj 2012) within a five year period. During an eight year period of implementation the National Housing Authority completed just over 250 000 housing units. These units range in design from low-rise condominiums and single detached houses to semi-detached houses and townhouses. The breakdown of housing unit types shows that during the period of the project implementation over 180 000 of the 253 164 houses constructed included low-rise condominiums. The average construction cost of one of these low income condominiums equates to 8000 THB per m² (Suenderman 2015). Due to the low cost nature of these housing estates, the units are characterised by their use of inadequate materials (Chiarakorn et al. 2014), the inferior quality of the design and the construction, and located in hard to reach urban zones (Archer 2010).

The climatic conditions in Thailand are characterized by three distinct climatic periods. The hottest temperatures are experienced from March to May, the rainy season occurs from June to October and a relatively colder period occurs from November to February (Antarikananda et al. 2006). The mean daily temperature ranges from 26℃-36° C with the average minimum temperature falling to 21°C in the 'winter' months with the annual average temperature reaching 28℃ (Bangkok Climate & Temperature 2015). The rela tive humidity remains high throughout the year averaging 74%-85% and peaking during the rainy months. Daytime temperatures are found to exceed those temperatures deemed thermally comfortable throughout the year (Suenderman 2015).

The incorporation of architectural specifications in the government-provided low income housing (which are incompatible with the prevailing climatic conditions of Thailand) is found to exacerbate issues associated with extreme indoor temperatures and comfort, adequate natural ventilation and low levels of indoor air quality in these dwellings (Santamouris et al. 2007). This has induced a dependency on mechanical forms of cooling once individuals can afford it (Antarikananda et al. 2006) and the residential energy consumption in Thailand set to increase more than twofold by 2030 (Suenderman 2015). The construction of housing that can adapt to dominant climatic conditions is a key element of providing appropriately sustainable housing and reducing energy consumption in an urban context (Hannula 2012).

The use of passive design strategies is proposed as an adequate method to achieve optimum indoor environmental conditions in residential buildings and thus reduce energy consumption (Antarikananda et al. 2006; Santamouris et al. 2007; Suenderman 2015). The distinct nature of the tropical climate means that housing design needs to incorporate strategies that exploit the benefits from the outdoor climate to achieve thermal comfort inside (Jayasinghe et al. 2002). The main design consideration is incorporating elements that minimise internal heat gains and maintain thermal comfort of inhabitants during periods of high solar radiation and relative humidity. The construction of housing that can adapt to these dominant climatic conditions is a key element of providing appropriately sustainable housing and reducing energy consumption in an urban context (Hannula 2012).

To this end, this paper intends to quantify the thermal performance of a single condominium housing unit under the Baan Ua-Arthorn programme. Under the long term outcomes of the ELITH project, this study aims to analyse elements of the building envelope that influence building performance and thereby make recommendations on viable options to solve the inadequacies. This study does not to propose a redesign or new concept design of low income housing for the National Housing Authority, but to indentify the dominant passive cooling strategies and areas of concerns that should be incorporated into low income housing design in this region.

2 Research Methodology

A case study housing design is established be used as a baseline example for assessment. Dynamic thermal simulations are conducted in IES VE to evaluate the thermal performance of low income housing in terms of material composition and design strategies under specific macro climate conditions.

The case study building including the prevailing roofing system (i.e. 5mm slate tiles) is simulated in combination with the standard walling materials (i.e. brick and cement rendering) for a fixed wall thickness of 200mm. A single combination scenario is run incorporating the material characteristics shown in Table 1. The baseline results are then validated according to adaptive thermal comfort standards to assess whether the internal temperatures exceed the acceptable thermal comfort threshold throughout the year and the margin by which these conditions are exceeded.

Table 1: Material description of typical housing unit (CIBSE 2007)

Material	Thermal Conductivity (W/m.K)	Thickness (m)	Surface Emissivity
Roof tiles	6.266	5mm	0.51
External Walls Clay brick and cement rendering	2.246	200 mm	0.75
Internal Partitions Concrete Block	3.384	100 mm	0.90
Windows glazing	2.7465	6 mm	0.90
Ceiling Gypsum	1.255	90 mm	0.85
Floor Reinforced concrete	3.618	250 mm	0.90

The floor plans of the original housing designs were provided by the NHA. Each of the apartments is composed of five rooms, namely: a balcony, a toilet, a living room, a bedroom and a kitchen. The bedroom is the only room with an outside facing window, while the kitchen and the living room both contain windows overlooking the internal hallway. The balcony is accessed through a door from the living room. The windows are set at dimensions of 1.5 m x 1.5 m and are situated 1 m above the base. The doors are set at 0.9 m x 2.5 m. Based on the concepts of zoning, each room in the apartment was identified as an individual zone for DTS purposes.

The typical occupancy pattern for the apartment includes an average of four people with working hours spanning from 8 am to 6 pm during the week. The apartment is considered as occupied during all other hours. The internal gain associated with sedentary person is 90 W/person/day and the gains associated with appliances include 106 W/m² from a gas cooking stove (Ministry of Information and Communication Technology 2013; The Chartered Institution of Building Services Engineers 2006). The buildings are free-running and include no forms of mechanical cooling (Suenderman 2015). The schedule of openings for the baseline model was created on the basis that windows are all open during the day and closed during the night. The house windows are all defined as louvre windows and the window openable area is 25%. The openable area for the doors was set to 50%. The balcony was modelled as a window that is continuously open at 100%.

For this study the weather data over a twelve month period for the Bangkok Metropolis (13.73°N, 100.57°E) is selected. The orientation for the baseline model is set to south facing. This is to simulate the worst case scenario for solar gains and to maximise the effect of the local shading devices over the bedroom windows.

Adaptive model Category II (normal expectation for new buildings and renovations), defined in BS EN 15251 (British Standards Institution (BSI) 2007) along with the flowing overheating criteria, defined in CIBSE TM52, are used to evaluate the risk of thermal discomfort (Table 2).

Table 2: Overheating assessment criteria

	Assessment Criteria*	Acceptable Deviations
Criteria 1	Percentage of occupied hours during which ΔT (ΔT = Top - Tmax rounded to the nearest whole degree) is greater than or equal to 1°C	Up to 3% of occupied hours
Criteria2	“Daily weighted exceedance” (We) in any one day >6 °C.h (degree hours)	0 day
Criteria 3	Maximum temperature level (Tupp) ΔT > 4 °C	0 h

* Refer to Abbreviations for more information.

3 Results and Discussion of Simulations

The simulations section evaluates the thermal comfort conditions based on the standard material composition of Baan Ua-Arthorn housing.

3.1 Performance of Baseline Model of Case Study Housing Unit

The results of the thermal performance of the baseline model were validated according to adaptive thermal comfort standards.

3.1.1 Hours of Exceedance (He)

In Fig.1, the percentage of hours of exceedance is shown for the living zones on the ground floor and the fourth floor. The initial observation is that the apartments greatly exceed the limiting factor of 3%. The apartments on the fourth floor are shown to have worse thermal performance than those on the ground floor. The worst performing apartment is the edge unit on the top floor (with two exposed external walls). The living room in this unit is the worst performing zone with a performance that exceeds the limiting factor by over five times at a value of 16.14%. The bedroom exceeds the limiting factor by over three times with a value of 10.06%.

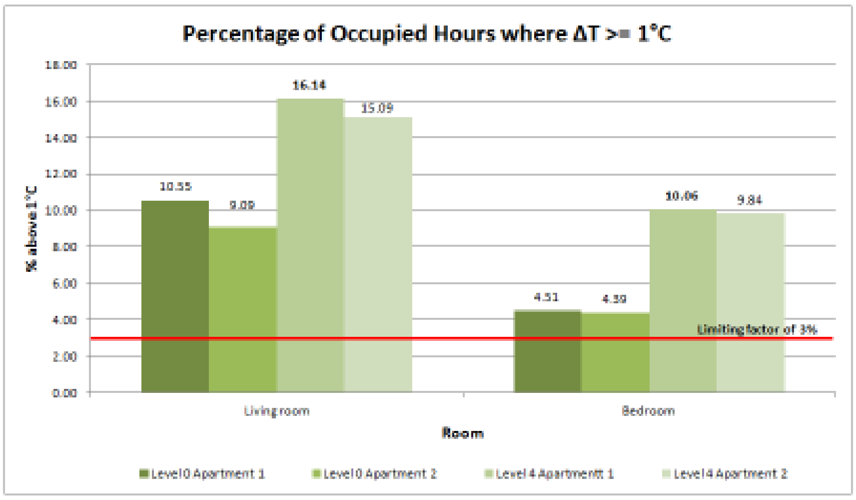

Figure 1: Performance of apartment according to criteria 1

3.1.2 Daily Weighted Exceedance (We)

This criterion was assessed by counting the number of days in a calendar year where the We exceeds 6℃Hr while that zone was occupied. In compliance with criteria 2, a zone should exceed this value for no days. The results for the baseline case are shown in Fig.2. As with criteria 1, the apartments are shown to exceed the limits of failure with the corresponding top floor apartment showing the greatest signs of overheating. Within this apartment the living room surpasses 6℃Hr for 115 days and the bedroom surpasses 6℃Hr for 77 days out of 365 days respectively. This indicates that the zon es within the apartment spend a large percentage of time at very high temperatures throughout the year.

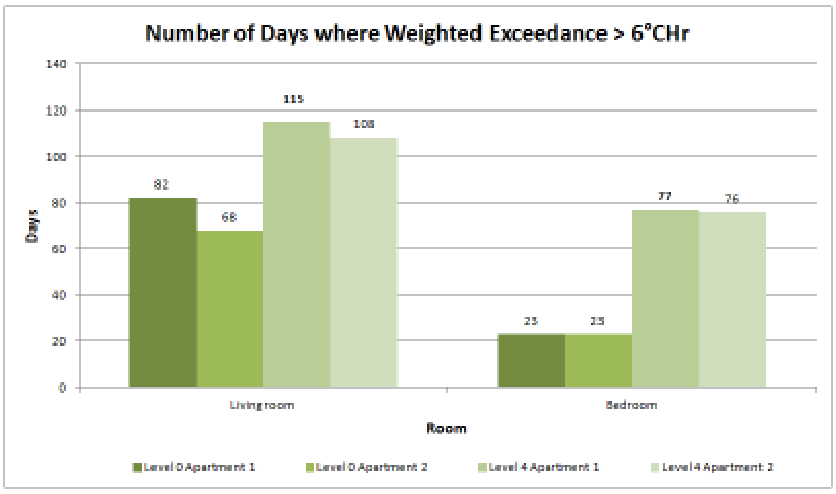

Figure 2: Performance of apartment according to criteria 2

3.1.3 Upper Temperature Limit for Overheating

The apartments on the lower ground are again found to perform better than those on the top floor. The living room is observed to be the critical zone within the apartments as it fails criteria 3 for three of the four apartments (Fig.3). The differentiation in the performance of the apartments on the lower floor is attributed to the location of the apartments. The unit with two exposed walls (apartment 1) has reduced capacity for providing thermal comfort within the adaptive comfort limits. The living room in apartment 1 on the ground floor and top floor exceed 4℃ by 4 hours and 11 hours annually, respectively.

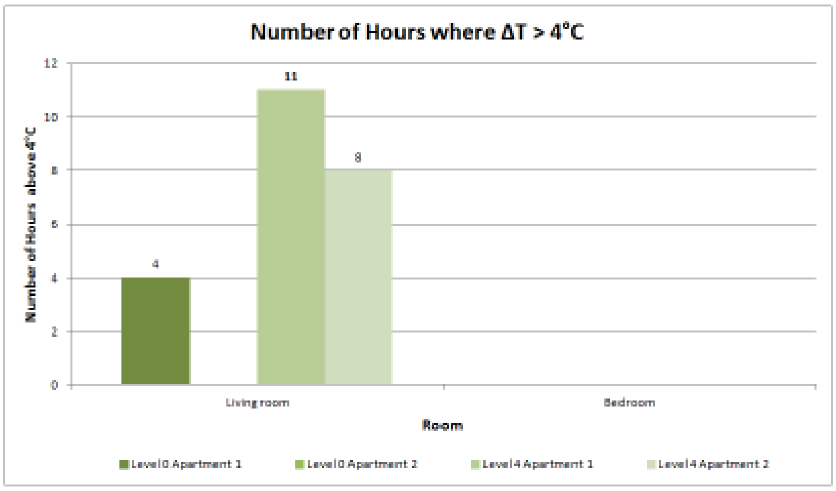

Figure 3: Performance of apartment according to criteria 3

The zones under consideration within the case study housing unit are found to exceed the acceptable limits of two or more of the CIBSETM52 criteria. The critical zone of concern is the living room as it incorporates the internal heat gains from the kitchen as these are interleading rooms.

The apartment with the poorer thermal performance was shown to be apartment 1 on the top and ground floors. This is attributed to the material properties of the structural features of the building envelope. This apartment is constructed with two exposed external walls allowing for a higher rate of heat transfer.

In conjunction with the location of the apartments on a level, the height of the condominium influences the thermal performance of the apartments. The building is subjected to effects from ‘buoyancy-driven air movement’ (Suenderman 2015). Hot air from the lower levels rises up through the building and with no means of escaping the living zones, accumulates on the top levels. Combining this with the effects from the building envelope corresponds to the inadequate thermal performance of apartment 1 on level four for all 3 criteria.

In terms of criteria 3, the bedrooms in each of the apartments do not show exceedance of 4°C over the year. This can be attributed to the classification of the bedroom as a ‘night-zone’ (Garde et al. 1999) which means it is only occupied at night. These criteria are assessed based on when the zone is occupied. This means that the external night time temperature drop below a certain point whereby the addition of internal gains from people is not significant enough to raise the temperature above Tupp. In comparison, the living room is either partially or fully occupied at all times. This incorporates those periods where external daytime temperatures reach their maximum.

While these results show that this housing model far exceeds what is deemed acceptable for TM52 it is important to note that TM52 is designed as a tool for mainly assessing overheating in summer in Europe and the UK. Thus its application to tropical climates tends to underestimate the amount of time spent at high temperatures (which in these regions is most of the day). This is particularly significant for the application of criteria 2. While this level of severity of overheating may be more unacceptable in temperate zones, inhabitants in Thailand are less critical of these conditions. These observations also correlate with those made by Eyre (2015) for low income housing in Tanzania and should be incorporated into continued research into establishing adequate thermal comfort criterion for tropical regions (Nguyen et al. 2012).

3.2 Summary of Findings

3.2.1 Diurnal Temperature Fluctuation

The 24-hour temperature profiles of the living room, the bedroom and the kitchen for the hottest day of the year (29 April) are shown in Fig.4, Fig.5 and Fig.6 respectively. The variation of room temperature with time shows a low diurnal temperature swing with the internal temperature patterns correlating to the external temperature changes. The internal operating temperatures remain relatively high throughout the day and night, fluctuating between the maximum acceptable temperature and the upper limit for overheating. The external night temperatures do not drop significantly enough to induce rapid cooling of the indoor environment.

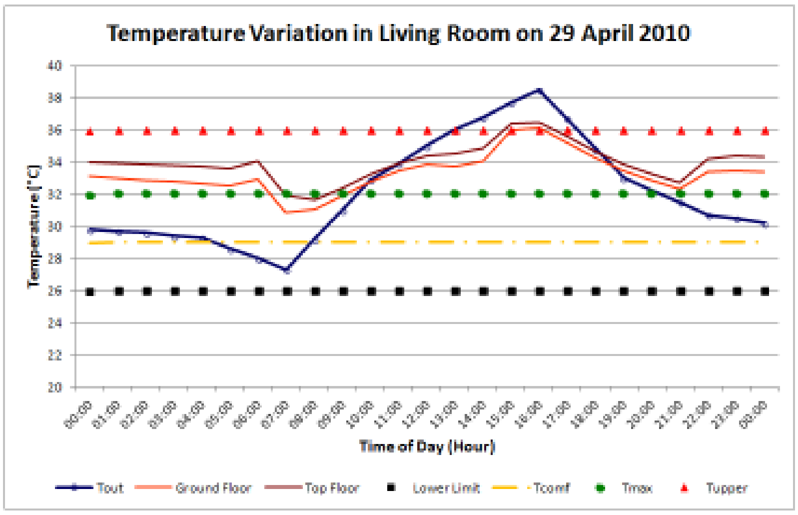

Figure 4: Diurnal temperature variation of living room

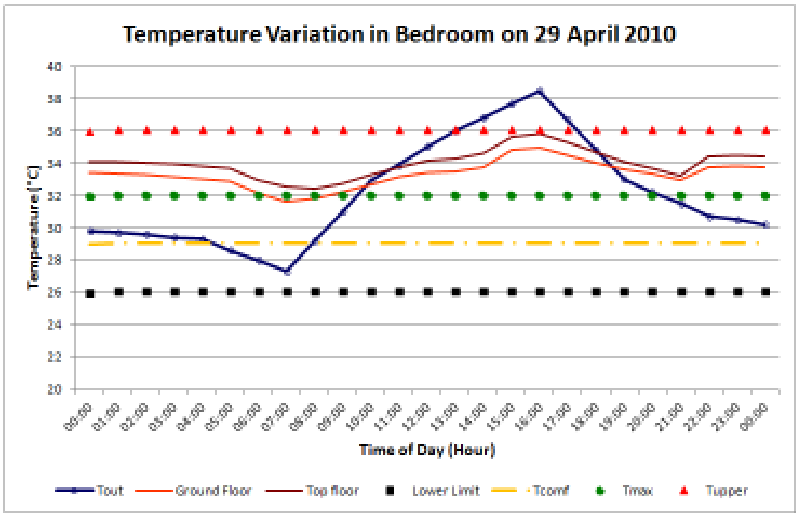

Figure 5: Diurnal temperature variation of bedroom

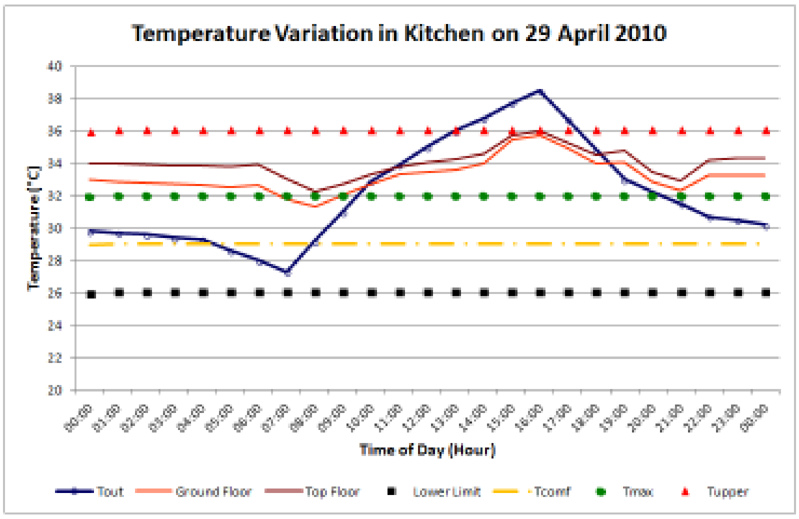

Figure 6: Diurnal temperature variation of kitchen

3.2.1.1 Influence of Building Envelope on Thermal Performance

The thermal mass has a significant influence on the cyclical nature of the temperature changes within the apartment units. As the external air temperature rises, the external walls and floor slab will absorb and store the heat. Once the external temperatures start to drop (7 pm) the heat within these materials rises to the surface and is released into the internal environment. This elevates the internal night temperatures of the living zones. This process is represented in Fig.7, where the fluctuations in the conduction gains of the external walls are influenced by changes in the outdoor temperature. This has the resultant effect of moderating the operating temperatures of the living zones. The critical issue is that this effect keeps the operating temperatures at high levels throughout the day, inhibiting sufficient cooling to occur.

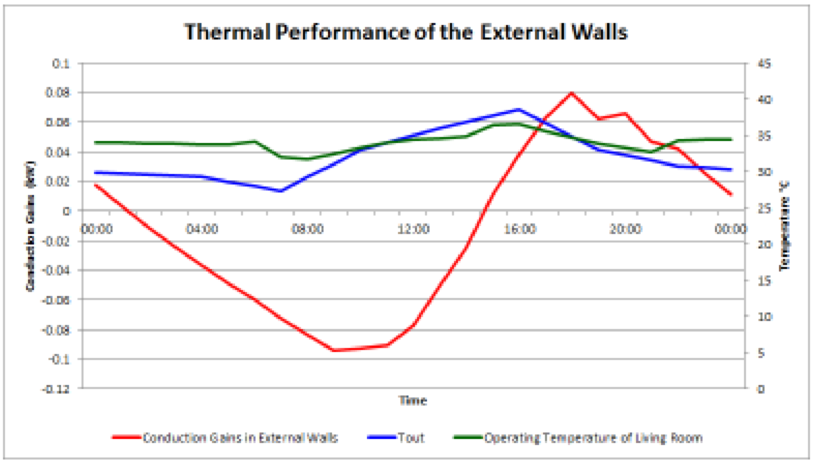

Figure 7: Thermal storage effect of external walls

In this study the windows were assumed to be closed at night due to security and social reasons. This limits the amount of airflow in the apartment at night, particularly in the bedroom which has only one window. With insufficient mechanisms to abate excess heat that is released into the zone at night, the operating temperatures of the apartment remain elevated. Fig.8 shows that about a 2℃ reduction in the operating temperature is ind uced in the bedroom if the window remains open at night and airflow is improved.

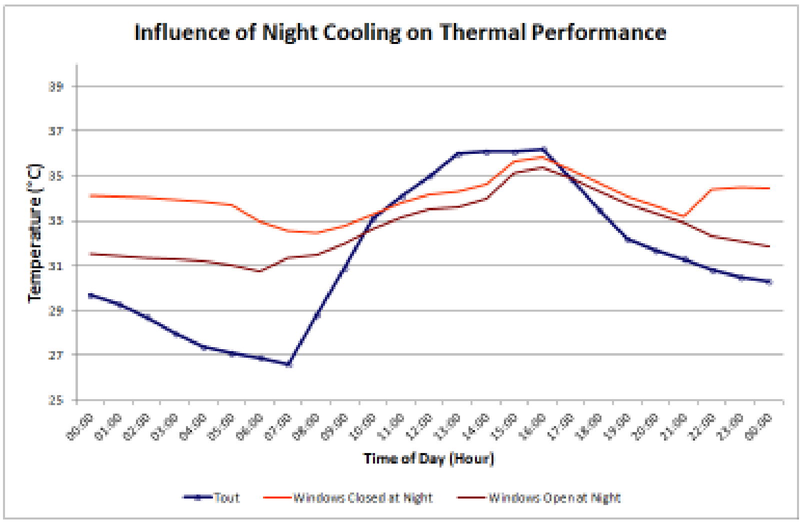

Figure 8: Improvement of ventilation with night cooling

3.2.1.2 Influence of Natural ventilation on Thermal Performance

The high internal operating temperatures are a result of both convection and radiation heat which build up over the day. Without any form of mechanical cooling natural air exchanges are responsible for the removal of this heat; however the current construction of the building and each apartment has a significant influence on the ventilation. While the narrow layout may aid in the circulation of air, the number and type of openings, the layout of the rooms and the restrictions of adjacent apartments means that ventilation between rooms is highly restricted. Fig.9 shows the quantity of airflow that enters into each zone. The value Wc refers to the minimum wind speed that is needed to ensure indoor comfort is maintained (Tantasavasdi et al. 2001). The daytime flow rate ranges from 0.11 m/s to 0.38 m/s. The windows remain closed at night which accounts for this rate dropping to zero overnight. The maximum airflow rate in the living room and kitchen is 0.81 m/s and 2 m/s respectively. To achieve a comfortable indoor environment, natural ventilation should provide an indoor air velocity of 0.4 m/s.

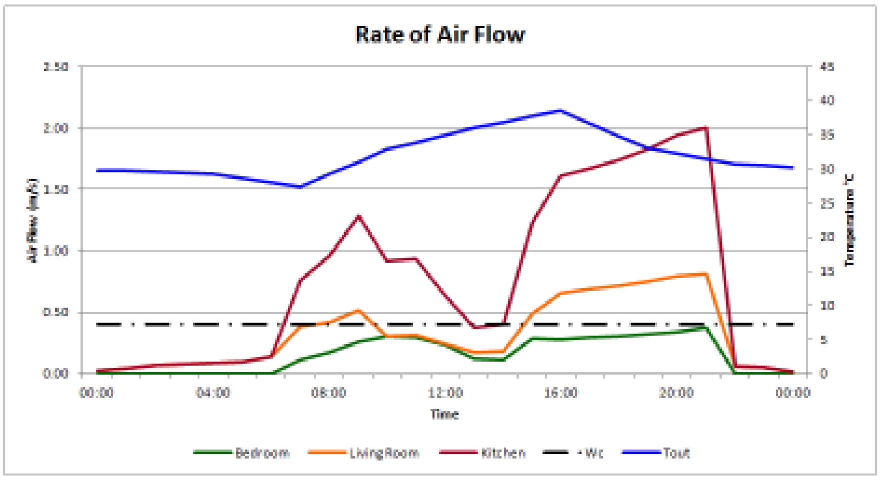

Figure 9: Rate of airflow through the apartment on 29 April 2010

Essentially the amount of cross ventilation that can occur through a single unit is highly restricted by design elements and local climatic conditions. The heat builds up and with no method of removal stagnates to increase the operating temperature as well as the discomfort of the internal environment.

3.2.1.3 Influence of Roof on Thermal Performance

The analysis of the progression of the operating temperature change over the 24 hours showed that the roof is subject to a significant temperature change over the course of the day. The temperature change in the roof is seen to begin at 09:00 as the external temperature rises and the solar radiation increases (Fig.10). The temperature of the apartments is seen to be about 5°C higher than in those on the ground floor at this time. By 14:00 the roof reaches its highest temperature.

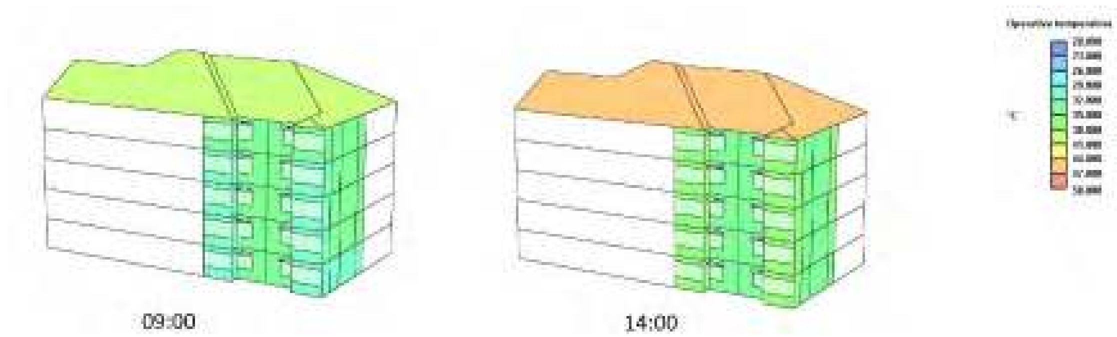

Figure 10: Progression of temperature change in the roof

The corresponding conduction gains in the roof over 24 hours are shown in Fig.11. The conduction values range from a minimum of 1.98kW at 07:00 to a maximum value of 21.86kW at 12:00. This corresponds to the increase in direct solar exposure over the day. The negative gains during the night are associated with reversal in the direction of heat transmission i.e. the roof temperature is higher than the external temperature.

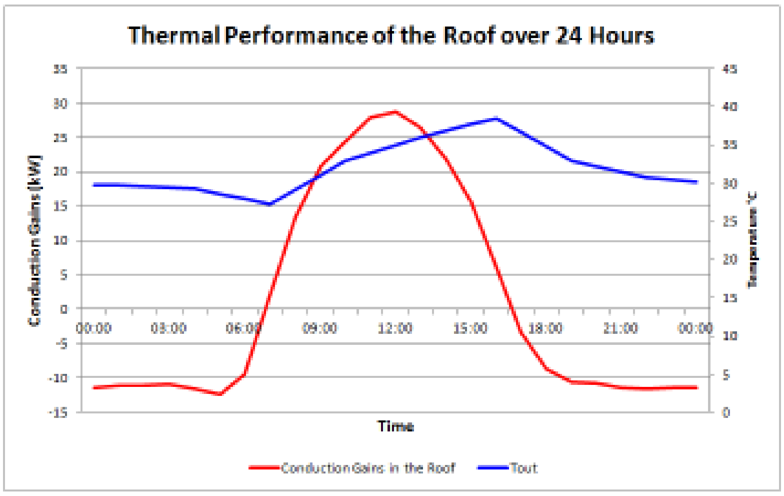

Figure 11: Severity of conduction gains in the roof on 29 April 2010

Various DTS studies that have been carried out on houses in tropical regions have shown that the roof is a key area of concern in terms of thermal performance (Hashemi 2016; Eyre 2015; Garde et al. 1999; Jayasinghe et al. 2002). The roof is continually exposed to high levels of solar radiation and materials used in roof construction tend to have low thermal storage and low thermal resistance properties. This means that a building remains vulnerable to high levels of heat transmission occurring through the roof. In the case study building, there is a significant difference in operating temperatures between the apartments on the upper level and those on the ground floor. This is partly due to the stack effect of air; however this can also be attributed to the high magnitude and the rapid transmittance of heat energy through the roof.

4 Conclusion

This paper evaluated the thermal performance of the dominant housing designs under the Baan Ua-Arthorn housing programme Bangkok, Thailand. Dynamic thermal Simulations (DTS) of the case study housing units were conducted with IES VE in order to determine weaknesses in the design in terms of providing thermal comfort to inhabitants to be identified. The results were assessed according to the CIBSE TM 52 guideline for assessing overheating in naturally ventilated buildings. It was observed that the building failed to comply with the limits of overheating established by this guideline. The primary concerns include the severity of overheating far exceeds what is deemed appropriate for achieving a comfortable internal environment and the living zones breached the absolute daily maximum daily temperature limit. This means that the current housing designs are not adequate for establishing a comfortable living environment for the inhabitant in this climate.

The main sources of the low thermal performance quality in these apartments were identified as resulting from:

I. Thermal storage effects due to the high thermal mass of the apartment walls and floor.
II. The lack of sufficient natural ventilation through the living zones resulting from the high levels of humidity and low natural wind speeds in the area but exacerbated by a poor indoor layout and a lack of sufficient openings in the building envelope.
III. The high conduction gains through the roof resulting from its inadequate material properties.

This paper intended to assess the adequacy of Baan Ua-Arthorn material composition and design techniques to further research around low cost design strategies for more sustainable housing supply in tropical climates. A sensitivity analysis is required to identify the parameters that have the most effect on the thermal performance. These results will be used to make recommendations based on the adequacy of the design strategies in naturally ventilated buildings in consideration of the Thai context. Further research is also required to establish the effects of potential climate change, the quantitative comparison between using mechanical cooling with passive design features and the social constructs regarding the perception of modernity and mechanical cooling. The economics of incorporating passive design elements in low income housing projects in Thailand should also be considered.

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