THERMAL COMFORT IN NATURALLY VENTILATED COURTYARD HOSPITALS

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ABSTRACT

As energy intensive building type, it is important for hospitals to adopt smart energy saving practices. A measured thermal comfort study was conducted at Langkawi and Slim River Hospitals in 2005. Both hospitals are courtyard hospitals with four internal courtyards and with different number of floors and façade treatment. The Langkawi Hospital is three storey high and has shading devices on the walls. The Slim River Hospital is five to six storey high with curtain walls on the facades and high retaining walls on the north and west side. The thermal comfort model used is the Auliciems' model with comfort range between 23.5^{o}C and 28.5^{o}C. The indoor condition of the naturally ventilated spaces in Slim River and Langkawi Hospitals can be thermally uncomfortable with indoor temperature between 25.9^{o} and 31.8^{o}C. Although naturally ventilated, the recorded air velocity in Langkawi and Slim River Hospitals was below 0.4 m/s. This condition, together with diurnal RH between 63% and 83% in Langkawi Hospital can be uncomfortable at times. Increased cross ventilation, shading and closing of windows during the afternoon may decrease heat gain and thermal discomfort. The lack of sun shading devices on the facades of Slim River Hospital contributes to higher indoor temperature and thermal discomfort compared with Langkawi Hospital. The courtyards should be exploited for cross ventilation purposes. In Slim River Hospital, the trees in the courtyard have not matured to provide shading, thus the courtyard is rarely used during daytime compared to the more mature landscaped courtyard in Langkawi Hospital. In most cases the survey results on the occupants' level of thermal comfort agree with the measurement taken on the indoor parameters.

Keywords: hospital wards, thermal comfort, building performance, natural ventilation

1. INTRODUCTION

Recently, the government of Malaysia as well as the private sectors have started to embark on energy efficient measures in buildings as a response to the government's call for energy efficiency (EE). In the case of hospitals, more research into the energy consumption pattern is needed for future development. Future hospitals in Malaysia need to be designed to be energy efficient. Existing hospitals can be run with less energy cost if EE features are implemented as a retrofit to these hospitals.

Hospitals are energy intensive building types, using at least double the energy used by office building and triple that of schools. It is now important for hospitals to adopt smart energy saving practices (Selayang Hospital and Ipoh General Hospital have shown to have high electricity bills as reported in EPU-Danida Energy Auditing Report May 2005).

It is the task of the designer to create a reasonable indoor climate in a hospital that fulfils the requirements of comfort. It can be quite a challenge for the designer to create an environment that has optimum comfort that is defined by *the sensation of complete physical and mental well-being* (Koenigsberger, *et al.*, 1974). Ultimately, a well-balanced environment is one that satisfies all our physiological needs (Olgyay, 1963).

This paper is the result of a measured thermal comfort study which was part of a building performance study for energy efficiency, conducted in the wards of Langkawi and Slim River Hospitals in 2005. Data

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taken from field measurement, occupant survey and documents, drawings and records made available to the research team were analyzed.

2. OBJECTIVES

The objectives of the study are to:

i) Measure the thermal performance of two courtyard-based hospitals at selected spaces/areas,
ii) Evaluate two courtyard based hospitals, from thermal performance aspect, and
iii) Summarize the findings.

3. METHODOLOGY

The approach to the study is based on the study of physical design efficiency through building performance in thermal comfort and indoor quality through field measurement. Results will be compared with existing standards. The research was conducted in 4 stages:

- Background study using building drawings, equipment manual, records, occupancy rates of wards and spaces, and the hospitals' electricity bills for last two years.
- Field measurements on selected areas in both hospitals for thermal performance
- Analysis of data
- Discussion of findings

The study for design sufficiency was focused on general key representative areas in hospital design used by the public, administrative office and the kitchen. Spaces such as the operating theatres (OT), pharmacy and highly clinical areas are not included as they are too specialized for the duration given and will require more extended research undertaking.

3.1 Equipment and Instruments for building performance measurement

The research team used a number of measurement equipment and data loggers that were calibrated to ensure that the field data collected are accurate and reliable to be used in building performance modelling.

4. BUILDING DESCRIPTION

4.1 Langkawi Hospital

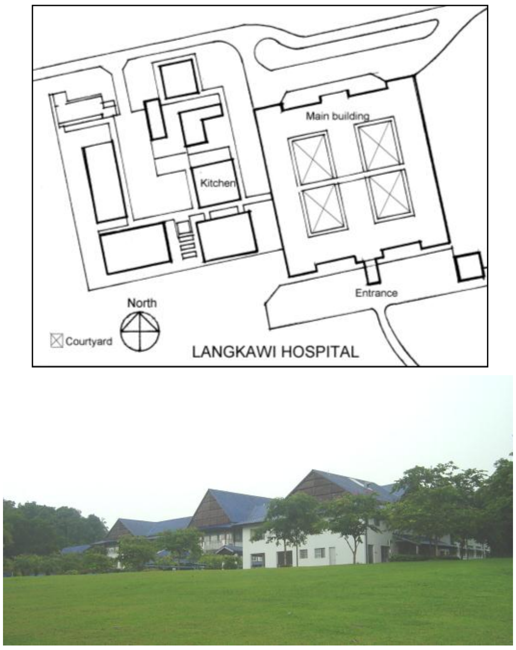
This medical facility is a three storey building with internal courtyard of reinforced concrete (RC) and brick infill with 34,427.80m^2 total floor area (Figure 1). It is roofed over with pitched and glazed tiled roof and with sun-shading devices over most windows along the facades. The building is equipped with standard facilities of a district hospital. It is located on an island and has been fully operational for 12 years. The lobby is located on Level 1, which is the first floor of the 3-storey building. The hospital provides 3 classes of wards of which only the third class wards (naturally ventilated) are fully operational during the study.

4.2 Slim River Hospital

The hospital is a 6-storey courtyard building of RC structure and brick infill with glazed aluminium framed windows on the flushed external walls (Figure 2). There is a high retaining wall outside the building on the north and west side. It covers a total floor area of 47,715.2 m^2. The hospital provides 3 classes of wards of which the 2nd and 3rd classes (naturally ventilated) are in operation while the 1st class wards are operational as and when necessary. It has been fully operational for the last 7 years.

4.3 General operating hours of studied areas for both hospitals:-

Daycare (outpatients) from 8.00am to 12.00pm
Administrative office from 8.00am to 5.00pm
Wards 24 hrs
The building elements and materials for both hospitals are described in Table 1:



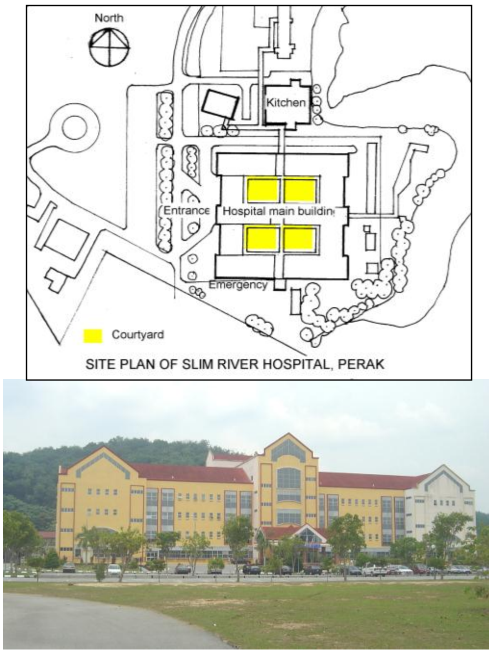


Figure 1: Langkawi Hospital **Figure 2**: Slim River Hospital

Table 1: Building Elements and Materials

		Slim River Hospital	Langkawi Hospital
Roof	Pitch Structure Roof tiles Surface area Material	30° and 45° timber trusses concrete (orange) 10,496.56 m^2 asbestos free (top floor) gypsum acoustic board (indoor spaces) reflective metal strips (lobby)	22° and 32° timber trusses ceramic clay (blue) concrete slab (top floor) mineral fibre acoustic tiles (indoor spaces) gypsum plaster glass ceiling (lobby)
Floor to floor height (mm)		4200 6000 (top floor)	3900 3600 (top floor)
Ceiling height		3300 5000 (top floor)	3000 3200 (top floor)
Floor	Lobby, external corridor Wards & indoor spaces	homogenous tiles vinyl	marble and homogenous tiles vinyl
Wall	External Internal	220 mm brickwall 15 mm cement plaster 220 mm brickwall 15 mm cement plaster 20 mm marble tiles at lobby	150mm brickwall 15 mm cement plaster 220 mm brickwall 15 mm cement plaster
Window	Panel	fixed glass top-hung casement	adjustable glass louvres fixed glass & top-hung

	Frame	aluminium	casement aluminium
Door	External Internal	4 hours timber fire door 2 hours fire door	4 hours timber fire door al. door with fixed louvres 2 hours fire door
Shading Device	Outside	curtain walling at lower floors façade (tinted) recessed window (300mm)	Fixed aluminium louvres Lean-to roof with aluminium fins at Ground floor

4.4 Identified Spaces for Field Study

The spaces chosen for detailed thermal performance field measurements for Langkawi and Slim River Hospitals are shown in Table 2. Priority is given to the west and east facing spaces due to the more severe effect of sun radiation and glare. However, when the wards are neither orientated to the west nor the east, study of spaces to other orientations (i.e., north, south) was undertaken.

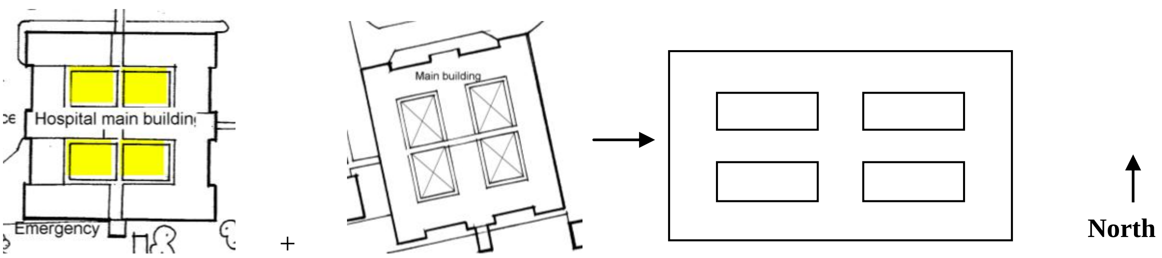
5. RESULTS AND DISCUSSION

The results for field measurements for Slim River and Langkawi Hospitals are indicated in Table 2. Selected spaces were based on public accessible spaces (lobby and wards) and the feedback from the users indicated that more in depth study of the spaces were needed due to thermal discomfort (kitchen). The administration offices were fully air conditioned and measurements were taken to investigate whether or not the indoor condition met the standards.

5.1 Orientation and Building form

Slim River Hospital is orientated to the compass cardinal points (Fig. 2) where the north façade faces true north. The orientation in Langkawi Hospital (Fig. 1) is slightly askew (about 15^o) to the northwest. Hence, the indoor conditions of the north facing spaces will have the effects of heat gain from sun radiation from the west.

Slim River and Langkawi Hospitals have similar shape configurations. They are both square buildings with 4 symmetrical courtyards in the middle of the building. Perhaps a more effective building form would be a rectangular shape with internal courtyards with the longer sides facing north and south (Fig. 4). This shape would have less heat built up from the wall exposed to the east and west sun.



Slim River Hospital *Langkawi Hospital* *Suggested building form*

Figure 4: Suggested orientation and building configuration for the 2 hospitals

5.2 Comfort criteria for naturally ventilated spaces

For naturally ventilated spaces in both hospitals, the degree or Kelvin hours (Kh) of overheating per day was used for evaluation of thermal comfort.

Auliciems' (1981) equation ($T_n = 17.6 + 0.31*T_m$) for all building types (A/C & N/V) was used to find the comfort range for this study . Based on the equation $T_n = 17.6 + (0.31xT_m)$, and using ARCHIPAK's climatic data for Kuala Lumpur where $T_m = 26.9^oC$ (Szokolay, 2002):

$$T_n = 17.6 + 0.31 \times 26.9^oC$$
$$T_n = 26^oC$$

By adding ± 2.5°C for 90% acceptability to this value, the comfort zone is between 23.5°C and 28.5°C. This range was used as benchmark of comfort for this study. If 1.5m/s air velocity from fans can produce 5K apparent cooling effect (Szokolay, 2000), the upper limit of comfort is 33.5°C.

The results from the naturally ventilated spaces are presented as residual discomfort and measured as degree hours of overheating. The degree or Kelvin hours (Kh) of overheating is measured above the comfort limits as set above (28.5°C).

The recommended MS 1525 indoor design conditions for A/C spaces are the same as ASHRAE Standards 55 summertime comfort band of 23-26°C. This comfort band is applicable to N/V buildings. Relative humidity of 60-70% suggested by MS 1525 for AC spaces is applicable to naturally ventilated spaces as well.

5.3 Thermal Performance: Results and analysis

The summary of results is shown in Table 2. The range of temperature and relative humidity are compared to the MS:1525 (Department of Standards Malaysia, 2001) and ASHRAE Standard 55 (1992) recommendations.

In general, the maximum indoor temperature in Slim River Hospital was lower than the maximum outdoor temperature (32.2°C). However, the kitchen area recorded quite high indoor temperature (31.1°C) and was uncomfortable throughout the day and night. The relative humidity conforms well with the MS: 1525 recommendation of 60-70%.

During the measurement of Langkawi Hospital, the outdoor temperature reached a maximum of 32°C. Again the kitchen recorded daytime temperature of 31.8°C which remained above the comfort limit of 28.5°C at night. This can be attributed to the low ventilation rate and the cooking activities which made the kitchen mostly uncomfortable. Air velocity of less than 0.4 m/s is a little low to provide relief from the thermal discomfort. The high humidity (68-78%) in the kitchen worsened the discomfort of kitchen staff.

The wards in Langkawi Hospital also recorded high daytime temperatures, a maximum of 30.7°C in the top floor female ward and 29.7°C in the 1st floor maternity ward. The high RH (63-83%) also added to the discomfort of patients and staff.

Table 2: Results of thermal comfort measurements in naturally ventilated spaces in both hospitals

Hospital	Measured spaces	Orienta-tion	Outdr Temp. °C	Indoor Temp. °C min-max	Air flow m/s	RH%	RH% MS 1525	Comments
Slim River Hospital	Lobby- G Floor	W	24.7 – 33	25.6-29.9	0 – 0.5	49-73	60-70	Temp. & RH acceptable
	Kitchen-annex bldg single storey	middle		27.9-31.1	0 – 0.2	49-67		Hot: heat gain from roof & facades
	Female/ Male Ward- 5th (top) Fl.	N		25.9-29.9	0 – 0.33	52-66		Hot: heat gain from roof
	Paediatrics Ward-3rd floor	W		26-30.3	0.01 – 0.22	49-69		Hot: heat gain from west exposure
Langkawi Hospital	Lobby- Level 1	S	24.9 – 32	27-29.4	0 – 0.4	75-82		Temp. acceptable except in late afternoon
	Kitchen-annex bldg. single storey	middle		28.2-31.8	0 – 0.2	68-78		Hot day & night

	Female Ward – Level 2 (top floor)	W-SW		27.8-30.7	0 – 0.34	63-83		Hot & humid: heat gain from west sun & roof
	Maternity Ward – Level 1	W-SW		28.2-29.7	0 – 0.41	64-82		Hot & humid: heat gain from west sun

*MS: 1525 for indoor temperature is 23 – 26^{o}C for air conditioned areas

5.4 Analysis of thermal discomfort in Slim River Hospital

The thermal discomfort in naturally ventilated spaces in Slim River Hospital over the 3 day measurement period is shown in Figure 5. As mentioned in 5.2, for naturally ventilated spaces in both hospitals, the degree or Kelvin hours (Kh) of overheating per day is used for evaluation of thermal comfort. The Kh of overheating is measured above the comfort limits, set as above 28.5^{o}C (refer to 5.2).

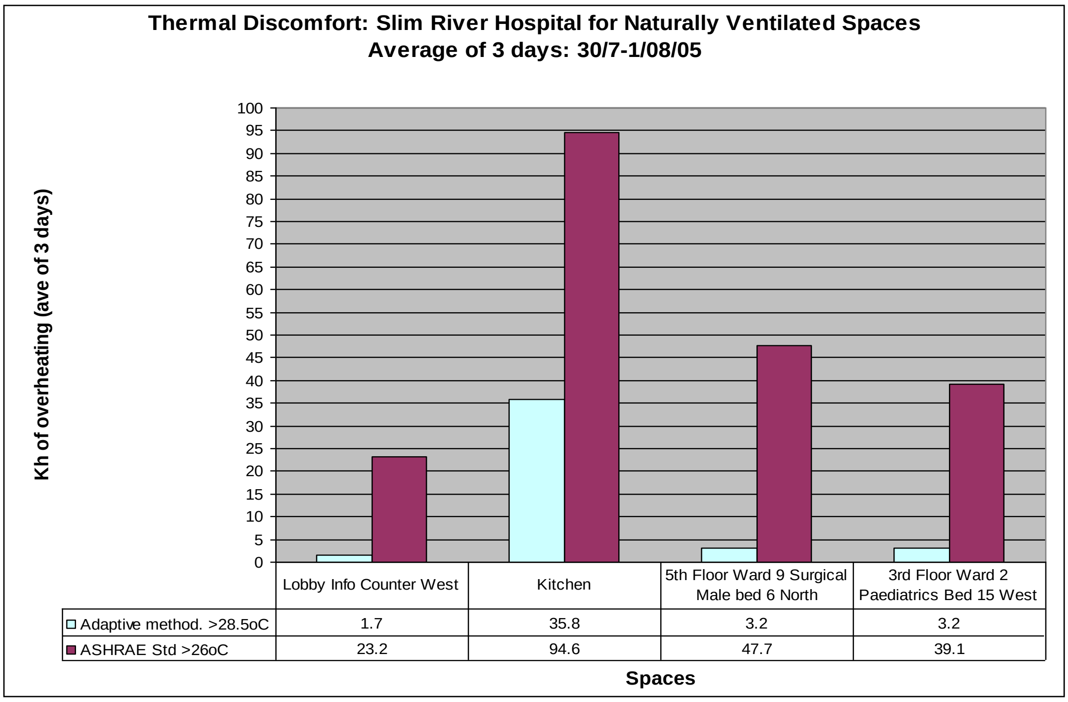


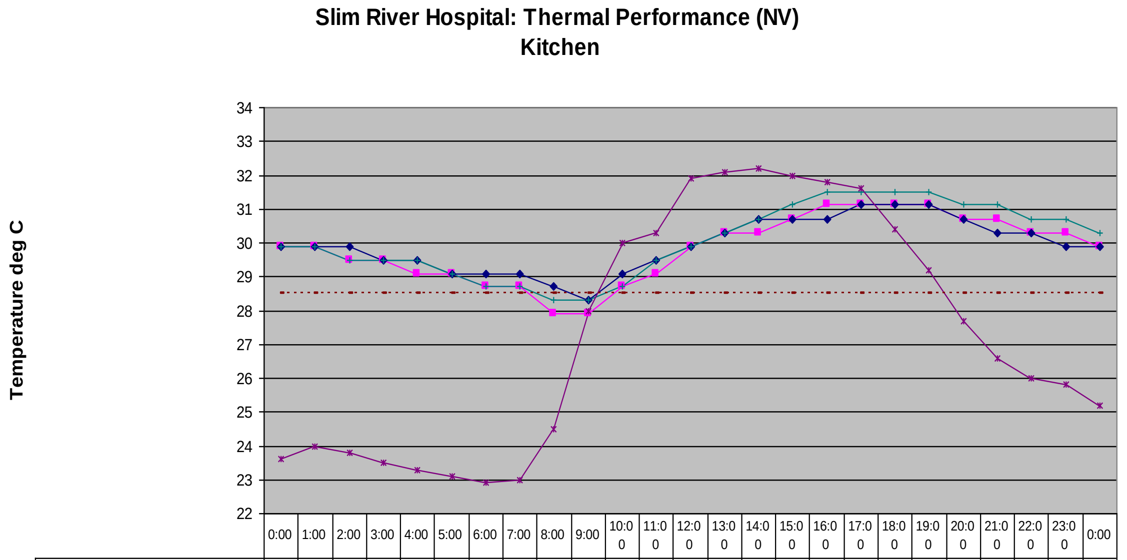
Figure 5: Thermal discomfort in Slim River Hospital (Kh = degree hours)

The bars show comparison between the upper limit of comfort of 28.5^{o}C (Adaptive method with 90% acceptability) and 26^{o}C (ASHRAE Std 55 & MS: 1525). The kitchen recorded the most discomfort over the 3 day period of study with an average of 35.8 Kh (degree/Kelvin hours) of overheating. For example, Figure 6 shows the indoor thermal performance in the kitchen. On that day, the kitchen was uncomfortable for a total of 22 hours. The only time the temperature fell below the comfort upper limit of 28.5^{o}C was between 8:00am and 10:00am. This pattern was repeated over the next few days of field measurement.

Figure 6, shows that even when cooking was not done, i.e., between 9:00pm and 5:00am, the kitchen remained uncomfortably hot. This indicates that the ventilation was not enough in the kitchen as shown in Table 2. From observation, there were very few fans installed in the kitchen. Perhaps, installing more fans would increase air flow and reduce thermal discomfort. These fans can be installed on the columns as ceiling fans would be impractical due to the high ceiling.

The results from the comfort survey (questionnaire) conducted on the occupants show that almost 70% of the respondents felt slightly warm which also concurred with the measured temperatures. For the air flow, 67% of the respondents felt that the air flow was slightly still and 33 % of the respondents felt that the air was still (not moving).

The lobby is comfortable on most occasions except during late afternoon due to exposure to the westward sun (Figure 7). The lobby on the ground floor is an open space with no walls and it faces the courtyard. This layout encourages plenty of cross ventilation. The results from the comfort (questionnaire) survey conducted shows that 100% of the people surveyed felt comfortable with the temperature and this concurred with the measured temperatures. For the survey result on air flow, 75% felt comfortable to breezy while 25 % felt that the air was still.



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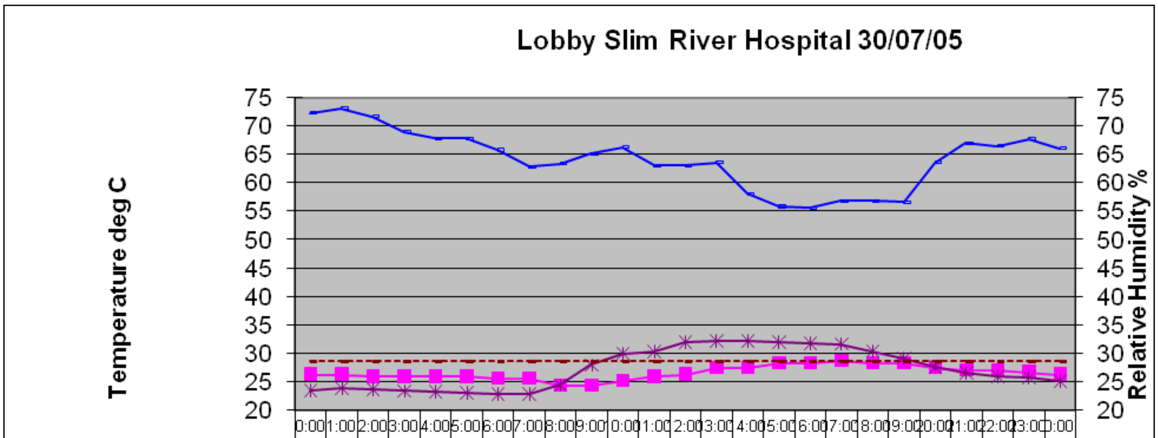
Temp. deg C 30/07/05 Saturday	29.9	29.9	29.5	29.5	29.1	29.1	28.7	28.7	27.9	27.9	28.7	29.1	29.9	30.3	30.3	30.7	31.1	31.1	31.1	31.1	30.7	30.7	30.3	30.3	29.9
Temp. deg C 31/07/01 Sunday	29.9	29.9	29.9	29.5	29.5	29.1	29.1	29.1	28.7	28.3	29.1	29.5	29.9	30.3	30.7	30.7	30.7	31.1	31.1	31.1	30.7	30.3	30.3	29.9	29.9
Temp. deg C 01/08/05 Monday	29.9	29.9	29.5	29.5	29.5	29.1	28.7	28.7	28.3	28.3	28.7	29.5	29.9	30.3	30.7	31.1	31.5	31.5	31.5	31.5	31.1	31.1	30.7	30.7	30.3
Outoor Temp oC	23.6	24.0	23.8	23.5	23.3	23.1	22.9	23.0	24.5	28.0	30.0	30.3	31.9	32.1	32.2	32.0	31.8	31.6	30.4	29.2	27.7	26.6	26.0	25.8	25.2
Comf. upper limit oC	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5

Hour

Figure 6: Thermal performance at kitchen, Slim River Hospital



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RH % 30/07/05 Saturday	72.	73.	71.	68.	67.	67.	65.	62.	63.	65.	66.	63.	63.	63.	58.	55.	55.	56.	56.	56.	63.	67.	66.	67.	66.
Outoor Temp oC	23.	24.	23.	23.	23.	23.	22.	23.	24.	28.	30.	30.	31.	32.	32.	32.	31.	31.	30.	29.	27.	26.	26.	25.	25.
Comf. upper limit oC	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.	28.

Hour

Figure 7: Temperature and RH at lobby, Slim River Hospital

The top floor Male/Female Ward recorded higher Kh of overheating compared to the 3rd floor west facing Paediatrics Ward due to:

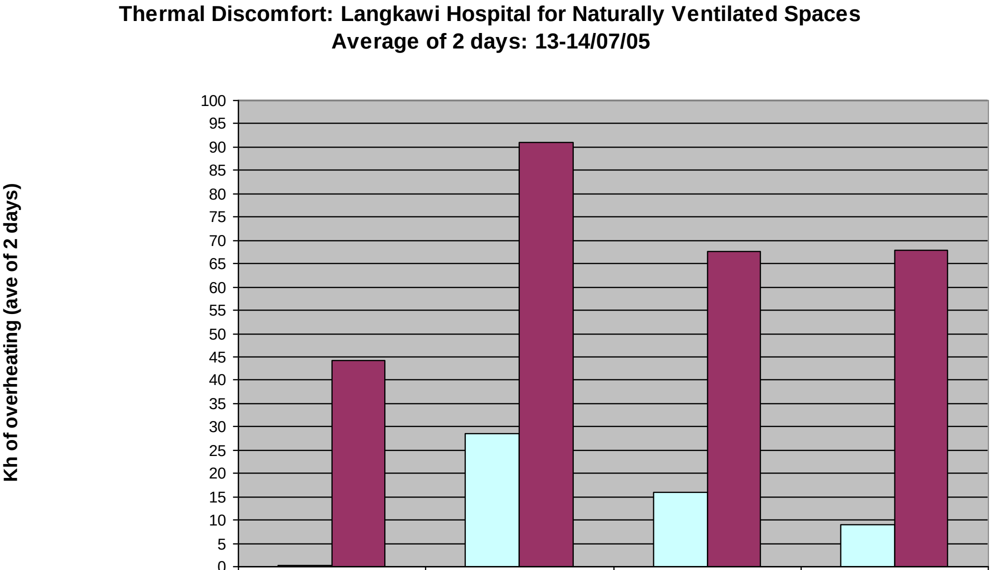
- the effects of heat gain from the roof and
- the effects of heat gain from the low afternoon sun from the northwest direction.

The results from the survey conducted show that 100% of the respondents felt slightly warm to very warm. For the survey result on air flow, 78% felt the air was very still to still while 11 % felt that the air was between slightly still and acceptable.

Slim River Hospital roof is not insulated except for the standard aluminium foil layer under the roof. The application of insulation will reduce thermal discomfort in the interior spaces (Sh.Ahmad, 2004). The external wall is covered with curtain walls instead of shading devices which would greatly reduce the thermal discomfort. Earlier study by Sh.Ahmad (2004) showed that the application of shading devices on the external walls may reduce Kh (degree hours) of overheating by two thirds.

5.5 Analysis of thermal discomfort in Langkawi Hospital

The thermal discomfort in naturally ventilated spaces in Langkawi Hospital over the 2 days of measurement is shown in Figure 8. The bars show comparison between the upper limit of comfort of 28.5°C (Adaptive method with 90% acceptability) and 26°C (ASHRAE Std 55 & MS: 1525).



	Lobby	Kitchen	Level 2 Female Ward West	Level 1 Maternity Ward West
Adaptive method. >28.5oC	0.3	28.6	15.9	8.9
ASHRAE Std >26oC	44.2	91.1	67.6	67.8

Figure 8: Thermal discomfort in Langkawi Hospital

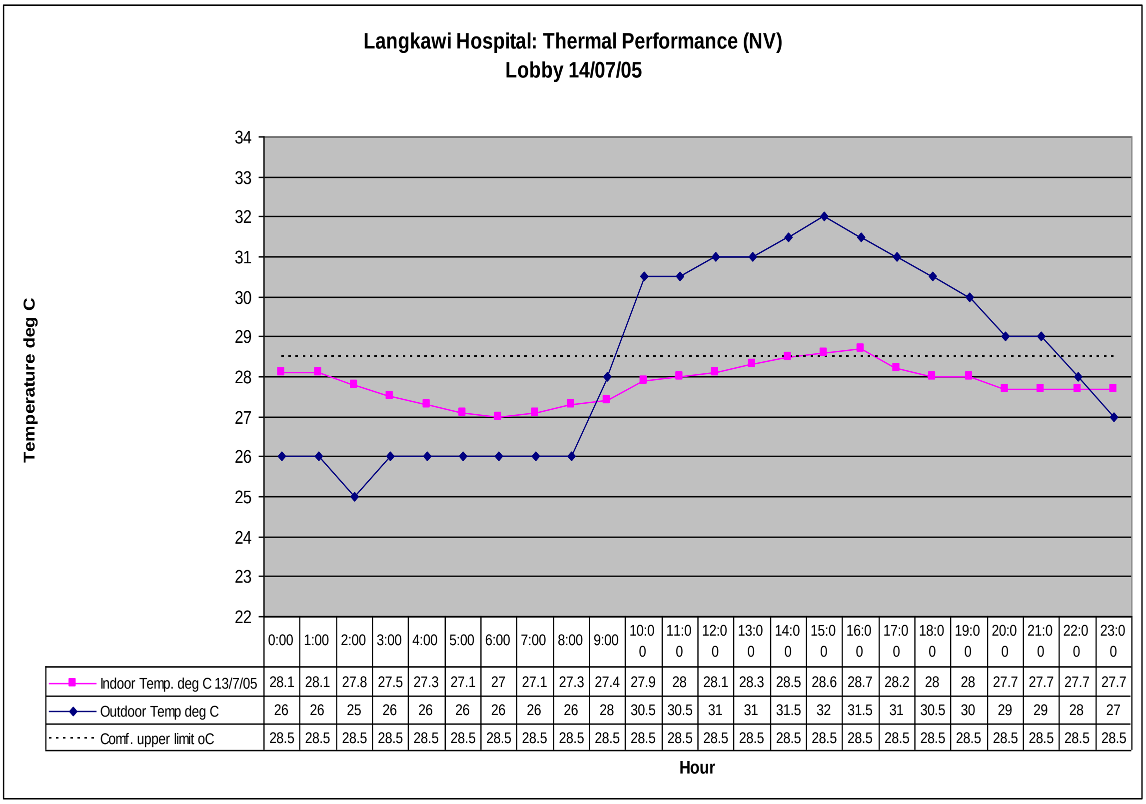
More pronounced pattern of thermal discomfort was observed in Langkawi Hospital compared to Slim River Hospital.

The lobby of the former was mostly comfortable due to the prevailing breezes and the installation of ceiling fans. Figure 9 shows the indoor temperature at the lobby fell within the comfort range except between 3:00pm to 4:00pm where it rose slightly. This result tallies with the result from the survey conducted which shows that 70% of the respondents felt comfortable with the temperature and 50% felt comfortable with the air flow.

The kitchen was uncomfortable due to the high indoor temperature (Figure 10) and relative humidity. More cross ventilation and air changes are needed to reduce discomfort. The results from the survey conducted show that 100% of the respondents felt slightly warm to warm. For the Air flow, 75% felt the air was between still and slightly still and another 25% cited that the air flow was acceptable. Thus one way to improve the comfort level in the kitchen is by increasing its air flow and ventilation rate.

The top floor Female Ward (west facing) recorded higher thermal discomfort compared with the first floor west facing Maternity Ward. Besides the heat gain from the westward afternoon sun, the top floor ward received extra heat gain from the roof. Figure 11 shows that the indoor temperature mostly fell above the comfort range.

The results from the survey conducted show that 50% of the respondents felt comfortable, while another 50% felt slightly warm to warm. Three quarters of the correspondents felt the air flow was slightly still while the others felt that the air flow was very still. Increasing the air flow using fans may increase the thermal comfort level



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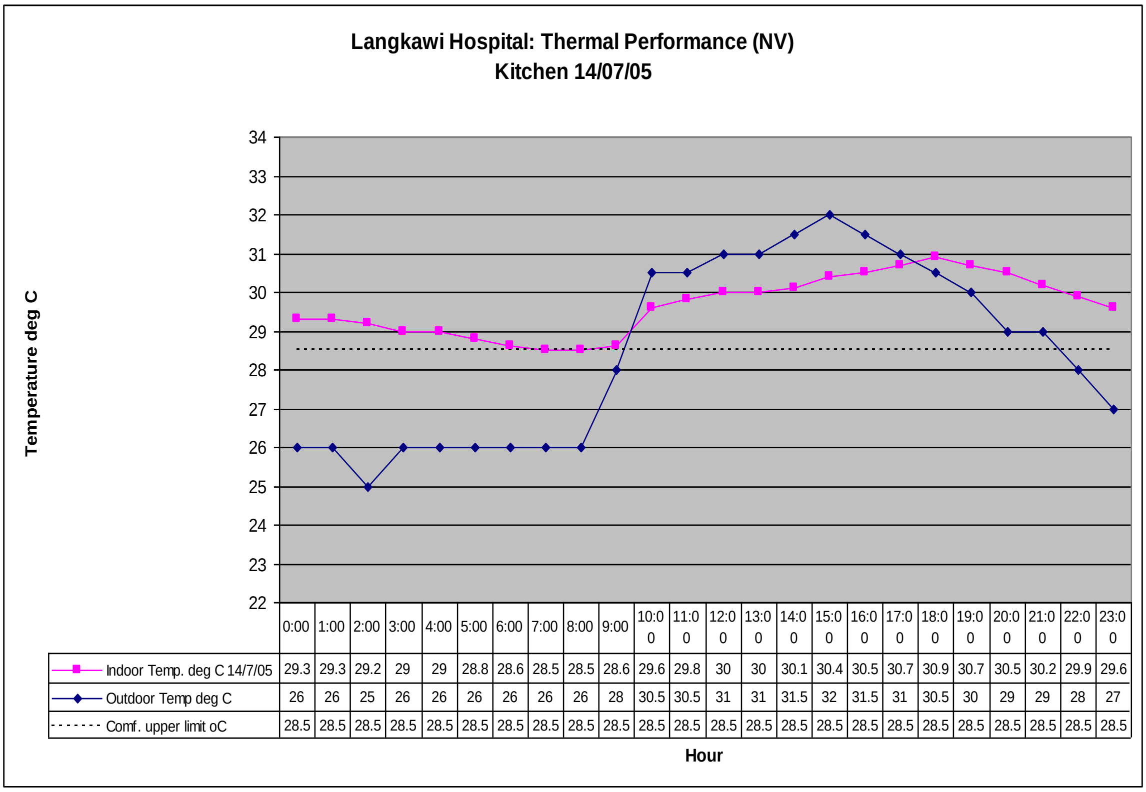
Indoor Temp. deg C 13/7/05	28.1	28.1	27.8	27.5	27.3	27.1	27	27.1	27.3	27.4	27.9	28	28.1	28.3	28.5	28.6	28.7	28.2	28	28	27.7	27.7	27.7	27.7
Outdoor Temp deg C	26	26	25	26	26	26	26	26	26	28	30.5	30.5	31	31	31.5	32	31.5	31	30.5	30	29	29	28	27
Comf. upper limit oC	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5

Figure 9: Thermal Performance at lobby, Langkawi Hospital



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Indoor Temp. deg C 14/7/05	29.3	29.3	29.2	29	29	28.8	28.6	28.5	28.5	28.6	29.6	29.8	30	30	30.1	30.4	30.5	30.7	30.9	30.7	30.5	30.2	29.9	29.6
Outdoor Temp deg C	26	26	25	26	26	26	26	26	26	28	30.5	30.5	31	31	31.5	32	31.5	31	30.5	30	29	29	28	27
Comf. upper limit oC	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5

Figure 10: Thermal Performance at kitchen, Langkawi Hospital

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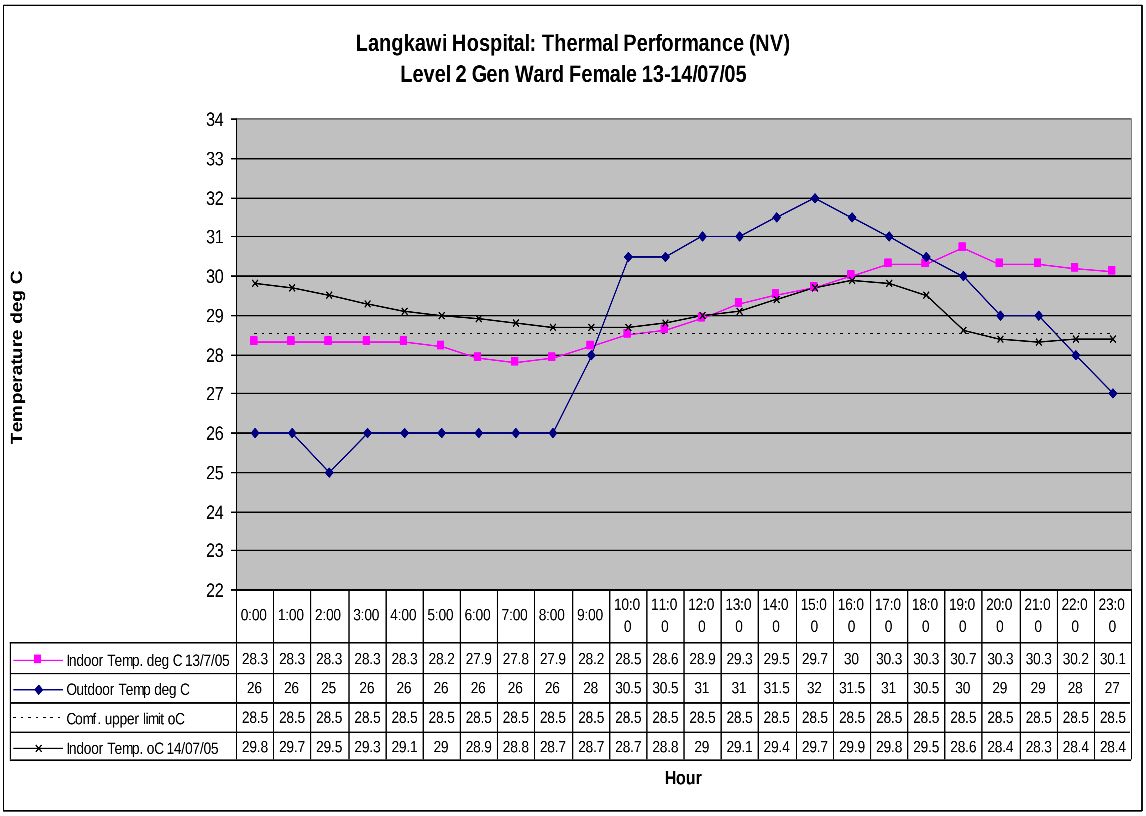

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Indoor Temp. deg C 13/7/05	28.3	28.3	28.3	28.3	28.3	28.2	27.9	27.8	27.9	28.2	28.5	28.6	28.9	29.3	29.5	29.7	30	30.3	30.3	30.7	30.3	30.3	30.2	30.1
Outdoor Temp deg C	26	26	25	26	26	26	26	26	26	28	30.5	30.5	31	31	31.5	32	31.5	31	30.5	30	29	29	28	27
Comf. upper limit oC	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5
Indoor Temp. oC 14/07/05	29.8	29.7	29.5	29.3	29.1	29	28.9	28.8	28.7	28.7	28.7	28.8	29	29.1	29.4	29.7	29.9	29.8	29.5	28.6	28.4	28.3	28.4	28.4

Figure 11: Thermal Performance at general female ward, Langkawi Hospital

Although there are sun-shading devices installed on the external wall, the indoor temperature and humidity remain high due to the lack of cross ventilation especially in all the wards. More mechanical means, i.e., exhaust fans are needed in the wards and toilet areas. Cross ventilation and the use of desiccants to reduce temperature and relative humidity respectively should be explored further.

6. SUMMARY

Slim River and Langkawi Hospitals are designed as square building with internal courtyards with similar pattern. As for the facades, the lack of sun shading devices in Slim River Hospital contributes to higher indoor temperature and thermal discomfort in the naturally ventilated interior spaces.

The lobby area was comfortable on most occasions except during the afternoon and late afternoon when the temperature rose above 28.5^{o}C. The installation of ceiling fans in Langkawi made conditions more bearable. Ceiling fans should be installed at the lobby area of Slim River Hospital to reduce thermal discomfort in the afternoon.

The indoor condition of the naturally ventilated kitchen and wards in both Slim River and Langkawi Hospitals can be thermally uncomfortable during the hot and humid season. Increased cross ventilation, shading and closing of windows during the afternoon may decrease heat gain and thermal discomfort.

The courtyards should be exploited for cross ventilation and daylighting purposes. In Slim River Hospital, the trees in the courtyard have not matured to provide shading, thus the courtyard is rarely used during daytime compared to the more matured landscaping in Langkawi Hospital. Carefully designed courtyards that provide naturally conducive and peaceful environment will help patients to heal faster.

Although naturally ventilated, the Langkawi and Slim River hospital air velocity measurements recorded were below 0.4 m/s. This condition, together with RH between 49 and 83% and indoor temperature between 25.9 and 31.8^{o}C, can be uncomfortable at times.

In most cases the survey results on thermal comfort agree with the measurement taken on the indoor parameters.

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