THE THERMAL PERFORMANCE EVALUATION OF A FUTURE CHINESE LOW-ENERGY APARTMENT WITHIN CHANGING CLIMATE IN 'HOT SUMMER AND COLD WINTER' ZONE IN CHINA

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ABSTRACT

The paper aims to evaluate the thermal performance of a typical Chinese low-energy residential building in 'Hot Summer and Cold Winter' zone where two prototypes within a six-storey healthy housing with low-energy standards have been investigated. According to the building simulation study undertaken, prototype 1 has relatively good thermal performance compared to prototype 2. In the study, the low-energy parameters have been taken into consideration for both prototypes as an input, which is defined as an energy efficiency building code in HSCW zone with an insulated construction and a criterion calculating indoor temperatures. The simulation resultshave shown that the existing Chinese low-energy building design standard cannot achieve the thermal comfort requirement introduced bythe ASHREA 55-2004 standard. Furthermore in the study, the adjustment mechanism of occupancy for thermal comfort has been incorporated with the simulation studies. Moreover, the regional thermal sensation measurements have proven that it is important to consider both thermal comfort and low-energy building studies together.

INTRODUCTION

The risk of global warming and providing a healthy housing is essential which is also confirmed by the Chinese government policy of energy saving and low-carbon emissionscode toencourage a further research challenge. In China, energy saving target of 50% (MHURD 2003) reduction in new buildings compared with the level in the duration between 1980-1981 has been clearly targetted in the last national development strategy (MHURD 2006) of the 11th 'Five-year Plan' (2005-2010). Moreover, a higher aim of energy saving is established for the detailed discussion in the 12th 'Five-year Plan' (2011-2015).

CHINESERESIDENTIAL BUILDING

The common residential housing is classified in four sections by Chinese official legislation(MHURD 2006), respectively including indemnificatory housing with the floor area around 40-60 m^2, economically affordable housing limited around 60-80m^2, comfortable housing limited around 80-100m^2 and rural housing which is around 120-150m^2. This official classification has been mentioned in the outline of 11th 'Five-Year Plans on Civil Construction Issues, 2006'. Healthy housing has been defined with the minimum limit of available floor area in a current residential building unit in 2004 (CNERCHS 2004). The minimum limit values of available floor area have been listed below in Table 1.

Table 1
The minimum limit of available floor area in a Chinese apartment unit

UNIT SPACE	The minimum limit area (m^2)
LIVING ROOM	16.20 (3.6mx4.5m)
DINING SPACE	7.20 (3.0mx2.4m)
MAIN BEDROOM	13.86 (3.3mx4.2m)
SUB BEDROOM (DOUBLE BED)	11.70 (3.0mx3.9m)
KITCHEN (SINGLE LAYOUT)	5.55 (1.5mx3.7m)
TOILET	4.50 (1.8mx2.5m)

Building Layout

According to the Chinese healthy housing technical essential code, a series of indoor floor area has been defined in six spaces. Two kinds of apartments have been investigated in this paper, which are totally defined at minimum floor area limit. Moreover these two testing unit are respectively combined in a six-storey building, which is frequently designed to be common prototypes in China. In a detail layout, prototype 1 is defined to be a rectangle shape with short faces towards north-south orientation, and prototype 2 has a square shape with as same direction as prototype 1. Figure 1 displays the prototypes used for simulation studies.

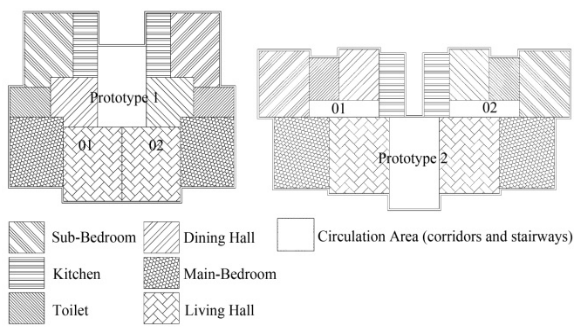

Figure 1 Layout of two prototypes

These two prototypes are two typical Chinese housing layout designed for current Chinese residential building market. In order to maximise the commercial profit, using prototype 1 could make the residential block contain more household to face one orientation. For example Prototype 1 is usually designed around the boundary of exploitation site and more housing unit could face a wonderful urban landscape/landmark. However the merits and demerits are both existed in this kind of building type. For a instance, because the shape of unit has long depth and short front facade, therefore the external area ratio of window to wall would be lower than the prototype 2 and thermal lost of exterior envelope would be reducted following the ratio decreasing. Meanwhile the less glazing envelope would reduce the day lighting inside. Considering the layout character of long depth in prototype 1, the natural ventilation and internal crossing draught hardly occured in this kind building layout. In prototype 2 less housing units are capable of design in longitudinal direction, however the natural wind could pass the whole building through the external windows easily. The internal lighting would be better as well

These two prototypes have been debated on their suitability for this regional climatic zone in the past long time. Thereby the study of thermal performance has a great significance in these two housing types for Chinese low-energy residential building thermal comfort and providing numerical data to to examine the discomfort indoor environment. Moreover this research could push up the development of Chinese residential building in the near future.

Building Construction Material

In this simulation study, building construction is one of the important inputs for the final assessment of building thermal comfort. The main materials of the two prototypes are consisted of external wall, internal wall, internal floor, windows and doors.

Table 2
Construction materials input

CONSTRUCTION	MATERIAL	U-VALUE (W/m^2K)
EXTERNAL WALL	Cement mortar (0.02m)	1.033
	EPS Expanded polystyrene (0.02m)	
	Concrete hollow block, medium weight (0.15m)	
	Limestone mortar (0.02m)	
INTERNAL WALL	Plaster (Dense) (0.02m)	2.061
	Brick-burned (0.2m)	
	Plaster (Dense) (0.02m)	
INTERNAL FLOOR	Cast concrete (Lightweight) (0.1m)	1.876
WINDOWS (OPENINGS)	Generic PYR clear (0.003m)	1.96
	Air (0.013m)	
	Generic Clear (0.003m)	
EXTERNAL DOORS	Plywood (Heavyweight) (0.006m)	2.04
	Air gap (0.03m)	
	Plywood (Heavyweight) (0.006m)	
INTERNAL DOORS	Painted oak (0.042m)	2.08

Table 3
U-value of building envelope (W/m^2K)

EX-WALL	IN-WALL	EX-WIN	FLOOR	DOOR
⩽1.0-1.5	⩽2.0	⩽2.5-4.7	⩽2.0	⩽3.0

OccupancyActivitySchedule

The occupancy living activity schedule is another important inputfor heating or cooling load calculation of comfort output. The occupancy living activity schedules predict the energy operation during the investigated periods. In this simulation the testing interval is designed in monthly, daily, hourly.

In thestudy, the occupancy activity schedule is based on Qu et al. (2005) and again it is focused on four indoor spaces (Kitchen, Living hall, Dining hall and Bedroom).In spite of some differences exist between main-bedroom and sub-bedroom, only one requirement has been defined in the simulation study. According to the schedule, three labels (People, Lighting and Device) are contained in the study.

Table 4
Activity schedule

INDOOR AREA	ACTIVITY SCHEDULE	FREQUENCY (%)
KITCHEN	7:00-9:00	80
	11:00-13:00	100
	17:00-19:00	100
LIVING HALL	10:00-12:00	30
	15:00-17:00	30
	19:00-21:00	20
DINING HALL	7:00-9:00	100
	11:00-13:00	40
	18:00-20:00	40

BEDROOM (MAIN)	20:00-23:00	90
	23:00-7:00	100

Table 5
Lighting schedule

INDOOR AREA	LIGHTING SCHEDULE	FREQUENCY (%)
KITCHEN	17:00-20:00	100
LIVING HALL	19:00-21:00	70
DINING HALL	18:00-20:00	100
BEDROOM (MAIN)	20:00-21:00	90

Table 6
Device schedule

INDOOR AREA	DEVICE SCHEDULE	FREQUENCY (%)
KITCHEN	7:00-9:00	50
	11:00-13:00	50
	17:00-19:00	50
LIVING HALL	10:00-12:00	50
	15:00-17:00	50
	19:00-21:00	50
DINING HALL	10:00-12:00	10
	18:00-20:00	10
BEDROOM (MAIN)	20:00-22:00	50

In these two simulation units air-conditioners are applied in living room and bedroom room only. Kitchen and dining hall are both free-running space. This is a common status for Chinese occupancy. The air-conditioners's working schedules are presented in the 'Device schedule'mentioned in Table 6, however for kitchen and dining hall the time and frequency standard for other equipments use except the lighting.

Thermal Parameters

One of the other important inputs to use in simulation is the status of outdoor and indoor thermal environment. For that reason, the regional thermal parameters are extracted for the thermal environmental control.

The simulation site is located in Yichang city in the central part of China. According to the China thermal design code (MHURD 2001)for civil buildings, five zones are defined in China. 'Hot Summer and Cold Winter' (HSCW) zone is the objective background and it is also fixed on 'III climatic region' in the Chinese standard of climatic regionalisation for architecture. This is also defined asa kind of humid subtropical climates ('Cfa') of group C of Köppen-Geiger climate classification(Köppen 1936). At later time, a simple climate classification system (Atkinson 1953) distinguished four types of zone for building design and the system is based on the nature of human thermal comfort. HSCW zone is also defined in warm-humid category (another three: cold, temperate and hot dry) and thermal sensation is aggravated by high humidity and the diurnal temperature variation is small.

In this study, 'CHN_HUBEI_YICHANG_CSWD' is the hourly weather data of EnergyPlus weather file from the ASHRAE. In Yichang city, the ASHRAE climate type is '4A'. The summer period starts from June to August and the winter time begins from December to next Feburary. In the study, two testing scenarioshave been chosen with different weather situation.One testing period is started from 1st June to 31st August in 2002. The other one is started from 1st December to 28th February in 2003.

ASHRAE standard 55-2004 mention its suitable scope in 'Section 2' that the standard requires the thermal environmental conditons exist at atmospheric pressure equivalent to altitudes up to 3000m (10,000ft) in interior space which designed for healthy adults. The ocupancy periods are not less than 15 minutes. HSCW zone is a huge climatic area, The altitudes of Yichang city is between 35-2427m. Therefore the ASHRAE standard 55-2004 could be used for residential building thermal comfort research in this simulation area(Yichang).

Accordingly with the China low-energy building design standard in HSCW zone(MHURD 2001), thermal parameters are listed in Table 7.

Table 7
Thermal parameters for energy efficiency of residential building in HSCW zone

PARAMETERS		STANDARD VALUE
FRESH AIR m^3/(h. person)		≥30
AIR CHANGE(Rate/h)		1
WINTER INDOOR TEMPERATURE (°C)		16-18 (18)*
SUMMER INDOOR TEMPERATURE (°C)		26-28 (26)*
COOLING ENERGY EFFICIENCY RATIO	Household heat pump air conditioners with some electric heaters	2.3 (2.2)*
HEATING ENERGY EFFICIENCY RATIO		1.9 *
INDOOR LIGHTING THERMAL GAIN(KWh)		0.014
NOTE: *: The figure is the calculated value for energyconsumption calculation		

With the regional weather data which was based on China standard weather data (Xiong et al. 2005) edited from 1971 to 2003 and recorded by 270 surface weather stations aroundthe mainland China. The data of thermal parameters contain the calculation values of winter/summer outdoor temperature, relative humidity, external air velocity and dominant wind direction. The list of parameters is thecorresponding calculation values for the simulation studies.

Table 8
The thermal parameters for thermal calculation in Yichang, Hubei, China

PARAMETERS	CALCULATION VALUE
WINTER OUTDOOR T(°C)	-0.8
WINTER OUTDOOR RH (%)	69
WINTER OUTDOOR MEAN VELOCITY (m/s)	1.4
WINTER DOMINANT WIND DIRECTION	SE (135)
WINTER DOMINANT WIND VELOCITY (m/s)	2.3
SUMMER OUTDOOR DRY-BALL T (°C)	35.6
SUMMER OUTDOOR WET-BALL T (°C)	27.8
SUMMER OUTDOOR MEAN DAILY T (°C)	31
SUMMER OUTDOOR RH (%)	62
SUMMER OUTDOOR MEAN VELOCITY (m/s)	1.9
SUMMER DOMINANT WIND DIRECTION	SE (135)
EXTREMELY MAX T (°C)	40.4
EXTREMELY MIN T (°C)	-9.8

SIMULATION

The simulation studies have been carried out using DesignBuilder software package. DesignBuilder (DB) is a state-of-the-art software tool for simulating building energy, CO_2, lighting and thermal comfort performance checking. It includes rapid building 3-D modelling and ease of use with state of art dynamic energy simulation engine.

Comfort data analysis is a part of simulation function based on EnergyPlus 6.0. It can generate extensive data on environmental conditions within building comfort levels. Four comfort-related outputs are listed below:

1. Internal operative temperature - The mean of the internal air and radiant temperatures.
2. Fanger PMV – Fanger's Predicted Mean Vote (PMV) calculated according to ISO 7730.
3. Pierce Thermal Sens. Index (TSENS) – The Thermal Sensation Index (PMV) calculated using the Pierce two-node thermal comfort model.
4. Discomfort hours (all clothing) – The time when the combination of zone humidity ratio and operative temperature is not in the ASHRAE 55-2004 summer or winter clothes region.

There are other two thermal parameters used in simulation results in this paper. One is outside dry-ball temperature and the other is RH value. These two parameters are key factors to present the impact of external thermal environment and conditions of indoor thermal performance within the two prototypes in HSCW zone.

Especially, discomfort hours analysis could be a difficult task which also becomes a challenge for thisstudy in this particular zone even with indoor air temperature displaying within the normal ranges. There are two possibilities:

1. The highly glazed space is modelled in summer or poorly insulated space is created in winter.
2. The impact of humidity has a very high or low value caused by inadequate ventilation. Dry air temperature of 21.7°C, which may be lower than heating temperature set points in winter.Likewise, the high humidity operative temperature is above 26.8°C with summer clothing in summer.

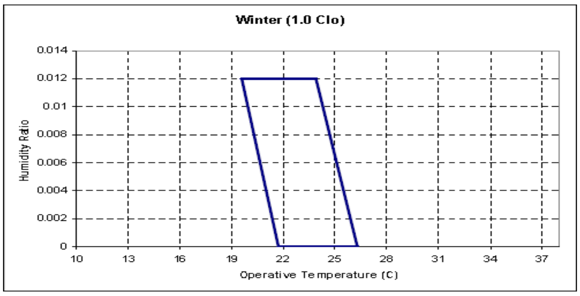

Figure 2 Comfort zone in ASHRAE Standard 55-2004 in winter

Air Temp(degC)	Humidity Ratio
19.6	0.012
23.9	0.012
26.3	0.000
21.7	0.000

Figure 3The corresponding air temperature to humidity ratio in winter

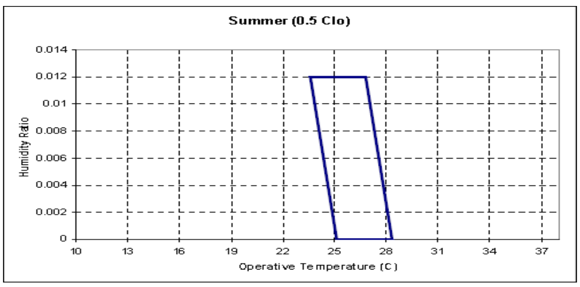

Figure 4 Comfort zone in ASHRAE Standard 55-2004 in summer

Air Temp(degC)	Humidity Ratio
23.6	0.012
26.8	0.012
28.3	0.000
25.1	0.000

Figure 5 The corresponding air temperature to humidity ratio in summer

SIMULATION OUTPUT

Comfort Performance of Prototype 1

In this six-storey building simulation study, block 5 is located on level 5; the result is concentrated in block 5 and each indoor space are part of Unit 01. In the simulation graphsof prototype 1, the following parameters arepresented; operative temperature, outside dry-ball temperature, discomfort hours, Fanger's PMV and Pierce Thermal Sensation Index.

According to the simulation data grid of comfort, the indoor operative temperature range is between 22-32**°C** in summer and 6-15°C in winter periods. It can be seen that more discomfort days are occurring during winter in prototype 1. Thermal sensation indexes displayed more discomfort responses than the Fanger's PMV range. The Fanger's PMV values even reaching -7.0 which means too much cold responses in this simulation unit.

In winter prototype 1 block 5, living hall has the highest temperature and relatively lower temperatures are occurring in kitchen and toilet. The RH mean values do not have significant difference in each indoor space which is around 55%. The similar phenomenon happened in the hot periodsshowing around 69%, which is higher than the standard calculation value (of 62%).

The values of indoor thermal sensation in prototype 1 block 5 presented discomfort periods in the block and in each indoor space. Two bedrooms have large duration in this three cold months (2160 hours) monitoring time (over 45.83%). PMV mean values predicted very cold feeling in the prototype; however, the Pierce thermal sensation represents comfort feeling which is around -1. In summer period, the two mean PMV values are both showing in/around comfort zone. Nevertheless, more discomfort hours are occurring in summer, especially the records collected in two bedrooms.

Table 9
Indoor temperature and RH of prototype 1

01/12-28/02	T_a	T_r	T_o	RH
BLOCK 5	11	11.1	11.1	56.0
DINING HALL 01	10.1	10.5	10.3	55.2
KITCHEN 01	9.6	9.8	9.7	57.1
LIVING HALL 01	12.0	12.3	12.1	55.5
MAIN BEDROOM 01	11.8	11.7	11.7	54.6
SUB-BEDROOM 01	10.7	10.3	10.5	58.8
TOILET 01	9.7	10.0	9.8	56.8
01/06-31/08	**T_a**	**T_r**	**T_o**	**RH**
BLOCK 5	28.6	29.1	28.8	69.3
DINING HALL 01	28.4	28.7	28.6	70.4
KITCHEN 01	28.7	29.1	28.9	69.3
LIVING HALL 01	28.2	28.9	28.6	67.8
MAIN BEDROOM 01	28.8	29.2	29.0	69.2
SUB-BEDROOM 01	28.9	29.3	29.1	69.0
TOILET 01	28.4	28.8	28.6	70.0

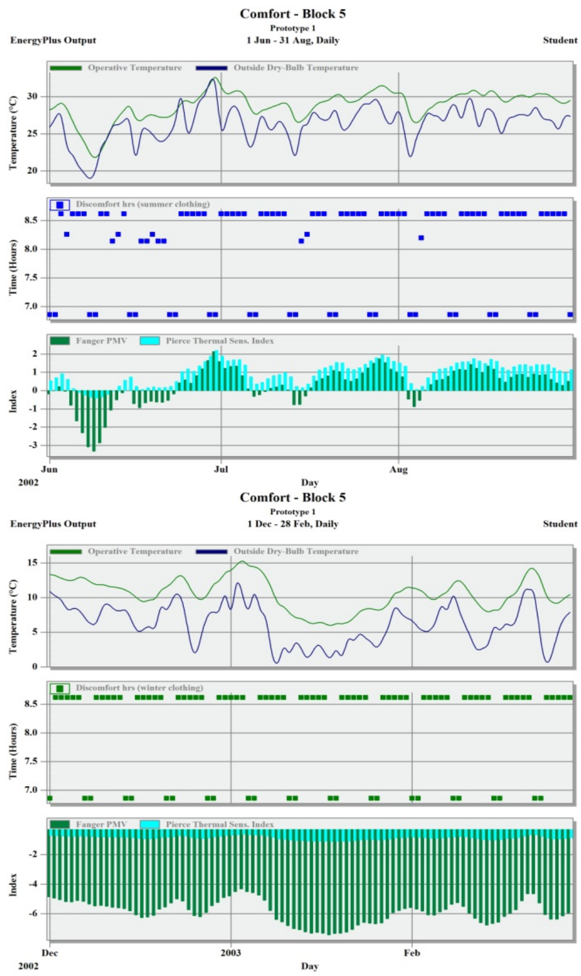

Figure 6 Comfort simulation output of prototype 1 block 5

Table 10
Indoor thermal sensation in prototype 1

01/12-28/02	DIS. HOURS	PMV	PIERCE THERMAL SENS.
BLOCK 5	732(33.8%)	-5.7	-0.8
DINING HALL 01	540(25%)	-7.2	-0.9
KITCHEN 01	540(25%)	-6.1	-0.9
LIVING HALL	540(25%)	-5.3	-0.8

01			
MAIN BEDROOM 01	990(45.8%)	-6.6	-0.9
SUB-BEDROOM 01	990(45.8%)	-7.1	-0.9
TOILET 01	455(20.6%)	-3.4	-0.8
01/06-31/08	**DIS. HOURS**	**PMV**	**PIERCE THERMAL SENS.**
BLOCK 5	741(33.5%)	0.3	1.0
DINING HALL 01	552(25%)	0.3	0.7
KITCHEN 01	552(25%)	0.4	1.0
LIVING HALL 01	532(24.1%)	0.1	0.9
MAIN BEDROOM 01	1012(45.8%)	-0.1	0.8
SUB-BEDROOM 01	1012(45.8%)	-0.1	0.8
TOILET 01	455(20.6%)	1.2	1.4

Comfort Performance of Prototype 2

Prototype 2 is the other model, which has a wide elevation towards north and south. It is designed with the same construction materials, and simulated with the same indoor thermal environment control parameters and occupancy activity schedule. The comfort data of block 5 has been listed in Table 11.Indoor temperatures are simulated around 10°C and 59% of mean RH in winter periods. In summer periods, the indoor temperature over 29°C and the RH values over 67%. According to the thermal sensation index value, some days of June have relatively lower outside temperatures (around 20°C) creating a cold feeling during thisperiod. The discomfort hours are also reduced in those days, but the reduction is not so much because of the high RH value. The indoor operative temperatures are almost over 28°C.

Table 11
Indoor temperature and RH of prototype 2

01/12-28/02	**T_a**	**T_r**	**T_o**	**RH**
BLOCK 5	10.5	10.5	10.5	58
DINING HALL 01	8.6	8.8	8.7	61.2
KITCHEN 01	8.7	8.8	8.7	60.8
LIVING HALL 01	11.3	11.5	11.4	58.1
MAIN BEDROOM 01	11.6	11.4	11.5	55.5
SUB-BEDROOM 01	10.6	10.1	10.3	59.6
TOILET 01	9.0	9.4	9.2	59.4
CORRIDOR 01	10	10.1	10.1	57.4
01/06-31/08	**T_a**	**T_r**	**T_o**	**RH**
BLOCK 5	28.9	29.4	29.2	67.4
DINING HALL 01	29.2	29.6	29.4	67.5
KITCHEN 01	28.9	29.1	29.0	68.6
LIVING HALL 01	28.3	29.1	28.7	66
MAIN BEDROOM 01	29.1	29.5	29.3	67.5
SUB-BEDROOM 01	29.1	29.6	29.4	67.4
TOILET 01	29.2	29.5	29.4	67.2
CORRIDOR 01	29.1	29.3	29.2	68.7

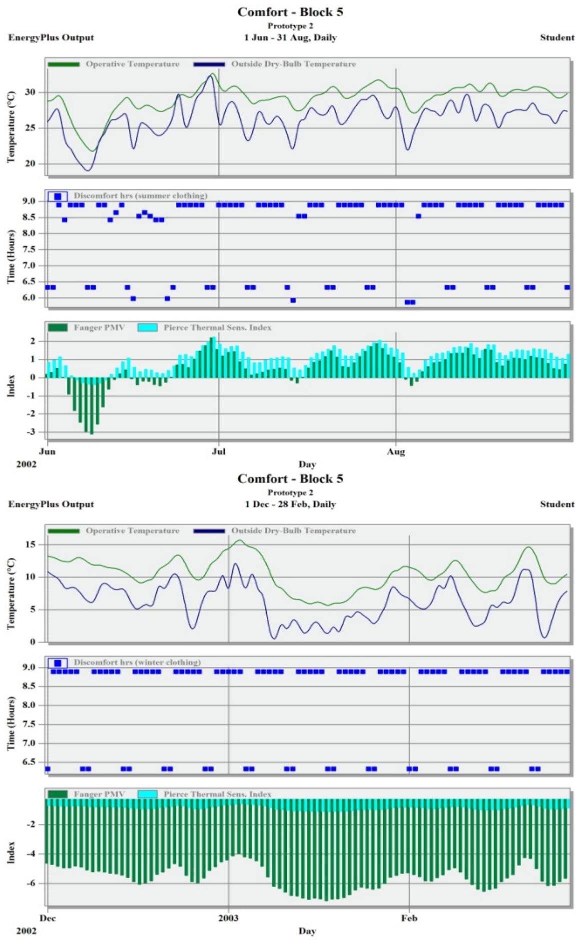

Figure 7 Comfort simulation output of prototype 2 block 5

Table 12
Indoor sensation in prototype 2

01/12-28/02	**DIS. HOURS**	**PMV**	**PIERCE THERMAL SENS.**
BLOCK 5	735(34%)	-5.6	-0.9
DINING HALL 01	540(25%)	-7.8	-1.0
KITCHEN 01	540(25%)	-6.4	-1
LIVING HALL 01	540(25%)	-5.5	-0.8
MAIN BEDROOM 01	990(45.8%)	-6.7	-0.9
SUB-BEDROOM 01	990(45.8%)	-7.2	-0.9
TOILET 01	455(20.6%)	-3.6	-2.5
CORRIDOR 01	780(36.1%)	-2.5	-0.8

01/06-31/08	DIS. HOURS	PMV	PIERCE THERMAL SENS.
BLOCK 5	742.3(33.6 %)	0.5	1.1
DINING HALL 01	552(25%)	0.1	1
KITCHEN 01	552(25%)	0.4	1.1
LIVING HALL 01	526(23.8%)	0.2	0.9
MAIN BEDROOM 01	1012(45.8%)	0.1	0.9
SUB-BEDROOM 01	1012(45.8%)	0.1	1
TOILET 01	455(20.6%)	1.4	1.6
CORRIDOR 01	780(35.3%)	1.5	1.6

Discomfort Analysis Summary

According to the Chinese design standard for low-energy building in HSCW zone,28°Cand 16°C are the upper and lower limits of recommended criterion in this thermal design zone. To compare the two prototypes' comfort data, different thermal performance has been presented in the following graph (see Figure 8). In summer season, July to August, the overheating periods reach up to nearly 90%, and more probability than that in June. However, in winter season, almost all indoor operative temperatures are lower than the recommended value of 16°C. That means even though the buildings have insulated constructions with low U-values for extreme hot summers, both of the prototypes' thermal performances are very bad. However,it is consideredthat the common residential building in Yichang city does not have central heating system in winter, and the comfort zone is actually not defined as general thermal comfort criterion. The result of the thermal comfort analysis presentedthrough simulation studies have shown that thermal comfort is hard to achieve in the regional low-energy buildings with existing Chinese residential building design standard.

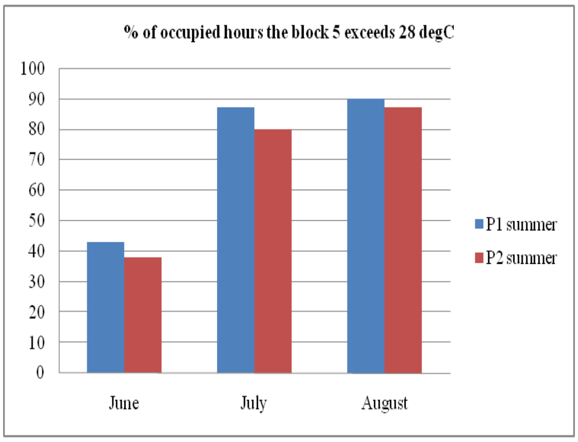

Figure 8 % of occupied hours the block 5 exceeds 28°C

CONCLUSIONS

1. Simulation method is a positive way to evaluate building design for thermal comfort at the initial phase of sustainable building practices.
2. Chinese healthy housing technical essentials provide a recommended prototype guideline. However, the relationship between thermal comfort and low-energy building is not very clear; especially in the case that regional factors are not involved in this standard.
3. HSCW zone usually faces overheating occurrence and very cold feeling in winter season. Although indoor temperatures frequently over 28°C in summer, both prototypes have provided a relatively warm comfort sensation.On the other hand in winter, the indoor temperatures are around 6-15°C, which is not a very cold temperature range for the occupants' tolerance.
4. Prototype 1 has higher mean RH values than that in prototype 2 in summer. Similar mean RH values presented in winter.Prototype 1 has deeperfloor layout than prototype 2, and therefore natural ventilation could hardly work through the block at north-southorientation.
5. The dominant wind direction is south-eastand therefore the apartment should be designed at north-south orientation for better natural ventilation purposes.
6. In summer periods, prototype 1 has good thermal performance than prototype 2.In winter periods, both of them have bad thermal comfort performances when considering the ASHRAE Standard 55-2004.
7. The existing thermal design standards in China makes it more complicated criterion for the new generation residential building practice. In addition,the ASHRAE thermal comfort criterion is also not suitable for the low-energy building in China.
8. HSCW zone has overheating occurrence and very cold feeling in winter season with high RH values.With the climate changing, thermal performance of China low-energy buildings should be focused on the balance of thermal comfort and energy efficiency.
9. For further research, adaptive thermal comfort could bea key factor to balance the thermal comfort and low-energy design in this particular zone. However, the simulation studies did not involve this adaptive thermal theory and occupancy activity schedule due to lack of adjustment mechanism of psychological adaptations and behavioural adaptations.

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