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# CLIMATE RESPONSIVE BUILDINGS IN CHINA

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Keywords: building design, integrated building concepts, simulation, renewable energy

## Abstract

There is a global need for a more sustainable building development. About 50% of energy is used in buildings indicating that buildings provide a considerable potential for operational energy savings. Studies were conducted with the following objectives:

- to perform a state-of-the-art review of responsive building elements, of integrated building concepts and of environmental performance assessment methods
- to improve and optimize responsive building elements
- to develop and optimize new building concepts with integration of responsive building elements, HVAC-systems as well as natural and renewable energy strategies
- to develop guidelines and procedures for estimation of environmental performance of responsive building elements and integrated building concepts

This paper introduces the ideas of this collaborative work within the framework of the Annex44 of the International Energy Agency (IEA) and discusses its usefulness for Hong Kong and China. Special focus was put on the description of the different climates in China and a detailed analysis revealed its potential for energy conservation strategies. It could be shown that Natural Ventilation (NV) has the potential to increase thermal comfort up to 29% (in Taipei).

## 1 INTRODUCTION

Energy usage for room heating, cooling and ventilation still accounts for more than one third of the total, primary energy demand in the industrialized countries, and is in this way a major polluter of the environment with CO<sub>2</sub> and greenhouse-gases. To successfully achieve the targets set out in the Kyoto protocols it is necessary to identify innovative energy technologies and solutions for the medium and long term which facilitates the implementation and integration of low carbon technologies, such as renewable power generation devices within the built environment. Deployment of low carbon technologies still faces major barriers in the built environment especially in relation to

- costs, building logistics,
- technological challenges,
- lack of understanding and knowledge and
- absence of requisite skills.

Moreover, there is world wide growing concern about the type of energy used for different purposes.

In this perspective Whole Building Concepts are defined as solutions where reactive building elements together with service functions are integrated into one system to reach an optimal environmental performance in terms of energy performance, resource consumption, ecological loadings and indoor environmental quality. Reactive Building Elements are defined as building construction elements which are actively used for transfer of heat, light, water and air. This means that construction elements (like floors, walls, roofs, foundation etc.) are logically and rationally combined and integrated with building service functions such as heating, cooling, ventilation and energy storage. The development, application and implementation of reactive building elements are considered to be a necessary step towards further energy efficiency improvements in the built environment (Annex44).

With the integration of reactive building elements and building services, building design completely changes from design of individual systems to integrated design of "whole building concepts, augmented by "intelligent" systems and equipment. Development of enabling technologies such as sensors, controls and information systems are needed to allow the integration. Design strategies should allow for optimal use of natural energy strategies (daylighting, natural ventilation, passive cooling, etc.) as well as integration of renewable energy devices (Annex44).

The annex will, based on the knowledge gained in the work so far (particularly the results of IEA Annexes 32, 35 and 37, SHC Task 23), address the following objectives:

- Define state-of-the-art of reactive building elements
- Improve and optimize reactive building elements and technologies
- Develop and optimize new building concepts with integration of reactive building elements, building services as well as natural and renewable energy strategies
- Develop tools for the early assessment of the impact of reactive building elements on the environmental performance of buildings
- Develop guidelines for procedures and tools for detailed simulation of environmental performance of reactive building elements and integrated building concepts

## **2 OBJECTIVE**

The aim of this paper was to analyze the climatic conditions as the most important factor with respect to the integration of climate responsive building elements and its energy conservation strategy. The impact of building location and climate, size and orientation on the thermal comfort were investigated for different climate regions in China. The study tries to determine the potential of thermal comfort improvements of each strategy. Special focus was put on the analysis of the potential of Natural Ventilation (NV) in these climates.

## **3 CLIMATE**

China is a large country with a vast territory and complex topography. The main feature of the climate of China is its diversity and complexity which together lead to the existence of a great number of climate types (Zhang and Lin 1992). China is a large country with an area of about 9.6 millionkm<sup>2</sup>. About 98% of the land area stretches between a latitude of 20°N to 50°N, from subtropical zones in the south to the temperate zones (including warm-temperate and cool-temperate) in the north (Zhang and Lin 1992). The maximum solar altitudes vary a great deal and there is a large diversity in climates, especially the temperature distributions during winters. As

China is located on the southeastern sector of the Eurasian continent towards the Pacific Ocean, air masses of either continental or maritime origin will affect its climate. The monsoons represent the overwhelming climate and weather regime for China which govern the climatic conditions throughout the year (Zhang and Lin 1992). In general, winter monsoon from mid-Siberia and Mongolia brings cold and dry air masses to China during the winter period; summer monsoon from the subtropical anticyclone in the Northwest Pacific and the cross-equatorial flow from the southern hemisphere generates precipitation and warm weather during the summer period (Hui and Cheung 1997). The two distinguished monsoons together create large differences in seasonal climatic conditions. Besides, characteristics associated with continental climates can be identified with warmer summer, cooler winter and a larger annual temperature range than other parts of the world with similar latitudes. China also has a complex topography ranging from mountainous regions to flat plains. These diversities and complexities have led to many different climates with distinct climatic features.

Different data are required for defining the climatic characteristics based on the intended application. Building designers are usually interested in those climatic variables which affect the indoor thermal comfort and the heat transfer through building fabrics and via ventilation. Weather data crucial to building designs and energy analysis include temperature (drybulb and wet-bulb), solar radiation (global, direct and diffuse) and wind conditions (speed and direction) (Lam et al. 2005).

### 3.1 Climatic data

For the purpose of building thermal design, the climate of China can be classified into five main types as shown in Figure 2, and the country can be divided into several climatic regions as shown in Figure 1 (Givoni 1992; Olgyay 1963). The zoning is based on the monthly average temperatures of the coldest and hottest months of the year (usually January and July, respectively), and the number of days with the daily average temperature below 5 ° C and 25 ° C. While the latitudinal and longitudinal distances represent an important climate-controlling factor, the physio-geographical setting and landforms will also affect the climate at a particular location (Hui and Cheung 1997).

**Table 1: Climatic data for China (Hui and Cheung 1997)**

Location	Lat. (north)	Long. (east)	Elev. (m)	Dry-bulb temperature (° C)				Rel. humidity (%)		Sunshine Hours
				Annual average	Annual diff.	HMA	CMA	HMA	CMA	
Hong Kong	22° 18'	114° 10'	33	23	13	28.8	15.8	80	71	1948.1
Guangzhou	23° 08'	113° 19'	6.6	21.8	15.1	28.4	13.3	83	70	1906
Kunming	25° 01'	102° 41'	1891.4	14.7	12.1	19.8	7.7	83	68	2470.3
Shanghai	31° 10'	121° 26'	4.5	15.7	24.3	27.8	3.5	83	75	2014
Beijing	39° 48'	116° 28'	31.5	11.5	30.4	25.8	-4.6	78	45	2780.2
Harbin	45° 41'	126° 37'	171.7	3.6	42.2	22.8	-19.4	77	74	2641

CMA = coldest month average; HMA = hottest month average; annual diff. = HMA - CMA

Table 1 gives a summary of the major climatic conditions for seven cities in China (including Hong Kong); their geographical locations are also shown in Figure 1.

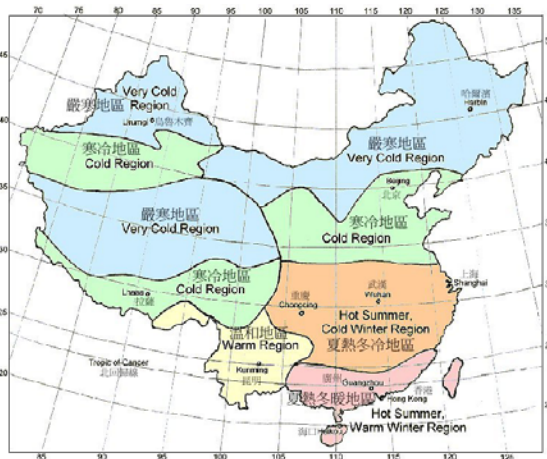


Figure 1: Climate regions of China (Hui and Cheung 1997)

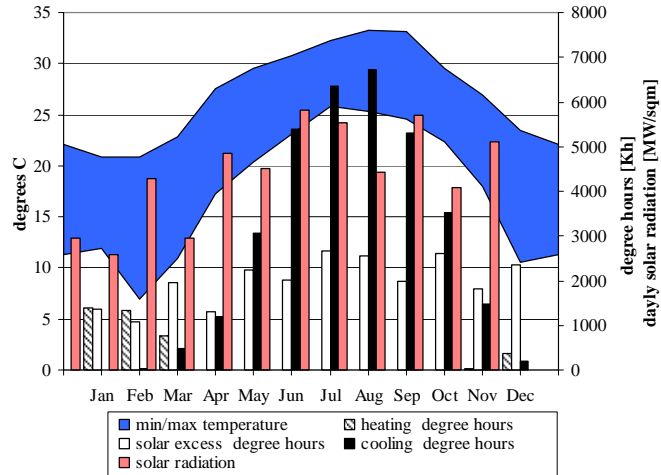


Figure 2: Temperature, degree hours, and solar radiation in Hong Kong

A new approach for building design that tries to take aspects of sustainable development into account has to consider the local climatic factors. Therefore, a weather data analysis for the different locations was carried out.

#### 4 CLIMATIC DATA ANALYSIS

There have been five different climates for the purpose of building design identified:

- Very cold climates, where the main problem is the lack of heat,
- Cold climates, where there is a long period of underheating and a short period of overheating
- Hot summer cold winter climates, where there is a seasonal variation between underheating and overheating with both extremes
- Warm climate,
- Warm-humid climates, where overheating during summer and it is aggravated by high humidity and small diurnal temperature variation.

Table 2: List of analyzed locations

location	latitude	longitude	Climate regions
Macau	22.2	113.5	Hot summer warm winter
Hong Kong	22.2	114.2	Hot summer warm winter
Guangzhou	23.1	113.3	Hot summer warm winter
Taipei	25,1	121.6	Hot summer warm winter
Kunming	25	102.7	warm
Shanghai	31.2	121.4	Hot summer cold winter
Beijing	39.8	116.5	cold
Harbin	45.7	126.7	very cold

The climate determines the amount of solar radiation and mean outside temperature that a building is exposed to. The climate also influences the amount of energy that is used for heating and cooling but also the amount of energy that is used for lighting. There is solar excess which determines the amount of solar energy that is not wanted in the building. With growing amounts

of glass and a glazing system that allows large solar heat gains, the impact of orientation is substantial. A detailed analysis of 12 different locations was conducted to evaluate the potentials for improving the thermal comfort. A list of locations is shown in Table 2. The first four locations were chosen from a warm-humid climate in China. The last four locations are taken from different climates in China as proposed by Lam et al [12].

#### 4.1 Solar data and temperature

The monthly temperatures vary for the different locations. They are strongly related to the solar radiation. Figure 2 gives an overview of temperature profile and solar radiation in Hong Kong. The concept of degree hours is explained in the next section.

#### 4.2 Degree days

A weather data analysis was carried out. Weather data of the twelve different locations were taken and the cooling degree hours and days (CDD), the heating degree hours and days (HDD) and the solar excess hours and days (SED) for each month were calculated. A degree hour is the difference in temperature above or below the reference temperature during the course of one hour and can be calculated if hourly temperature data are available. Summing up the degree hours from one day gives a daily degree hour value. Next, the daily degree hours of the month are summed up to obtain monthly degree hours. Dividing monthly degree hours value by 24 (hours in a day) delivers degree-days for the specific month.

$$\text{CDD} = T_m - T_b \qquad \text{HDD} = T_b - T_m \qquad (1 \text{ and } 2)$$

with

$T_b$  = base temperature (26°C for cooling and 18°C for heating)

$T_m$  = average of maximum and minimum temperatures

Next, the heating degree hours for the different locations were calculated.

Once any form of radiation (long-wave or short-wave) comes into contact with the external fabric of the building, heat conduction transfers energy through the envelope, adding heat gain to the interior space. This increases the surface temperature which accelerates the rate of heat conduction. This heat transfer through the envelope of the building varies over time. The surface temperature is called the sol-air temperature: and can be described as the equivalent outdoor temperature that will cause the same rate of heat flow at the surface and the same temperature distribution through the material as the current outdoor air temperature, the solar gains on the surface and the net radiation exchange between the surface and its environment.

Finally, the solar excess degree hours were calculated. Solar excess degree hours are the amount of degree hours where the sol-air exceeds the outside air. Sol-Air is defined as:

$$T_s = T_o + dT_e \qquad (3)$$

$$dT_e = (G * a_w * R_{so}) = \text{sol-air excess temperature (K)}, \qquad (4)$$

with

$T_s$  = Sol-air temperature (°C),

$T_o$  = Outside air temperature ( $^{\circ}\text{C}$ ),  
 $G$  = total incident solar radiation ( $\text{W}/\text{m}^2$ ),  
 $a_w$  = solar absorptance of wall (0-1)  
 $R_{so}$  = outside air-film resistance.

Solar excess degree hours are effectively an excess cooling load on the building due to incident solar radiation. This calculation uses a formula based on latitude and the ratio of vertical to horizontal surfaces in a 'standard' building, as well as the following assumptions [15]:

- All windows are fully shaded in the overheated period.
- A well designed building with north-south orientation and an aspect ratio of 1.4.
- Solar radiation on north and south walls will be negligible in the overheated period as the sun is near its zenith and a well-designed building will provide adequate eaves/shading.
- The roof is taken as a horizontal surface.
- An assumed absorptance of  $a_r = 0.3$  for roofs and  $a_w = 0.52$  for the east and west walls, with surface film conductances of  $h_r = 22 \text{ W}/\text{m}^2\text{K}$  and  $h_w = 18 \text{ W}/\text{m}^2\text{K}$  ( $R_{so} = 1/h$ ).

#### 4.3 Optimum orientation analysis

The orientation calculation involves rotating a  $1\text{m}^2$  vertical surface through a full  $360^{\circ}$  and recording the average daily incident radiation over each of these periods as well as for the entire year. **Fejl! Henvisningskilde ikke fundet.** shows averaged daily values for each orientation in  $\text{kWh}/\text{m}^2$ . Light and dark blue arrows are then drawn through the maximum values for each. The aim is to maximize incident solar radiation during the under-heated period whilst minimizing it at times of over-heating. The ratio between the blue and yellow lines is shown in the colored ring around the circumference of the graph. The dark blue values represent the best orientations. Simply orienting the building to get the most favorable ratio in winter ignores what is happening in summer. A concurrent aim is to ensure the minimum incident solar radiation during the overheated period. This will occur if the angle of maximum summer radiation occurs at  $90^{\circ}$  to the orientation of the surface. In many climates, where the two blue and yellow arrows are not at  $90^{\circ}$  to each other, there must be some compromise between the two aims. The degree of compromise is based on the relative amounts of heat and cold stress. This is calculated as the number of degree hours spent above the comfort zone in the over-heated period compared to the degree hours spent below it in the under-heated period.

#### 4.4 Thermal comfort

Thermal comfort was calculated followed by an analysis of the potential of different sustainable design strategies. The adaptive model based on a neutral temperature approach was chosen as described by Auliciems [3].

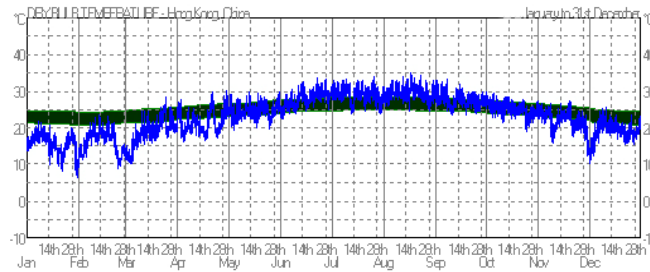
$$T_n = 17.6 + 0.31 T_{ave} \quad (5)$$

with

$T_n$  (Thermal Neutrality) = the air temperature at which, on average, a large sample of people would feel neither hot nor cold.

$T_{ave}$  = outdoor average dry bulb temperature (DBT)

The Thermal Neutrality with the range of  $\pm 1.75K$  for Hong Kong is shown in Figure 3 as a green shred. It can be seen that during winter  $T_n$  is above the temperature (DBT) and slightly below during summer. But in order to visualize the influence of humidity  $T_n$  can also be plotted in the psychrometric chart and is shown in Figure 3 as the base comfort zone.

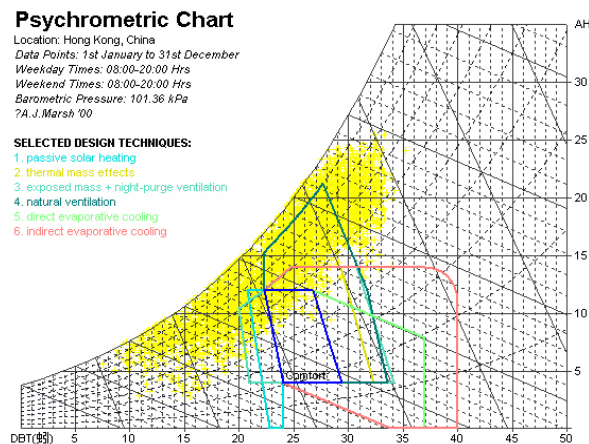


**Figure 3:** Thermal Neutrality for HK

The method used for estimating the potential of different passive strategies was taken from Szokolay [16]. He established six strategies for improving thermal comfort and evaluated their potential:

- Thermal mass effect
- Exposed mass + night purge ventilation
- Passive solar heating
- Natural ventilation (NV)
- Direct evaporative cooling
- Indirect evaporative cooling

These effects are based on a fundamental set of assumptions laid out by Olgyay and Szokolay [14,15] and extend the area of the comfort zone based on their ability to moderate the effects of climate. It is therefore possible to determine the effectiveness of particular passive design strategies by comparing the number of data points inside the base comfort area and the extended area resulting in percentages. It should be noted that the base comfort zone relates to the Thermal Neutrality discussed above.



**Figure 4:** Potential of strategies for improving thermal comfort for HK

Figure 4 gives an exemplary overview of the six different design strategies for Hong Kong and their possible impacts on thermal comfort in a psychrometric chart. All calculations are based on assumptions as to the moderating effects of passive systems within a building. It is assumed that



the techniques used are of average efficiency ( $\eta=0.6$ ) with adequate thermal insulation used when required. The passive solar heating values refer to the use of an indirect solar gain system with a glazed area of 20% of the equator-facing facade.

#### 4.5 Natural ventilation

Natural ventilation (NV) in this work is the use of increased air movement and its increasing effect on thermal comfort. It is therefore a passive cooling strategy that tries to make use of air movement in the building at temperatures and humidity above the comfort zone. The potential was estimated for an assumed increase in air movement of 1 m/s in the building [16]. Annual NV potential is only useful in climate with no or very small HDD. In order to evaluate the usefulness of NV strategy to reduce peak cooling load its potential was analysed for the three hottest months for each climate.

### 5 RESULTS

Table 3 shows the yearly data for cooling, heating and solar excess degree days. It can be seen that for all warm-humid climates the cooling degree days exceed the heating degree hours. In temperate climates the heating degree hours increase and exceed the cooling degree hours. The results are summarized in Table 3. A hot summer warm winter climate can be described by HDD between 162 (Hong Kong) and 432 (Guangzhou). Interestingly, the SED does not show significant variations for the different climates. It ranges between 793 in Guangzhou and 1223 in Harbin.

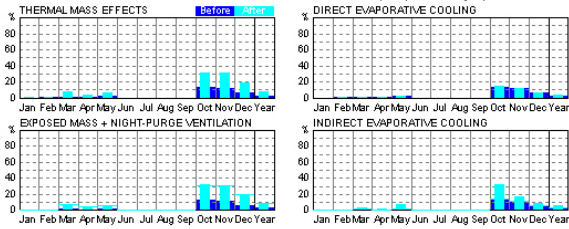
**Table 3:** Analyzed locations with degree days, optimum orientation and NV potential

<b>location</b>	<b>HDD</b>	<b>CDD</b>	<b>SED</b>	<b>optimum orientation</b>	<b>NV potential</b>
Macau	252	1395	1076	172,5	20%
Hong Kong	162	1405	997	192,5	24%
Guangzhou	432	1453	793	175,0	20%
Taipei	242	1443	1021	175,0	29%
Kunming	1256	154	1083	177,5	14%
Shanghai	1680	772	935	170,0	12%
Beijing	2770	611	1154	175,0	13%
Harbin	5197	239	1223	172,5	13%

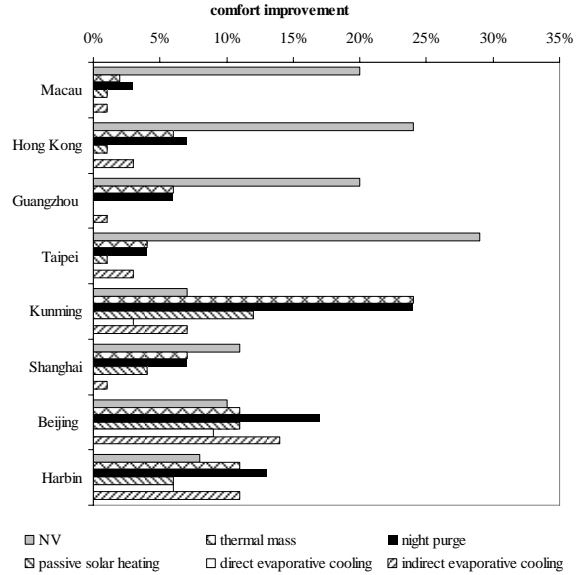
Table 3 shows the optimum orientation of a building for each climate. Optimum orientation for hot warm climate ranges between 172.5° (Macau) and 192.5° (HK). For the other climates the optimum orientation ranges between 170° in Shanghai and 177,5° in Kunming. Cooling and heating degree hours and solar excess hours are useful as indicators of different climates. Figure 5 gives an overview of the different strategies and their potential for improving thermal comfort for Hong Kong. It should be noted that NV has the highest potential despite the variation in the months of the year. A detailed analysis of the potential for each climate zone has been made in order to further differentiate the different potential. Figure 6 shows the results for all six strategies. It can be seen that NV has a higher annual potential in warm climate with up to 29% (Taipei). Figure 7 shows the monthly potential for all climate zones for thermal comfort improvements by using NV. It illustrates that there are months with varying improvements for each climate. But the different climates also show different pattern.

**Comfort Percentages**

NAME: Hong Kong  
 LOCATION: China  
 WEEKDAYS: 08:00 - 20:00 Hrs  
 WEEKENDS: 08:00 - 20:00 Hrs  
 POSITION: 22.2° 114.2°  
 ?A.J. Marsh '00

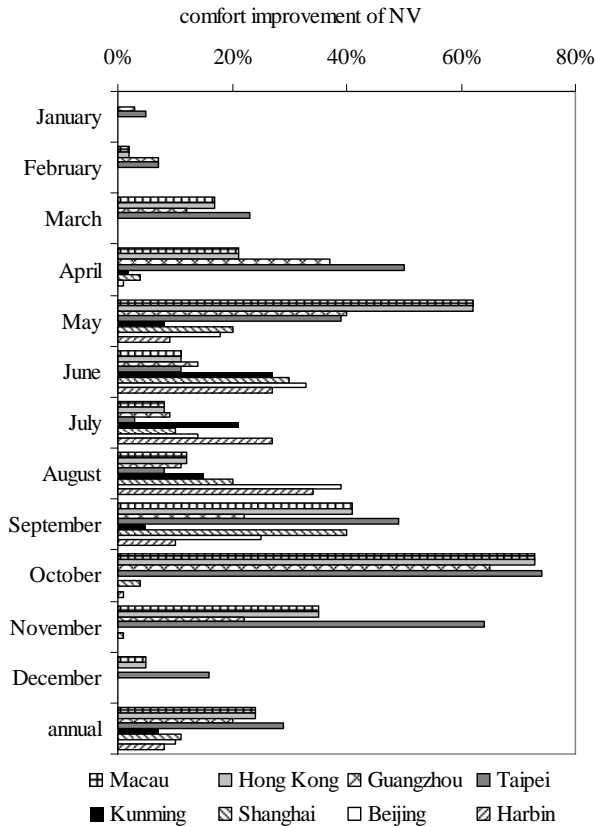


**Figure 5: Annual thermal comfort improvement potential for HK**

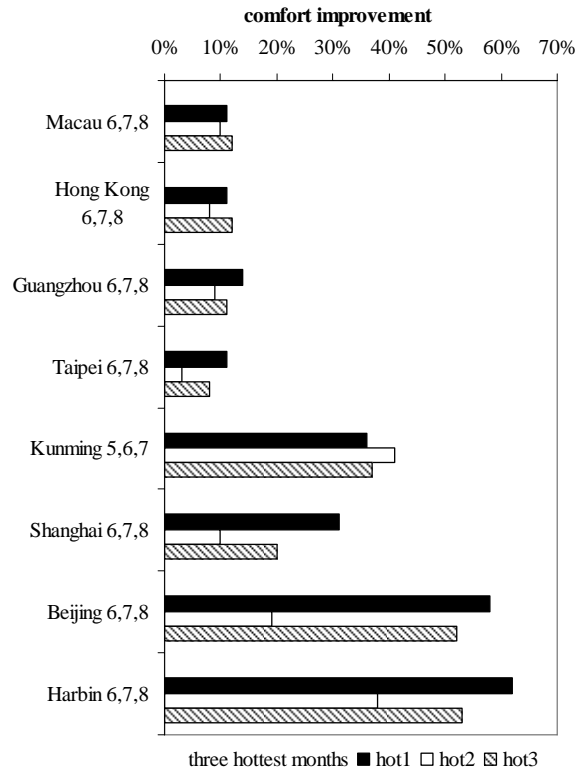


**Figure 6: Potential of different conservation strategies**

For a warm climate the months April and May and September, October and November show a potential of up to 74% (Taipei in October). This is a slightly higher potential than in most of the remaining months. The higher the cooling degree days the lower the potential for NV. Even in warm climate some months have no potential at all (Hong Kong in January).



**Figure 7: NV potential per month**



**Figure 8: Combined potential for hottest three months**

The potential varies over the year for each climate zone differently. with different figures for the three hottest months. Figure 11 shows the results for the three hottest months of the location. In a tropical climate the improvement in comfort by NV is between 9% (Bangkok in April) and 41% (KL in April). For a subtropical climate the improvements vary between 3% (Taipei in July) and 14% (Hanoi in August). In a temperate climate the improvements vary between 8% (Shanghai in July) and 56% (Kunming in June).

## **6 DISCUSSION AND CONCLUSIONS**

The aim of this paper was to analyze the climatic conditions as the most important factor with respect to the integration of climate responsive building elements and its energy conservation strategy. The impact of building location and climate, size and orientation on the thermal comfort were investigated for different climate regions in China. The study tried to determine the potential of thermal comfort improvements of each strategy. Special focus was put on the analysis of the potential of Natural Ventilation (NV) in these climates. The results of the weather data analysis show significant monthly differences in all climates. For building design purposes there are six different energy conservation strategies. In order to evaluate these sustainable building design strategies a detailed analysis is essential.

A climate responsive building envelope design should assist the design strategies and try to exploit climatic conditions.

NV has a good annual potential in hot summer warm winter climate zones. But the results show that when looking at the summer period (hottest three months) and NV as a cooling strategy it has only around 10% potential for thermal comfort improvement. Other climates in China have a larger potential for NV as a cooling strategy in summer. The design of climate responsive building envelopes should take this into consideration.

In most climates any effort to ensure thermal comfort by passive means would reduce the active control requirements. One exclusion is the hot summer warm winter climate since a design that maximises cross-ventilation is not suitable for air conditioning [16]. Accordingly, design solutions must be found for the building envelope that allow NV and air conditioning in hybrid mode.

One possible design element could be a double-skin façade. If properly designed it could not only support the passive heating strategy in the cold period of the year but also enhance NV in the building [5].

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