Sustainable Façade Design for Zero Energy Buildings in the Tropics

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ABSTRACT: Detailed analysis of the weather conditions in tropical and subtropical climate and their main characteristics have been analysed indicating evitable cooling in this climate. A mechanical ventilation and air conditioning (MVAC) system is usually operated to get rid of the cooling loads. The amount of mechanical cooling is growing rapidly in developing regions like China.
An ecological building design strategy is proposed that consists of a three steps approach; energy conservation, increasing energy efficiency, utilizing renewable energy. The energy conservation process should start at the building design stage. Six established energy conservation strategies in the design stage have been evaluated for 9 different locations in warm humid Asia. Analysis of energy consumption pattern in 9 different tropical and subtropical regions was used to further calculate the annual electricity potential.
It could be shown that 50% of the energy used for ventilation in buildings can be conserved in warm-humid climate. The façade design can further help to develop energy responsible buildings in tropical and subtropical climate. Building characteristics have a substantial influence on the annual electricity potential of a building. Building height and depth have been analyzed in order to show their implications on the amount of energy that can be used for cooling. This can have an important influence for further developments of sustainable buildings in South East Asia.

Keywords: facade design, hot-and humid climate, renewable energy, simulation, thermal comfort

1. INTRODUCTION

There is a world-wide need for a sustainable development [1]. There are basic explanations of what sustainable development is and how it is reached [2][3] [4,5].
Different countries have developed their specific vision of how to incorporate sustainable development particularly to the built environment. Special focus should be put on the building envelope design since the local climate requires customized solutions. The US Department of Energy for example has a clear ‘Roadmap’ to the Building Envelope design within the next 15 years which is closely linked to other ‘Roadmaps’ that incorporate visions for 2020 on lighting and HVAC systems. The building envelope ought to be [6]:

- Affordable
- Durable
- Energy-positive
- Environmental
- Healthy and comfortable
- Intelligent

The European Commission declared in their Directive:
“…Decoupling environmental degradation and resource consumption from economic and social development that requires a major reorientation of public and private investment towards new, environmentally-friendly technologies” [7]. The latest developments show that an impact assessment will be developed that will measure all impacts of decisions towards sustainability [8].
In Hong Kong, the Chief Executive made clear in his 1999 Policy Address that Hong Kong follows the framework for sustainable development (www.susdev.gov.hk). The Sustainable Development Department Hong Kong is working on formulating a Hong Kong specific strategy.
This study firstly tries to establish a new strategy of energy responsible facade design approach for warm and humid climates in Asia. The aim was to analyze the climatic conditions as the most important factor with respect to energy conservation and the use of renewable energy in buildings. The impact of building location and climate, size and orientation on the thermal comfort were investigated. The study secondly tries to determine the potential of building envelopes in different locations in Asia as listed in Tab 1. Special focus was put on the analysis of the potential of natural ventilation for the different locations and its implications for the use of renewable energy.

2. BUILDINGS AND CLIMATE

The building types and the climate are very special in warm and humid climates [9-11]. Hong Kong can help to act as a model for modern urban environment hat is dense and high-rise with usually 40 floors and above [12]. However, as tall buildings are getting predominant in Asia, more attention should be paid to designing them in an ecologically responsive way [13]. This includes the importance of a careful façade design that ensures optimised energy conservation but also the utilization of solar radiation to meet the energy needs in the building. Hong Kong's building stock analysis can help to focus on the main issues related to tall building energy consumption in Asia.

2.1 Tropical and sub-tropical climate

The seasonal and daily climate with respect to mean temperature, humidity and wind speed distribution in Hong Kong is different to the climate in Singapore [10,14,15].

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. Cooling degree hours and days (CDD), heating degree hours and days (HDD) and solar excess hours and days (SED) for each month is given in Tab 1. A degree hour is the difference in temperature above or below the reference temperature (26°C for cooling and 18°C for heating) during the course of one hour and can be calculated if hourly temperature data are available [16].

Table 1: List of analyzed locations

Location	HDD	CDD	SED	climate
Singapore	0	2627	1133	tropical
Kuala Lumpur	0	2453	1019	tropical
Bangkok	1	2950	1275	tropical
Manila	0	2672	1052	tropical
Hanoi	160	1674	1092	sub-tropical
Macau	252	1395	1076	sub-tropical
Hong Kong	162	1405	997	sub-tropical
Guangzhou	432	1453	793	sub-tropical
Taipei	242	1443	1021	sub-tropical

2.2 Energy use in office buildings

The build environment in Hong Kong has a great potential for improving its sustainable development [17]. The improvements can be reached by taking an energy responsible approach to design buildings that have a reduced impact on the environment [18-21].

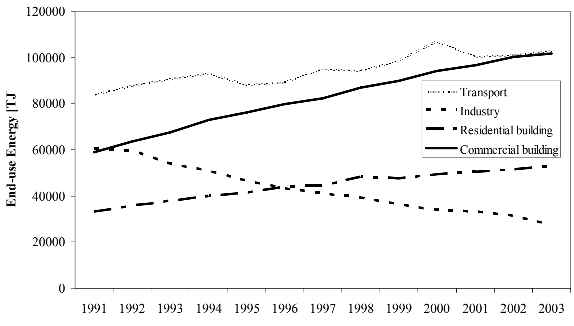

Figure 1: Energy consumption in buildings [22]

Figure 1 shows that 53.3% of the end-use energy in Hong Kong is consumed by buildings. Office and commercial buildings are using 35% energy [22]. It can also be seen that the amount of energy consumed by building sector has significantly increased particularly in the commercial sector. If other climatic regions are determined to follow the example of Hong Kong there can be a rapidly growing demand for energy expected in the near future.

Lam (2000) examined the energy performance of office buildings in Hong Kong and Lam et al (1997) determined the influence of the different energy consuming units in office buildings [23,24]. Very useful is also Lam and Li´s analysis of solar heat for cooling dominated office buildings [25]. Their analysis of the building energy consumption in Hong Kong gave peak cooling energy which is shown in Fig. 2. It can be seen that the building envelope design accounts for 36% of the peak cooling load.

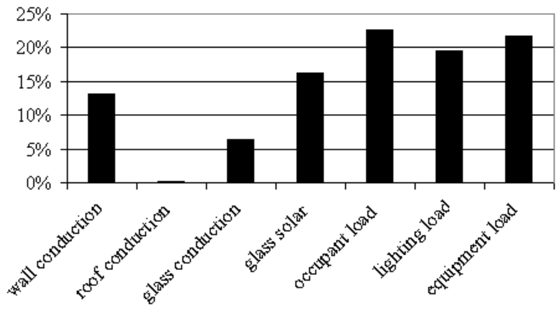

Figure 2: Peak cooling load [25]

It is possible to take the amount of cooling load from artificial lighting into account of the envelope since the daylight design can help to further reduce internal loads. That means that more than 55% of the peak cooling loads are influenced by the building envelope design. A good building envelope design therefore has to minimise these impacts. But it also shows that nearly 45% of the cooling loads are determined by the internal heat sources and even the best building envelope design cannot avoid the resulting internal cooling load. Assuming very efficient office equipment and artificial lighting there still remains a significant amount of cooling load, mainly due to occupants and equipment impacts. This is the main reason why a low energy building design should try to activate the façade and develop an advanced building envelope that not only reduces the amount of solar heat gains but integrates the utilization of renewable energy technology.

3. SUSTAINABLE FAÇADE DESIGN

A three steps approach is proposed that is related to the work of Lysen [26]. The energy triangle approach is based on the following considerations. First, it is necessary to analyse the energy that is consumed in order to be able to estimate the potential savings. It is second essential to reduce the energy consumption by using energy in the most efficient way. Third, the remaining energy need should be produced by means of renewable energy sources.

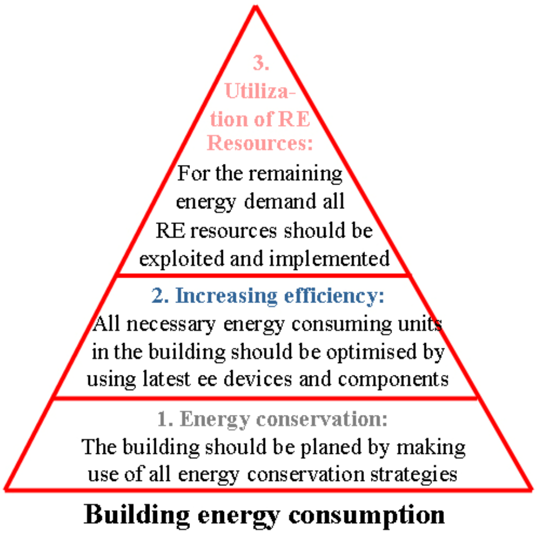

Figure 3: Energy triangle for low energy building design

3.1 Energy conservation

Generally there are six established energy conservation strategies in the design stage [28,29]:

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

Typical weather data files were used to analyse the climatic conditions for different locations which are based on data developed by the American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) [27]. The files are derived from up to 18 years of hourly weather data and supplemented by solar radiation estimated on an hourly basis from earth-sun geometry and hourly weather elements, particularly cloud amount information. The different potential of these different strategies has been estimated. Table 2 summarizes the findings for comfort improvements by exploiting Natural Ventilation (NV) and other means [14]. The most promising strategy for these climates is Natural Ventilation (NV) and should be incorporated into the building design

Table 2: Optimum orientation and Natural ventilation potential [14], modified

Location	optimum orientation	annual NV potential	rest cooling potential
Singapore	165.0	43%	0%
Kuala Lumpur	150.0	45%	0%
Bangkok	188.0	36%	12%
Manila	170.0	50%	0%
Hanoi	322.5	27%	2%
Hong Kong	192.5	24%	10%
Guangzhou	175.0	20%	12%
Taipei	175.0	29%	11%

3.2 Energy efficiency

The possibility for reducing energy consumption by the use of energy efficient technology in the built environment is long established [30-34]. The indicators of energy consumption within air-conditioned buildings that have been identified as most sensitive to changes are described in Lam et al (1997) [35]. New concepts in activating building components like Active walls and ceilings and the rigorous use of daylight can further reduce significantly the internal cooling load. The optimum orientation has been calculated taking the summer and winter periods into account [14, 29]. Table 2 gives the results for the optimum orientation that has been used in this study. Figure 4 shows the definition of optimum orientation and the façade orientations as used in this work.

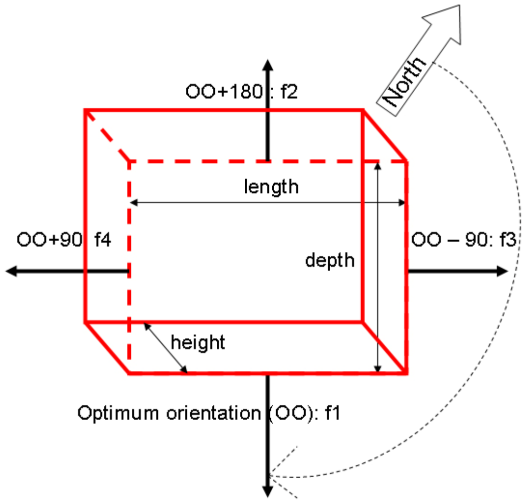

Figure 4: Optimum orientation of a building

In order to estimate the amount of energy efficiency that is necessary it is therefore interesting to evaluate the amount of renewable energy that is available. This will be discussed in the next chapter.

3.3 Renewable energy resources

Recent work focusing on the energy production sector identified several possibilities for implementing renewable energy (RE) in Hong Kong [17,36]. The study by the Electrical & Mechanical Services Department analysed the potential of different RE sources in Hong Kong. It suggests Building Integrated Photovoltaics (BIPV) and wind power as good possibilities. But BIPV and urban wind turbines have the additional advantage of producing energy integrated in buildings near the energy demand [37]. Since this study focuses on the potential of façade design only BIPV was taken into consideration by providing data of annual solar radiation on four different vertical facades starting with the optimum orientation (Tab 2). The annual amount of solar radiation falling on the four vertical facades and the roof should cover the energy demand of the building. In office buildings the time span of energy demand coincides with the period of the day with solar radiation. Different building forms were taken to run a parametric study on the amount of electricity that can be generated. The following assumptions and calculations have been used:

AEP = BE x η / GFA

with
AEP = annual electricity potential
BE = building exposure
= Sum (EAfi x SEi) + Ear x SEr
SEi = solar exposure, i.e. annual solar radiation incident on facade (in kWh/sqm)
Index i = indicating four façade orientations: f1 – f4 (see Figure 4 for further explanation)
SEr = solar exposure, i.e. annual solar radiation incident on roof (in kWh/sqm)
EAr = exposed roof area, roof area covered with PV
= l x d x cr (in sqm)
$EAf_{1,2}$ = exposed facade area, facade area covered with PV (in sqm)
= WR x l x n x h for optimum orientation and OO+180
$EAf_{3,4}$ = WR x d x n x h for OO+90 and OO-90
GFA = gross floor area = l x d x n (in sqm)

Table 3: Building characteristics used in this study

Building characteristics	symbol	values
roof coeff	cr	90% covered with PV
PV efficiency	η	14%
wall ratio	WR	56% (44% WWR)
floor height	h	4.0m
building depth	d [m]	15, 18, 20, 22.5, 27, 30
building length	l [m]	30
number of floors	n	5 20 40

4. RESULTS

The efficient use of electricity in buildings depends much on the building characteristics. The annual solar radiation on horizontal roofs and vertical facades has been calculated from weather data [27]. Then two building characteristics have been analyzed. First, the depth was changed for a 30m long and 40 storeys high building. The results shown in Fig 5 indicate that a 15m deep building has a better potential for electricity production than deeper buildings. This means that a narrow building plan is beneficial for electricity potential.

But the results vary for different locations. The highest potential is in Bangkok (36.7kWh/sqm) and the lowest potential in Guangzhou (24.8kWh/sqm) for a 15m deep building. Generally, a deeper building decreases in all locations the amount of electricity potential per floor area. A building with 30m depth decreases to 26.3 kWh/sqm for Bangkok and to 17.1 kWh/sqm for Guangzhou. The potential for electricity production is considerable low in a high-rise building.

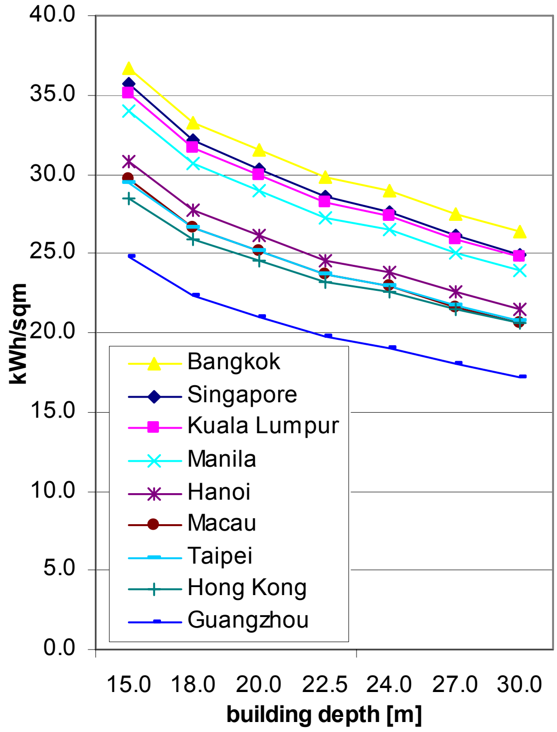

Figure 5: Electricity potential for different building depth with 30m length

Secondly, for an office tower with 30m length and 15m depth different heights were taken into consideration and results are shown in Fig 6.

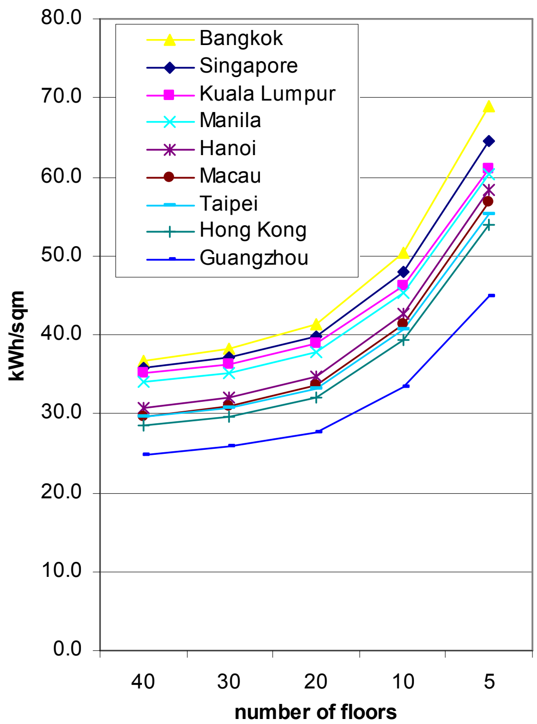

Figure 6: Electricity potential for different building heights

Due to high solar exposure on horizontal surfaces a building height of 5 floors provides the highest electricity potential. Again the annual electricity potential is highest in Bangkok (68.9 kWh/sqm) and lowest in Guangzhou (44.9 kWh/sqm). The difference is rather significant with 36% between the two extremes. With additional floors the electricity potential is further reduced. High-rise buildings with 40 floors (that are common in Hong Kong) provide only between 36.7 kWh/sqm (in Bangkok) and 24.8 kWh/sqm (in Guangzhou) electricity potential.

In order to illustrate the effect of floor number a 30m wide and 30m deep building was chosen and the electricity potential for different floor numbers has been calculated.

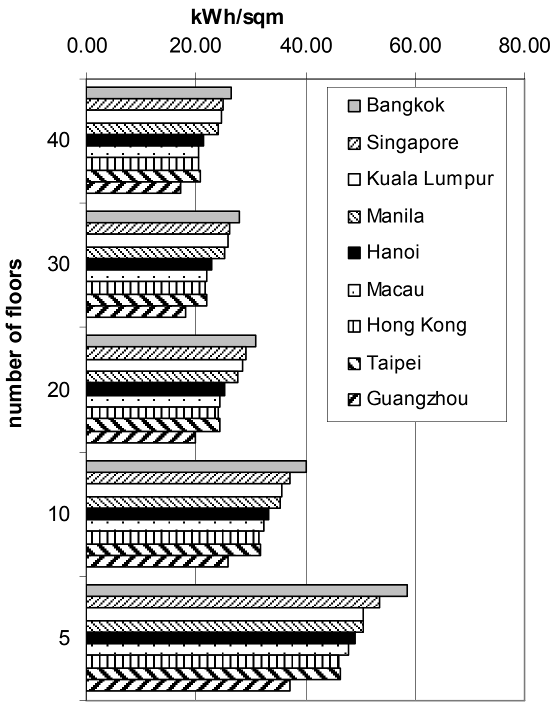

Figure 7: Electricity potential for different locations and floor numbers

When looking at buildings with specific number of floors it can be seen from Figure 7 that this building with 5 floors has a potential range between 58.5 kWh/sqm (Bangkok) and 37kWh/sqm (Guangzhou). For buildings with 10 floors the potential reduces to a range between 40.1 kWh/sqm (Bangkok) and 25.7 kWh/sqm (Guangzhou). This is further reduced for 20 floors and 30 floors. Finally, the range for buildings with 40 floors is between 26.3 kWh/sqm (Bangkok) and 17.1 kWh/sqm (Guangzhou).

5. CONCLUSION

Following the three steps of the energy triangle approach can help to develop new building design that has the potential to contribute to sustainable development in Asia. The approach systematically supports building design which consumes less energy by exploiting the potential for natural ventilation.

It became apparent that the building design strategy defines the utilization of RE in the facade. The amount of available solar radiation on unobstructed facades is large but depends on the building characteristics like length, depth, and height. The amount of electricity potential could further be utilized to cool the indoor environment.

Shallow buildings that are optimal orientated provide the highest electricity potential. This is further supporting the common design strategy of shallow buildings for exploiting wind for NV. Also the use daylight is more easy applicable in shallow buildings.

High-rise buildings provide less electricity potential due to reduced solar exposure of the different façade orientations.

The potential for reducing the cooling load by the use of natural ventilation is considerable and depends on the location. The maximum reaches 50% (Manila) which means that the other 50% have to be cooled mechanically. Taking this into consideration there remains the problem of a hybrid ventilation strategy to ensure that buildings are naturally cooled when possible and the annual electricity potential is used additionally. A storage system is needed that can act as a back-up system.

Further studies are needed in order to ensure that the optimised design strategy can be implemented into appropriate building and façade design. Especially the integration of highly dynamic outdoor wind pattern with the building's need for NV and the integration of PV in the façade needs more careful considerations.

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