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Rules of thumb for Air conditioning design in Hong Kong

Zhang Jin

MEng in BUILDING SERVICES ENGINEERING

THE HONG KONG POLYTECHNIC UNIVERSITY

2009
Declaration

The research described in this thesis is the original work of the author except where otherwise specified or where acknowledgements are made by reference. The work was carried out under the supervision of Dr. Joseph H.K. Lai. The work has not been submitted for another degree or award of other academic or professional institution.

Name:

Dated: 27/5 2009
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I am thankful to all the people who have helped me to carry out this project, particularly to my research supervisor, Dr. Joseph H.K. Lai, Assistant Professor of Building Services Engineering Department, The Hong Kong Polytechnic University, for all the kind help, invaluable guidance, unending encouragement and continuing support that he has offered to me during the course of the project. I am gratified to have such an enjoyable and learning opportunity to work with the person who is so energetic and always serious about his work.

Appreciation is also due to Dr. Nancy Choi who gives lots of useful help and suggestion for organizing my dissertation.

Last, but not least, I deeply thank, from the bottom of my heart, my classmate Lin Gen who gives me great help on using HTB2 program and highly relevant information about this study. His kindness help make this study go through smoothly and successfully.
Abstract

Abstract of dissertation entitled: 

Rules of thumb for air conditioning design in Hong Kong.

Submitted by:  Zhang Jin

for the degree of MEng in Building Services Engineering

at The Hong Kong Polytechnic University in May 2009.

Over sizing is a very common problem in the air conditioning system design in Hong Kong [3]. One main reason for over sizing problem is that many consulting companies have their own method of cooling load estimation which is actually higher than the real value [3]. Another main reason is that there is no public set of rules of thumb for commercial and office buildings, but not hotel buildings which greatly contribute to the economic development of Hong Kong and consume a lot of energy. In this study, the effects of lighting power density, small power density, ventilation rate, indoor air temperature setting, window wall ratio, shading coefficient and U-value of ex-wall on the cooling load for the different forms of hotel buildings are analyzed. After identifying four key factors (ventilation, window to wall ratio, shading coefficient and indoor temperature setting) influencing the cooling load, new rules of thumb for cooling load is proposed.
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Chapter 1    Introduction

1.1 Background

Cooling load is basic and essential information for HVAC designers to design the system and ensure the HVAC work efficiently. This is because cooling load is not only the key to size the equipment, but also the fundamental data for operating the equipment at high efficiency[2]. Proper cooling load ensure the equipment is neither oversize nor undersize. This is because equipment and systems are sized by “design” cooling loads and operated at the part cooling loads condition at the most of the operation time. In some cases, however, loads are substantially underestimated that leads to the temperature in the room rising in summer and the occupants and users will likely be hot. In most of other cases, loads are substantially overestimated, equipment will be oversized. This wastes money, reduces efficiency, increases energy consumption, and often imperils comfort.

However, the thermodynamic performance of building and HVAC system is so complex that there is no universal agreement among engineers on cooling load calculation. The process of calculating cooling load involves a lot of parameters and repeated works. It links with numerous characteristics, such as building envelope, lights, occupants, equipments, the other parameters in and out of the building[2]. Taking the building envelope for example, the thermal characteristics of the envelope—opaque walls and roof, fenestration, and even the floor—affect the magnitude and duration of the building heat loss and cooling load. Orientation,
envelope construction, and shading greatly influence solar loads. Cooling load directly influences the required capacity of the primary energy conversion devices (boilers and chillers) and the size, complexity, and cost of the distribution systems (ducts, fans, pipes, pumps).

Therefore, the building envelope construction and material, lighting and equipment power intensity, occupant, and the parameters in and out of the building, and other parameters for calculating the accurate cooling load are needed to be ensured. However, to some extent, most of those needed parameters are unknown or unsure for the designer at the beginning stage of the project. The designer would like to take some specific, easily remembered numbers which give a good approximate design guide to those situations instead of calculating the load carefully. Those numbers may be defined as rules of thumb for air conditioning system cooling load.

Additionally, it is also a common practice for designers to obtain a rapid assessment of the approximate values of system design parameters and costs based on rules of thumb. However, in Hong Kong, rules of thumb exist in many leading building services consulting firms and are viewed as commercially confidential or personal information and a public set of such rules applicable to local building services design does not seem to exist [3]. Furthermore, the design conditions of modern building have changed greatly. Building envelopes continue to improve for taking high thermal performance construction material. Low-emissivity coatings and gas-fill for fenestration, and opaque sections with greater insulation levels and fewer thermal bridges, can reduce heating loads and sometimes eliminate the need for separate perimeter heating systems. Lighting loads continue to go down, and in many cases
office equipment loads are lower due to more efficient PCs [4]. All of those changes are greatly reducing the cooling load. Furthermore, most of existing rules of thumb do not demonstrate the using condition which are crucial for designer to use the rules of thumb on special projects. At the same time, those rules of thumb produced by personal experience are difficult for widely using, because different designer has different risk attitude to take safe margin on load calculation. According to Lao [3], those rules of thumb generally are greater than exact cooling loads in the real situations. This is the main factor leading to oversize. So it is necessary to analyze the key factors which greatly influences on the cooling load calculation, and develop more rules of thumb for air conditioning design in different situations.

1.2 Research objectives

Lao's research worked on the rules of thumb, and provided suitable method to develop the rules of thumb for estimating cooling load for office in Hong Kong, and get reasonable results [3]. However, this work is mainly based on one special project and some assumed conditions are not common. On the other hand, there is limited relevant research works on other important buildings in Hong Kong, namely hotel which greatly contribute to the economic development for Hong Kong and consume a lot of energy which is also increasing year by year.

Therefore, this study focused on rules of thumb for air conditioning system cooling load in hotel buildings in Hong Kong.

Main Objective
Finding out the key factors influencing the cooling load, and proposing new rules of thumb for cooling load for hotel building in Hong Kong.

Sub-objectives

1. Determining the ranges for the needed parameters for cooling load calculation, which include lighting power density, small power density, ventilation rate, indoor air temperature setting, window wall ratio, shading coefficient and U-value of ex-wall.

2. Comparing the influences of the key factors on different forms of hotel building.

1.3 Outline of dissertation

The main objective of this study is to identify the key factors influencing the cooling load, and propose new rules of thumb for hotel building in Hong Kong. After introducing the background of this study and reviewing the relevant studies, the range of needed parameters for cooling load calculation was collected and determined from ASHRAE, HK-BEAM, HK-COP and other relevant papers. Second, three types popular form models were identified, namely the octagon form model, the rectangular for model and the square form model. Third, when inputting all needed parameters and the models into HTB2 program, the cooling load was produced. Fourth, by comparing the sensitivity of each parameter, the key factors were determined for developing the rules of thumb. Finally, the rules of thumb and three equations were identified for three models. They were detailed in the following procedure.
Electrical energy used in Hong Kong, studies on cooling load calculation and the existing rules of thumb for air conditioning cooling load are introduced in literature review chapter.

The software HTB2, model buildings and needed parameters are detailed in methodology chapter.

The key factors influencing the cooling load are analyzed and determined first. Finally, the new rules of thumb for hotel building are proposed in findings and discussion chapter.

The contributions and limitations of this study are seen in conclusion chapter.
Chapter 2  Literature review

With the trend of energy conservation, increasing number of study pay more attention on energy conservation. The relevant papers to this study are presented and commented in this chapter. The discussion of the papers in this chapter is divided into three parts: electrical energy used in Hong Kong, studies on cooling load calculation and the existing rules of thumb for air conditioning cooling load.

2.1 Electrical energy consumption in Hong Kong

Corresponding with the development of the society, the energy consumption in Hong Kong has been dramatically increased in recent years. The electricity consumptions from 1996 to 2006 are shown in Figure 2-1, Figure 2-2, Table 2-1 and Table 2-2.

Figure 2-1 and Table 2-1 show the distribution of electricity consumption of residential, commercial, industrial and transport in Hong Kong from 1996 to 2006. It can be seen that the commercial sector and residential sector consumed the greatest amount of electricity among all sectors and increases dramatically. However, because of the prices of land and labor force are higher than the price in the mainland of china, many industries in Hong Kong transferred into the mainland of china. This leads to Hong Kong transfers from an industrial-oriented region into a service-oriented one, the electricity energy consumption on industry dropped year by year. Therefore, the domestic and commercial sectors are major energy consumers in Hong Kong and growing trend of energy use in both sectors could be continuously experienced in the future due to the climate changes and economic developments. [5]
Figure 2-1 Electricity consumption by sectors

From Hong Kong Energy End-use Data 2008 [6]

Table 2-1 Electricity consumption by sectors

<table>
<thead>
<tr>
<th>Year</th>
<th>Residential</th>
<th>Commercial</th>
<th>Industrial</th>
<th>Transport</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>29 194</td>
<td>61 702</td>
<td>19 934</td>
<td>3 049</td>
<td>113 879</td>
</tr>
<tr>
<td>1997</td>
<td>28 937</td>
<td>65 036</td>
<td>18 965</td>
<td>3 124</td>
<td>116 061</td>
</tr>
<tr>
<td>1998</td>
<td>32 793</td>
<td>70 408</td>
<td>18 489</td>
<td>3 756</td>
<td>125 446</td>
</tr>
<tr>
<td>1999</td>
<td>31 400</td>
<td>72 339</td>
<td>17 547</td>
<td>4 002</td>
<td>125 288</td>
</tr>
<tr>
<td>2000</td>
<td>32 234</td>
<td>76 689</td>
<td>17 769</td>
<td>3 983</td>
<td>130 675</td>
</tr>
<tr>
<td>2001</td>
<td>32 799</td>
<td>80 589</td>
<td>16 759</td>
<td>3 991</td>
<td>134 138</td>
</tr>
<tr>
<td>2002</td>
<td>33 394</td>
<td>83 549</td>
<td>16 112</td>
<td>4 057</td>
<td>137 112</td>
</tr>
<tr>
<td>2003</td>
<td>34 365</td>
<td>84 921</td>
<td>14 851</td>
<td>4 297</td>
<td>138 434</td>
</tr>
<tr>
<td>2004</td>
<td>34 134</td>
<td>86 671</td>
<td>15 430</td>
<td>4 967</td>
<td>141 202</td>
</tr>
<tr>
<td>2005</td>
<td>35 811</td>
<td>88 561</td>
<td>14 635</td>
<td>5 163</td>
<td>144 171</td>
</tr>
<tr>
<td>2006</td>
<td>35 428</td>
<td>93 317</td>
<td>14 015</td>
<td>2 444 ^ {3}</td>
<td>145 204</td>
</tr>
</tbody>
</table>

From Hong Kong Energy End-use Data 2008 [6]

Figure 2-2 and Table 2-2 show electricity end-use in space conditioning, lighting, refrigeration, industry, cooking, heating water, office equipment, rail and others in Hong Kong from 1996 to 2006. Two conclusions can be drawn from Figure 2-2 and
Table 2-2. One is space conditioning consumes the greatest amount of electricity (about 30% of the total electricity consumption). This is because Hong Kong belongs to the subtropical climate where the summer is hot, humid and long. The cooling seasons begin from late March and end in early November [7]. Another is electricity consumption in space conditioning sector was increasing year by year. However, in Lai and Yik study [8], since the Asian financial crisis, which triggered the collapse of the overheated property market in 1997, the desire of developers to invest in new building construction declined. Compared with the years before 1997, few new building and new air conditioning systems were built in recent years. The increasing electricity consumption on spacing conditioning may be caused by the efficiency of existing air conditioning system which reduced year by year.

Figure 2-2 Electricity end-use

From Hong Kong Energy End-use Data 2008  [6]
<table>
<thead>
<tr>
<th>Year</th>
<th>Space conditioning</th>
<th>Lighting</th>
<th>Refrigeration</th>
<th>Industrial Process</th>
<th>Cooking</th>
<th>Hot water</th>
<th>Office equipment</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>37,571</td>
<td>19,212</td>
<td>5,516</td>
<td>12,825</td>
<td>4,298</td>
<td>3,264</td>
<td>4,229</td>
<td>3,049</td>
</tr>
<tr>
<td>1997</td>
<td>38,163</td>
<td>20,156</td>
<td>5,644</td>
<td>12,409</td>
<td>4,334</td>
<td>3,312</td>
<td>4,553</td>
<td>3,124</td>
</tr>
<tr>
<td>1998</td>
<td>41,409</td>
<td>20,864</td>
<td>5,855</td>
<td>12,422</td>
<td>4,703</td>
<td>3,425</td>
<td>4,776</td>
<td>3,756</td>
</tr>
<tr>
<td>1999</td>
<td>40,509</td>
<td>21,785</td>
<td>5,920</td>
<td>11,678</td>
<td>4,571</td>
<td>3,451</td>
<td>5,122</td>
<td>4,002</td>
</tr>
<tr>
<td>2000</td>
<td>42,225</td>
<td>22,807</td>
<td>6,089</td>
<td>11,825</td>
<td>4,674</td>
<td>3,540</td>
<td>5,383</td>
<td>4,989</td>
</tr>
<tr>
<td>2001</td>
<td>40,948</td>
<td>23,128</td>
<td>6,168</td>
<td>11,220</td>
<td>4,769</td>
<td>3,509</td>
<td>5,468</td>
<td>4,991</td>
</tr>
<tr>
<td>2002</td>
<td>41,162</td>
<td>23,102</td>
<td>6,305</td>
<td>10,851</td>
<td>4,893</td>
<td>3,599</td>
<td>5,491</td>
<td>4,057</td>
</tr>
<tr>
<td>2003</td>
<td>40,847</td>
<td>22,956</td>
<td>6,392</td>
<td>10,117</td>
<td>4,988</td>
<td>3,647</td>
<td>5,451</td>
<td>4,267</td>
</tr>
<tr>
<td>2004</td>
<td>41,682</td>
<td>23,456</td>
<td>6,467</td>
<td>10,575</td>
<td>4,950</td>
<td>3,695</td>
<td>5,643</td>
<td>4,967</td>
</tr>
<tr>
<td>2005</td>
<td>42,501</td>
<td>23,370</td>
<td>6,719</td>
<td>10,145</td>
<td>5,556</td>
<td>3,838</td>
<td>5,647</td>
<td>5,163</td>
</tr>
<tr>
<td>2006</td>
<td>42,469</td>
<td>24,265</td>
<td>6,490</td>
<td>9,737</td>
<td>4,895</td>
<td>3,705</td>
<td>5,959</td>
<td>4,444</td>
</tr>
</tbody>
</table>

Unit: Terawatts

From Hong Kong Energy End-use Data 2008 [6]
Within tourism sector, hotels have been generally regarded as the major energy end-user. In the past three decades, the rapid growth in the number of hotels has brought a considerable increase in energy consumption [9].

Regarding the typical hotel building, one unique type of commercial building, which great contribute the economic development especially after the Hong Kong transfers from an industrial-oriented region into a service-oriented one, the operating schedules is different for different functional facilities; the occupancy levels is variable throughout the year. These lead to different operating schedules of building services systems and therefore different energy consumption situations in hotel buildings, as compared to other types of commercial buildings [10].

In Hong Kong, energy consumed by hotels includes electricity, gas and diesel, and the dominated consumption is electricity consumption, in terms of both consumption and cost [10]. Electricity is mainly used for operating all building engineering services systems which includes HVAC, vertical transportation, lighting, etc. The purposes of gas and diesel are specific. Gas is mainly used in kitchens for cooking, but may also be used for hot water heating. Diesel oil is used for boiler plants to generate steam. However, there are a few hotels where hot water heating is by electricity.

In Hong Kong, an earlier study worked on electrical energy requirement for hotel buildings. In this study, the averaged electricity consumption intensities are 257.8kWh/m² [11].Normally, for hotel building in Hong Kong, 48-55% of the electrical energy consumed is for air conditioning depending on the type of heat rejection method, 15-18% for lighting, and 7-8% for lifts and escalators [12].
majority of electricity consumption is for air conditioning system. That is because the air conditioning system is running 24 hours a day and year-round for the subtropical climate. In many quality hotels in Hong Kong, air conditioning will still be provided to prevent odors or discomfort even when a guestroom is not occupied. This partly explains why hotel occupancy level does not directly influence the energy performance of a hotel building [10].

A large amount of electricity is produced by burning coal which greatly was blamed for the green house gas emissions and climate change in Hong Kong. Therefore, reduction of the electrical energy consumption in Hong Kong has further meaning for environment sustainability, especially on air conditioning system which consumes 30% of the total electrical energy.

There have been growing concerns about climate change and green house gas emissions for environment. The concept of Earth Hour has been accepted by more and more people. From the Earth Hour website [13], just take the Hong Kong as example, there were more than 1,800 buildings and landmarks, over 160 schools, over 600 companies and organizations and all universities joined thousands of citizens across Hong Kong participated the activity of Earth Hour by switching off their lights for an hour. These activities not only supported of WWF’s Earth Hour, but also as a call for energy conservation and protecting our environment. These inspiring activities also showed that increasing number of people had awareness to reduce the electricity consumption for energy conservation and protecting our environment.
2.2 Studies on cooling load calculation

There are lots of studies focusing on saving energy, such as improving the thermal performance of building envelop elements (wall, window, roof el.), improving the lighting system efficiency and maintain the efficiency of the air conditioning system by facility management. One type of those studies is about cooling load calculation.

One type of cooling load calculation studies worked on the Overall Thermal Transfer Value (OTTV) [14-18]. OTTV was initiated by ASHRAE [19] and used to describe the maximum rate of thermal transfer permissible into the building through the building fabric, due to outdoor-indoor temperature difference and solar heat gain [18]. This is because majority cooling load is transferred by the heat gains though building fabric. Therefore, one important way to reduce electricity consumption is to limit heat gain through the building fabric, and hence reduce cooling load for air-conditioning during cooling seasons. The OTTV calculation is considered to study key factors affecting the heat transfer. These key factors include building orientation, exterior wall area and its construction type and surface finish, window area, glass type, external shading, and roof area and its construction details [20].

Based on a survey, wall OTTV was about 20% larger than that stipulated in the local energy code in Hong Kong. These could have energy saving implications for the energy conservation programs involving building energy codes and standards. [21]

In another paper [7], Lam took the advantage of computer building simulation techniques (DOE-2.1 E) to investigate the interrelationship between the OTTV and
other key design parameters and their impacts on electricity use and discusses the implication for energy efficiency strategy in commercial buildings. Firstly, he found, compared with the external walls, the heat gain through the roof has small impact on the total cooling load and pointed out two reasons. One reason is that most commercial buildings in Hong Kong are high rise, normally 20 storeys or more. This makes the roof area much smaller than the area of external wall area. Another reason is that most of the roofs composed of 40-50 mm of thermal insulation. The U-value of the roofs is less than 0.64 W/m²k with no skylight. Secondly, the research indicated that the building envelop only accounts for about 30% of the total building cooling load. And the fresh air load and the internal load are responding for other 70%. This suggests that some other design parameters may be more energy-sensitive than the building envelop. Thirdly, the factor of indoor design temperature setting is more sensitive than building envelops and has far greater influence on energy efficiency than the variations in the building envelop designs in a commercial building. Fourthly, several researches suggested greater energy-saving potential of better and more energy-efficient lighting designs, and this will be the key design aspect to address in energy efficiency programmers for commercial buildings. However, Lam’s study only considered one building form and one particular air conditioning system, and this also could not be applied to other situations directly.

Another type of cooling load calculation studies is about the simulation programs. Because the cooling load links with numerous characteristics, such as building envelope, lights, people, equipment, the parameters in the building and out of the building, the cooling load calculation is complex and involves numerous repeated work. Numerous heating and cooling load calculation procedures and software programs are available to the designer in different countries, such as
TSBI3 (Denmark), DOE2.1E (US), ENERGY2 (UK), CHEETAH (Australia), HTB2 (UK), TASE (Finland). Most of those procedures are based upon ASHRAE research and publications, with simplifications and adjustments sometimes incorporated for specific applications. There is a study compared those building energy simulation programs and found even HTB2 is not the latest and best simulation programs, it is still close to the average level and the data transferred by this software is reasonable and within the error reign [22].

Another study investigated the method of chilled plant sizing avoiding over sizing, and compared the results from software HTB2, CLTD method and the real capacity [23]. It indicates that the cooling load simulated by HTB2 is only 0.03-0.04% over the summer months from June to September. This level is still lower than the 2.5% occurrence level by CLTD which is the target for ASHRAE cooling load calculation method.

Regarding to the accurate about computer simulation programmer HTB2, a lot of studies found reasonable results by using HTB2. In one paper [24], Sat and Yik have discussed the performance of programs HTB2 and BECON by comprising of the simulated building energy consumption and the metered data. The paper investigate the energy consumption of equipments in the air conditioning systems including the chillers chilled water pumps, condenser water pumps, cooling towers and VAV systems the result shows that the root-mean-square error values of the predicted monthly electricity consumption for the majority of the water-side air conditioning equipment is within 10% of the corresponding measured monthly average value.

Based on the literatures above, even HTB2 is not the latest and best simulation
programs, it is still close to the average level and the data transferred by this software is reasonable and within the error range. Therefore, the software HTB2 is employed to simulate the cooling load for the hotel building in Hong Kong.

2.3 The existing rules of thumb for air conditioning cooling load

Before the designers calculate the cooling load, the parameters building envelope construction and material, lighting and equipment power intensity, occupant, and the parameters in the building and out of the building, and other parameters for calculation the exactly cooling load should be determined first. However, to some extent, most of those needed parameters are unknown or unsure for the designer at the beginning stage of the project. The designer would like to take some specific, easily remembered numbers which give a good approximate design guide to those situations instead of calculating the load carefully. Those numbers may be defined as rules of thumb for air conditioning system cooling load.

One case study worked on an over sizing chiller system for a hotel building in Hong Kong [25]. This hotel building built in 1988 serviced by four 580 tons chillers (2320 tons), but the actual peak cooling load is just 1000 tons. This means the chillers was over sized 132%. This study pointed out five possible reasons for over sizing. First reason is lack of actual end-used data. Second reason is inadequacy in cooling load calculation methods. Third reason is the misuse of safety margins or standby capacity for sizing chillers. Fourth reason is the fee of consulting engineers is may be linked with the total sum of project investment. Fifth reason is the speculative nature of some buildings. Therefore, a good rules of thumb can help reduce the over sizing
problems. These rules of thumb should detail the background conditions which include the building form, the window wall ratio, the U-value of ex-wall, the Ventilation rate, the indoor temperature setting, the lighting power density and the small power density. This information could help the HVAC engineers to estimate the cooling load for the design building by using the rules of thumb.

According to Lao's research [3], existing rules of thumb used by several leading BSE consulting firms are great larger than measured cooling load density and contributes to oversize equipment in office buildings. He developed new rules of thumb for office buildings by using the method of CLTD/SCL/CLF, commercial simulation package (Carrier E-20) and research simulation package (HTB2). On the other hand, he pointed out that using computer simulation packages can produce generally better estimate of cooling load than using rules of thumb. Moreover, he suggested further work should be done for evaluating the design rules of thumb for other important design parameters, such as heating load, supply air flow rate and for other types of buildings such as hotel buildings, residential buildings, and those works will contribute to a full set of suitable design rules of thumb, also make senses to reduce project initial cost, increased energy efficiency of HVAC plants and equipment and more efficient use of limited building space. However, his study is based only on a special office building, of which constructor material and building form (i.e. square) are particular, and other important design parameters are constant, such as lighting power intensity, occupant, and equipment power intensity. Therefore, his work can't directly used by other situations.
Chapter 3  Methodology

As discussed in the literature review chapter, the software HTB2 was chosen to simulate the cooling load for hotel buildings in Hong Kong. Before the reference space cooling load being calculated for developing the rules of thumb for hotel building, the model building forms, construction data, indoor and outdoor design information should be defined. Therefore, the functions and characteristics of HTB2 software are introduced in the beginning of this chapter. After that, the model buildings used for simulation are shown. Finally, the ranges of needed parameters for simulations are determined.

3.1  Software HTB2

According to the HTB2 USER MANUAL [26], HTB2 is a building heat transfer model for investigating thermal performance of buildings. It was developed by Welsh School of Architecture, University of Wales, in Cardiff Collage, in UK. It was used for both modeling and monitoring the thermal environment of modern buildings, rather than a simple design model. The model was used to investigate the detailed workings of a building, incorporating the many aspects of thermal transport and gain (i.e. fabric conduction, ventilation, isolation, heating and incidental systems) providing energy consumption on short time-scales.

3.1.1  Principles of the model

In Figure 3-1, it can be seen that “the building is considered as a series of spaces linked to each other and to the outside by elements (walls, windows) and ventilation
paths. The thermal transfer is driven by the external climate, heating system(s) operating under control system(s), and a network of incidental heat sources. These thermal forces acting on the building result in transferred a set of heat fluxes, air movements and moisture movements which in turn produce a set of temperatures and moisture levels in each space” [26]

In order to represent the complex set of interactions which constitute the thermal behaviors of a building (Figure 3-1); the approach adopted in HTB2 is to divide time into discrete intervals. At same time, the model assumes that within a time interval or ‘time-step’, each heat transport mechanism remains constant and independent of the others (Figure 3-2).

Figure 3-1 Fundamental Building Processes and Interactions

From HTB2 USER MANUAL [26]
Figure 3-2 Partitioning of Time and Processes

From HTB2 USER MANUAL [26]

“At the end of every time step, a new set of conditions are calculated based on the accumulative effects of these heat transports. In addition, with any changes to the boundary conditions, plant statuses are implemented. These new values are in turn held constant for the duration of the next time interval and the cycle repeated for the duration of the simulation run.” [25]

The time interval used must be small enough so that the sub-processes affects interact over time scales of interest. The length of this time step is effectively dictated by the requirements of the fabric transport procedure and would normally be less than one minute. The structure of HTB2 has been developed to take advantage of this short time step so that, for instance, heat sources may be altered or data can be output at this time scale.
3.1.2 The files in HTB2

Figure 3-3 is HTB2 hierarchical file structure [26]; it can be seen that to run HTB2, 9 kinds of third level file: building file, construction file, layout file, heater file, occupancy file, ventilation file, lighting file, small power file and diary file are needed.

From HTB2 USER MANUAL [26]

Fig 3.3 indicates that the information of building itself can be fully described by the four files: one at second level file-building file, and three at third level file-layout file, construction file and material file. The information about the internal plant and operation of the building are defined by six files: one at second level file-service file, five at third level file-heating file, lighting file, occupant file, small power equipment file and ventilation file. The time schedule of the building is described by the dairy file. The following are descriptions about the nine needed third level files.

The building file is to define the location of the building, the model spaces it contains and point to definition files for the layout of the space, the constructions of the walls
and windows dividing these spaces and the materials used.

The construction file sets out the name, sequence and the thickness of the materials which make up each of the types of elements and windows used in the building. The database of construction techniques are needed in this file, such as wall, floor. For example, Figure 3-4 and Figure 3-5 are about construction of external wall in HTB2 in forms of text and picture, respectively. From these two figures, it can be seen that the external wall was named as “1 external wall”, the sequence and the thickness of the materials also clearly. The U-value of ex-wall was calculated by the HTB 2 (Figure 3-5). The different construction material has different heat storage capacity and time delay which influence the peak cooling load greatly. However, the HTB2 could not simulate the cooling load by the ex-wall parameter independently. In this study, only one popular group of ex-wall construction material was considered. (Figure 3-4, Figure 3-5).

Figure 3-4 The construction of external wall in HTB2 in form of text

```
!CONSTRUCTION '1 external wall'
!TYPE OPAQUE
!PARTS
* from outside in
* (using std ottv props.)
* part material width slices
  * : : : :
  -1 = 01 0.025 0 * granite panel
  -2 = -1 0.050 0 * normal cavity
  -3 = 02 0.100 0 * concrete
  -4 = 08 0.020 0 * plaster

!END
```

Figure 3-5 Construction of external wall in HTB2 in form of picture
The occupancy file specifies the heat and water-vapor output of individual occupants of the building. Different occupant types are definable for each space for the different situations. For example, Figure 3-6 is about the information of occupancy in space 1. From this figure, the two different occupant types are defined. One is for sleeping model. Another is for light activity style. The information about heat and water-vapor output of individual occupants are according to ASHRAE.

Figure 3-6 Occupant information in HTB2

```
:OCCUPANCY SPACE = 1
:ACTIVITY LEVEL #1 = 50.0  0.01
:ACTIVITY LEVEL #2 = 70.0  0.01
:END
```

Within HTB2, a building is regarded as “a series of spaces, linked to each other and to the outside by construction elements and ventilation paths” [26]. The layout file “defines the surface connections and properties of those elements and assigns pointers to thermo-physical properties defined in the construction and materials files”. For example, Figure 3-7 and Figure 3-8 are about the layout information of ex-wall
and window. The information about construction type, area, orientation and the space connected of the ex-wall and window can be seen. The construction type of this ex-wall is 1 (linking with the Figure 3-4), area is 27 m², orientation towards 180° and the space connects from outside into inside of the room.

![Figure 3-7 Layout information of ex-wall](image1)

![Figure 3-8 Layout information of window](image2)

The small power file defines the appliance power output for whole space and each sub-zone. Figure 3-9 is about the small power information in HTB2. There are two distribution of the small power output which includes the convection and radiation.

![Figure 3-9 Small power information in HTB2](image3)

HTB2 treats the heating of a building in terms of a set of heating systems. Each heating system is described “in terms of its maximum heat output, the proportion
given out as convective, radioactive and direct heat, and its warm-up and cool-down time constants; in terms of the number and identity codes of spaces, zones or elements to receive heat, the proportions of the total system output received by each; and in terms of automatic on/off times of the system, the type of thermostat and its characteristics” [26]. Figure 3-10 is the information about the indoor air temperature setting and humidity setting in winter and summer.

Figure 3-10 Indoor air temperature setting and humidity setting in HTB2

```
!HEATSYS 'Ideal heating system #1'
!STAT TYPE IDEAL   * force to maintain air temp.
!POWER OUTPUT = -1  * assumed htg cap.; (unltd. cooling)
!CONVECTIVE CONNECTIONS
  #1 = 1.0     * convective to space 1
}

!SETPOINT HEAT = 22.0
!SETPOINT COOL = 24.5
!SETPOINT RH = 50.0
!STAT AIR CONNECTIONS
  #1 = 1.0     * stat monitoring space 1
\n!END
```

Ventilation in HTB2 encompasses both infiltration and purpose provided air movement. Three fixed rates are available for each space, according to space temperature and/or status as set via the diary. This is the simplest model, it allows some programmed response to the internal environment, but considers exchange to the outside only; inter-space air-flows are not specified. Figure 3-11 is the ventilation information for one space in HTB2. The three fixed rates are 0.1, 0.9 and 1.5.

Figure 3-11 ventilation information in HTB2

```
1  * in space 1
0.1, 0.9, 1.5  * <- Inf. @ .1 ach & .2 during occ
50.0
```
Lighting systems are treated as sources of heat in HTB2. Any numbers of lighting circuits are allowed, each operating independently with a separate specification of heat output, output connections, and operating schedules. Figure 3-12 is about the lighting system information in HT2. It defines the lighting power output and two types of distribution including convection and radiation.

![Figure 3-12 Lighting information in HTB2](image)

The diary file provides a flexible and powerful method of scheduling events within the simulation running. Figure 3-13 is a mixed scheduling in Saturday. It includes the time of on/off and the output proportion for lighting system, small power system, heating system and ventilation system, and occupant activity level. The mixed scheduling (Figure 3-14) for hotel guestroom is from HK-BEAM [27]. It defined the occupancy, lighting, infiltration rate, equipment and fresh air supply scheduling during one typical day.

All other relevant files in HTB2 are detailed at Appendix B. It includes MOD.TOP,
MOD.BLD, MOD.CON, MOD.LAY, MOD.LBY, MOD.SRV, MOD.HTR, MOD.LGT, MOD.SPW, MOD.OCC, MOD.VNT and MOD.DRY files

Figure 3-13 Definition of scheduling events in HTB2

<table>
<thead>
<tr>
<th>Time</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00:00</td>
<td>SET LIGHTING STATUS #1 = MANUAL ON</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET LIGHTING OUTPUT MANUAL #1 = 0.20</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET SPOWER STATUS #1 = ON</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET SPOWER OUTPUT #1 = 0.3</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET OCCUPANCY USAGE #1 = 1</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET OCCUPANCY USAGE #2 = 1</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET OCCUPANCY USAGE #3 = 1</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET OCCUPANCY USAGE #4 = 1</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET OCCUPANCY USAGE #5 = 1</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET OCCUPANCY LEVEL #1 = 10</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET OCCUPANCY LEVEL #2 = 10</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET OCCUPANCY LEVEL #3 = 10</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET OCCUPANCY LEVEL #4 = 10</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET OCCUPANCY LEVEL #5 = 5</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET VENT STATUS #1 = ON</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET VENT STATUS #2 = ON</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET VENT STATUS #3 = ON</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET VENT STATUS #4 = ON</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET VENT STATUS #5 = ON</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET HEATER STATUS #1 = ON</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET HEATER STATUS #2 = ON</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET HEATER STATUS #3 = ON</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET HEATER STATUS #4 = ON</td>
</tr>
<tr>
<td>00:00:00</td>
<td>SET HEATER STATUS #5 = ON</td>
</tr>
</tbody>
</table>

Figure 3-14 Default daily patterns of occupants, fresh air supply and loads in Hotel guest room

<table>
<thead>
<tr>
<th>Hour From</th>
<th>Hour To</th>
<th>Occupancy</th>
<th>Fresh Air Supply</th>
<th>Infiltration rate (ach)</th>
<th>Lighting</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7</td>
<td>0.95</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>0.95</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>0.20</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td>0.20</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>10</td>
<td>11</td>
<td>0.20</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>0.20</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>12</td>
<td>13</td>
<td>0.20</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>13</td>
<td>14</td>
<td>0.20</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>14</td>
<td>15</td>
<td>0.20</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>15</td>
<td>16</td>
<td>0.20</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>16</td>
<td>17</td>
<td>0.20</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>17</td>
<td>18</td>
<td>0.20</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>18</td>
<td>19</td>
<td>0.20</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>19</td>
<td>20</td>
<td>0.20</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.35</td>
</tr>
<tr>
<td>20</td>
<td>21</td>
<td>0.95</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.60</td>
</tr>
<tr>
<td>21</td>
<td>22</td>
<td>0.95</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.60</td>
</tr>
<tr>
<td>22</td>
<td>23</td>
<td>0.95</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.60</td>
</tr>
<tr>
<td>23</td>
<td>24</td>
<td>0.95</td>
<td>On</td>
<td>0.10</td>
<td>0.20</td>
<td>0.60</td>
</tr>
</tbody>
</table>

From HK-BEAM[27]
3.2 Description of the model building

The cooling load density equals the total cooling load divided by the area of the conditioning zone. On one hand, the area of the conditioning zone and envelop of buildings are determined by the building form. On the other hand, the area of conditioning zone and envelop of the building are basic parameters for calculating the total cooling load. Both the area of air conditioning zone and total cooling load are influenced by the building form. Regarding the limitation of Lao’s study [3], the model was based only on a specific office building, of which building form (square) is in particular. Popular building forms were developed in this study, such as square, rectangle and polygon.

The main aim of this study is to develop rules of thumb for cooling load. As discussed in previous, rules of thumb are specific, easily remembered numbers which give a good approximate design guide to some particular services. Therefore, the model must be popular and the detailed information was not considered, such as the detailed layout of building and construction details. Those models in this study were based on the average number of guestrooms and floor areas of 16 exiting hotels as discussed in Yik’s works [28]. The typical floors of these three models have an area of 800 m² accommodating 20 guestrooms. The first model is the octagonal form (Figure 3-15). Although, this model is seldom in Hong Kong, it is convenient to analyze how the orientation influences the cooling load for each zone. That is because each zone faces one orientation and eight zone face eight orientation. The second model is the rectangular form (Figure 3-16). The third model is the square form (Figure 3-17). Those two models are common and popular in Hong Kong.
Figure 3-15 Layout of the octagonal model on a typical floor

<table>
<thead>
<tr>
<th>Zone</th>
<th>NW</th>
<th>N</th>
<th>NE</th>
<th>E</th>
<th>SE</th>
<th>S</th>
<th>SW</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (m²)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>Total floor area (m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>800</td>
</tr>
<tr>
<td>Air conditioning area (m²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>700</td>
</tr>
<tr>
<td>Floor to floor height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.5m slab to slab</td>
</tr>
<tr>
<td>Shading—External or internal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>Abnormal high ground-reflected solar radiation from such as adjacent water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>Solar Load from adjacent reflective building</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>
Figure 3-16 Layout of the rectangular model on a typical floor

![Diagram of a typical floor layout](image)

Table 3-2 Zoning details of rectangular model on a typical floor

<table>
<thead>
<tr>
<th>Zone</th>
<th>NW</th>
<th>NE</th>
<th>SW</th>
<th>SE</th>
<th>Core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (m²)</td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>80</td>
</tr>
<tr>
<td>Volume(m³)</td>
<td>630</td>
<td>630</td>
<td>630</td>
<td>630</td>
<td>280</td>
</tr>
<tr>
<td>Total floor area (m²)</td>
<td>800</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Air conditioning area (m²)</td>
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<td></td>
<td></td>
<td>700</td>
</tr>
<tr>
<td>Floor to floor height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.5m slab to slab</td>
</tr>
<tr>
<td>Shading—External or internal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>Abnormal high ground-reflected solar radiation from such as adjacent water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>Solar Load from adjacent reflective building</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>
Figure 3-17 Layout of the square model on a typical floor

![Layout of the square model on a typical floor](image)

Table 3-3 Zoning details of square model on a typical floor

<table>
<thead>
<tr>
<th>Zone</th>
<th>NW</th>
<th>NE</th>
<th>SW</th>
<th>SE</th>
<th>Core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (m$^2$)</td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>180</td>
<td>80</td>
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<tr>
<td>Volume (m$^3$)</td>
<td>630</td>
<td>630</td>
<td>630</td>
<td>630</td>
<td>280</td>
</tr>
<tr>
<td>Total floor area (m$^2$)</td>
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<td></td>
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<tr>
<td>Air conditioning area (m$^2$)</td>
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<td>700</td>
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<td>Floor to floor height</td>
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<td></td>
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<td>3.5m slab to slab</td>
</tr>
<tr>
<td>Shading—External or internal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>Abnormal high ground-reflected solar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>radiation from such as adjacent water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Load from adjacent reflective</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>building</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Normally, a hotel building can be divided into two parts according to the different usage. One part is guest floors; another part is non-guest floors which would include all area except guestrooms [29]. Because the factors in non-guest floors are different for different hotel class, cannot be properly taken into account. In this study, only the guest floors are chosen to develop the rules of thumb for cooling load.

3.3 Ranges of needed parameters

The cooling load of a building is affected by many factors, and the affection of each factor is different. One of the objectives in this study is to analysis the effects of each factors, and to determine the key factors of affecting the cooling load. Therefore, the changing range of each factor, the high level and low level, is required for the process. The changing range of the cooling load corresponding to each factor can be summarized as following discussions.

3.3.1 Building envelop

Based on the study [21], 144 buildings were surveyed in Hong Kong. The ex-wall of those buildings usually had 125–250 mm thick concrete, mostly with mosaic/ceramic tiles applied to cement render. Typically, the range of U-value of the ex-wall ranged is from 2.2 to 2.9 W/m²*K which links with the type of surface finish and thickness of concrete. The study pointed out two reasons for the ex-wall without of the insulation in Hong Kong. Firstly, because of the winter is mild and short in Hong Kong, heat loss was not critical and there was no need to hold the heat by using insulated wall. Secondly, most of the heat gain into a building was caused by the
solar heat through windows during the hot summer months. As rules of thumb the
U-value of the ex-wall must be meet the comment situations. Therefore, the U-value
of the external wall in this study ranges from 2.2 to 2.9 W/m²*K; and the middle
level is 2.55 W/m²*K.

The study [14] pointed out that in Hong Kong, most buildings are high-rise (20
storeys or more). Compared with the area of the ex-walls, roof area is very much
smaller. Additionally, all the roofs tend to have 40–50 mm thermal insulation in
Hong Kong which can efficiently avoid the top floor residential units from getting
excessively warm. U-value of the roofs is much lower, compared with the single
glazed windows and non-insulated walls, and all the buildings surveyed have solid
opaque roofs without skylights. Therefore, in Hong Kong building envelope heat
gain is mainly caused by solar heat through windows, conduction heat gain through
the roof is much smaller than that through the external walls and windows. For
simplicity, the cooling load the roof is limited; one typical floor without roof was
considered in this study.

3.3.2 Window area and shading coefficient

The paper [21] found that, among all types heat gain through the building envelope
in Hong Kong, the single largest component is solar heat, which is associated with
the glass shading coefficient and the glass area.

Normally, “window area was represented by the window-to-wall ratio (WWR),
defined as the ratio of the total area of windows to the overall gross external walls area (including windows)” [21]. In Hong Kong, building envelope heat gain is mainly caused by solar heat through windows. All surveyed 140 buildings in [21], the range of the WWR is from 20 to 40%. Buildings with WWR less than 25% were found in the older and more densely populated area. These buildings were close to each other and their windows were on the shorter facades. On the other hand, bigger windows of which WWR are greater than 35% are used in larger luxury flats and located in more up-market area. Because the focused building in this study is hotel building which rooms generally have an exterior exposure, and have larger window area, the range of the WWR in this study is from 30% to 50%. The middle level is 40%.

The solar heat gain component links with the concept of glass shading coefficient (SC), which is defined as “the ratio of solar heat gain of the fenestration to solar heat gain of the reference glass”. In paper [21], all surveyed buildings had single glazing. Double glazing is seldom used in Hong Kong for acoustic consideration but not thermal performance. Therefore, the thickness of the glass is 6 mm; and the range of shading coefficient is from 0.25 to 0.9 in this study.
To describe the shading coefficient in HTB2, each group of 11 values are needed for setting the transmission coefficients characteristic and reflectance coefficient characteristic. Take the 6 mm Reflective glass with shading coefficient = 0.50 for example, just as in Table 3.5, 11 values in Line 3 are needed for setting the transmission coefficients characteristic. The first value defines the net diffuse transmission coefficient. The next 10 values define the direct beam transmission coefficients for incidence angles from 0 to 90 degree (i.e. in 10 degree steps). The same format for setting the reflectance coefficient that can be seen in Line 4. Other needed value for transmission coefficients characteristic and reflectance coefficient characteristic for different shading coefficient value are detailed in Appendix.
3.3.3 Interior lighting

Interior lighting plays an important role in providing a comfortable environment for guests and an efficient working environment for employees. In the quest for energy efficiency it must not be forgotten that if the resulting quality of the lighting is poor, the lighting system is inherently inefficient and the energy efficiency initiative is counterproductive. Because, natural daylight not only helps reduce the electricity consumption, but also reduces sensible cooling load which caused by artificial lighting and lower the peak power demand of buildings [17].

Lighting in a hotel typically accounts for between 15% and 18% of total electricity consumption [12]. Energy efficient lighting can reduce electricity costs significantly. The requirements of this section match that of the Code of Practice for Energy Efficiency of Lighting Installations [30] which regulate that Maximum Allowable Values of Lighting Power Density for Various Types of Space for Hotel guest room is 25W/m². In the ASHRAE pocket guide [31], the suggest range of the lighting power density is from 10.8 to 32.3 W/m². Therefore, for simplification and considering the requirement in Code of Practice for Energy Efficiency of Lighting Installations, the range of lighting power density is from 10 to 25 W/m²; the middle level is 17.5 W/m².
3.3.4 Small equipment power density

HBEAS [12] encourages adoption of the Government’s Energy Efficiency Registration Scheme for Buildings. The requirement of this section matches that of the Code of Practice for Energy Efficiency of Electrical Installations [32]. In the ASHRAE pocket guide [31], the suggest range of the small equipment power density is from 12.5 to 17.5 W/m². Therefore, the range of small equipment power density is from 12.5 to 17.5 W/m²; the middle level is 15 W/m².

3.3.5 Ventilation

Acceptable indoor air quality is defined in ASHRAE Standard 62-1999 [33] as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction". The purpose of ASHRAE 62-1999 is to specify minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to minimize the potential for adverse health effects.

Prescriptive requirement ventilation rate for hotel building in ASHRAE pocket guide [31] is present two part. One part of requirement is for people, another part of requirement for building. The prescriptive requirement ventilation rate for hotel can be present by equation 3.1.

\[ V = R_p P_z + R_a \Delta Z \]  

(3.1)

Where

\[ \Delta Z = \text{zone floor area, m}^2, \]
$P_z =$ zone maximum occupant

$R_p =$ outdoor air required per person

$R_a =$ outdoor air required per unit area.

The requirement unit for ventilation in HTB2 is air change rate per hour. So when Zone floor area ($\square_Z =$ 800 m$^2$, $P_z =$ 40, $R_p =$ 2.5 and $R_a =$ 0.75 (ASHRAE Standard 62.1 – 1989P [31]), the air change rate per hour $= 0.9$. When zone floor area ($\square_Z =$ 800 m$^2$, $P_z =$ 40, $R_p =$ 2.5 and $R_a =$ 0.3 (ASHRAE Standard 62.1 – 2007[34]), the air change rate per hour $= 0.44$. Here, all guest rooms in the typical floor are treated as one for simplification. Because the requirement is specify minimum ventilation rates, considering high comfort requirement for hotel, the air change rate per hour $= 0.44$ are taken as lower level; the air change rate per hour $= 0.9$ are taken as middle level and the air change rate per hour $= 1.5$ are taken as high level for simulation procedure.

### 3.3.6 Indoor air temperature setting

From the Figure 3-20 of thermal environment conditions for human occupancy, the indoor temperature according to the different cloth values can be found. The target of software simulation is finding out the peak load, the season is chosen to be summer. The relative humidity (RH) for summer is set to be 50% RH which is from Code of practice [35]. Plotting the curve of 50%RH, the corresponding operative temperatures are from 23.1 °C to 26.3 °C. However, the government suggests setting the indoor air temperature at 25.5 °C[35]. Therefore the low level of indoor temperature setting is 23 °C; and the high level is 25.5 °C. The middle level is 24.5 °C.
All the ranges for the needed parameters which include lighting power density, small power density, ventilation rate, indoor air temperature setting, window wall ratio, shading coefficient and U-value of ex-wall, are summarized in Table 3-4.
<table>
<thead>
<tr>
<th>Unit</th>
<th>Lighting intensity</th>
<th>Small power density</th>
<th>Air change rate</th>
<th>Indoor air temperature</th>
<th>Window/ex-wall rate</th>
<th>U value of ex-wall</th>
<th>Shading coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>10 W/m²</td>
<td>12.5 W/m²</td>
<td>0.44 times/hour</td>
<td>23°C</td>
<td>0.3</td>
<td>2.2</td>
<td>0.25</td>
</tr>
<tr>
<td>Middle</td>
<td>17.5 W/m²</td>
<td>15 W/m²</td>
<td>0.9</td>
<td>24.5°C</td>
<td>0.4</td>
<td>2.53</td>
<td>0.45</td>
</tr>
<tr>
<td>High</td>
<td>25 W/m²</td>
<td>17.5 W/m²</td>
<td>1.5</td>
<td>25.5°C</td>
<td>0.5</td>
<td>2.9</td>
<td>0.95</td>
</tr>
</tbody>
</table>
Chapter 4 Findings and discussion

In this chapter, the key factors influencing the cooling load are analyzed and determined first. Finally, the new rules of thumb for hotel building are proposed.

This study aims to develop the rules of thumb for cooling load in hotel buildings in Hong Kong. The typical hotel building models and the range for needed parameters were described in methodology chapter. Because cooling load is determined by the numerous factors analyzed in the literature review chapter, this study could not simulate all different factors to form the rules of thumb. For this reason, there is a need to discover the key factors which influence the cooling load greatly before developing the rules of thumb.

In this study, the sensitivity method was adopted to discover the key factors. In order to calculate the sensitivity of each factor, the low level value for each factor was subtracted from the high level value for the same factor, and then the range of cooling load was divided by this number. The sensitivity is just like a measurement of the changing rate of cooling load for each factor and it will not be affected by the range of the factor. Even though in some cases the factor may not be within the range, sensitivity is still a widely used index to indicate the significance of each factor to the cooling load.
4.1 Key factors

After inputting all files into the HTB2 with necessary parameters determined in the methodology chapter for running the program, the cooling loads of the hotel buildings were transferred. The cooling load densities corresponding to different parameters at different levels for the octagon form model, the rectangular form model and the square form model is summarized in Table 4-1, Table 4-2 and Table 4-3.

From Table 4-1, Table 4-2 and Table 4-3, those following conclusions can be drawn. First, when all parameters concerned are at middle level, compared to the cooling load density among the three models, the biggest one (89.13 W/m²) is for the octagon model, the middle one (82.92 W/m²) is for the rectangular model, and the smallest one (81.62 W/m²) is for the square model. That is because the major cooling load is transferred by the external building envelop for hotel buildings. When the plan areas are same for different forms, the external vertical areas are different. Take the three models for example, the three models have same floor area 800m², but the ex-wall and window area are different. The biggest one (360 m²) is for the octagon model, the middle one (210 m²) is for the rectangular model, and the smallest one (198m²) is for the square model. This order of the vertical areas exactly matches the cooling load density order for the three models. Therefore, the building form is one critical factor in determining the cooling load. The designers should balance this factor with others when they design the building form.
<table>
<thead>
<tr>
<th></th>
<th>Low level</th>
<th>Medium level</th>
<th>High level</th>
<th>Range</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>Unit: w/m²</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cooling load (w/m²)</td>
<td>86.95</td>
<td>89.13</td>
<td>91.32</td>
<td>4.37</td>
<td>0.29</td>
</tr>
</tbody>
</table>

| Small power         | Unit: w/m² |              |            |        |             |
| Cooling load (w/m²) | 88.13      | 89.13        | 90.13      | 2      | 0.4         |

| Air change rate     | Unit: Times/hour |              |            |        |             |
| Cooling load (w/m²) | 67.11         | 89.13        | 118.53     | 51.42  | 48.51       |

| Indoor air temperature setting | Unit: °C |              |            |        |             |
| Cooling load (w/m²)           | 95.54     | 89.13        | 84.75      | 10.79  | 4.32        |

| Window / Wall ratio         | Unit: 1   |              |            |        |             |
| Cooling load (w/m²)         | 84.23     | 89.13        | 93.88      | 9.65   | 48.25       |

| U value of ex-wall         | Unit: 1   |              |            |        |             |
| Cooling load (w/m²)         | 87.98     | 89.13        | 93.88      | 5.9    | 8.42        |

| Shading coefficient        | Unit: 1   |              |            |        |             |
| Cooling load (w/m²)         | 79.79     | 89.13        | 110.21     | 30.42  | 43.46       |
Table 4-2: Range of cooling load corresponding to each factor for rectangular form model

<table>
<thead>
<tr>
<th>Factor</th>
<th>Unit</th>
<th>Low level</th>
<th>Medium level</th>
<th>High level</th>
<th>Range</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>w/m²</td>
<td>10</td>
<td>17.5</td>
<td>25</td>
<td>15</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>Cooling load</td>
<td>80.63</td>
<td>82.92</td>
<td>85.71</td>
<td>5.08</td>
<td></td>
</tr>
<tr>
<td>Small power</td>
<td>w/m²</td>
<td>12.5</td>
<td>15</td>
<td>17.5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load</td>
<td>82.69</td>
<td>82.92</td>
<td>84.82</td>
<td>2.13</td>
<td>0.426</td>
</tr>
<tr>
<td>Air change rate</td>
<td>Times/ hour</td>
<td>0.44</td>
<td>0.9</td>
<td>1.5</td>
<td>1.06</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load</td>
<td>61.26</td>
<td>82.92</td>
<td>113.85</td>
<td>52.59</td>
<td></td>
</tr>
<tr>
<td>Indoor air temperature setting</td>
<td>°C</td>
<td>23</td>
<td>24.5</td>
<td>25.5</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load</td>
<td>91.15</td>
<td>82.92</td>
<td>79.86</td>
<td>11.29</td>
<td></td>
</tr>
<tr>
<td>Window / Wall ratio</td>
<td>1</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load</td>
<td>81.95</td>
<td>82.92</td>
<td>86.62</td>
<td>4.67</td>
<td></td>
</tr>
<tr>
<td>U value of ex-wall</td>
<td></td>
<td>2.2</td>
<td>2.53</td>
<td>2.9</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load</td>
<td>81.95</td>
<td>82.92</td>
<td>88.04</td>
<td>6.09</td>
<td></td>
</tr>
<tr>
<td>Shading coefficient</td>
<td>1</td>
<td>0.25</td>
<td>0.45</td>
<td>0.95</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load</td>
<td>81.31</td>
<td>82.92</td>
<td>92.80</td>
<td>11.49</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low level</td>
<td>Medium level</td>
<td>High level</td>
<td>Range</td>
<td>Sensitivity</td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------</td>
<td>--------------</td>
<td>------------</td>
<td>-------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>Lighting</td>
<td>Unit: w/m²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>17.5</td>
<td>25</td>
<td>15</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load (w/m²) 79.36</td>
<td>81.62</td>
<td>84.87</td>
<td>5.42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small power</td>
<td>Unit: w/m² 12.5</td>
<td>15</td>
<td>17.5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load (w/m²) 80.63</td>
<td>81.62</td>
<td>82.77</td>
<td>2.14</td>
<td>0.428</td>
<td></td>
</tr>
<tr>
<td>Air change rate</td>
<td>Unit: Times/hour 0.44</td>
<td>0.9</td>
<td>1.5</td>
<td>1.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load (w/m²) 59.04</td>
<td>81.62</td>
<td>112</td>
<td>52.96</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Indoor air temperature setting</td>
<td>Unit: °C 23</td>
<td>24.5</td>
<td>25.5</td>
<td>2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load (w/m²) 87.49</td>
<td>81.62</td>
<td>77.63</td>
<td>9.86</td>
<td>3.94</td>
<td></td>
</tr>
<tr>
<td>Window/ Wall ratio</td>
<td>Unit: 1    0.3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load (w/m²) 79.78</td>
<td>81.62</td>
<td>84.43</td>
<td>4.65</td>
<td>23.1</td>
<td></td>
</tr>
<tr>
<td>U value of ex-wall</td>
<td>Unit: 1    2.2</td>
<td>2.53</td>
<td>2.9</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load (w/m²) 80.73</td>
<td>81.62</td>
<td>86.52</td>
<td>5.79</td>
<td>8.27</td>
<td></td>
</tr>
<tr>
<td>Shading coefficient</td>
<td>Unit: 1    0.25</td>
<td>0.45</td>
<td>0.95</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling load (w/m²) 77.11</td>
<td>81.62</td>
<td>88.78</td>
<td>11.67</td>
<td>16.67</td>
<td></td>
</tr>
</tbody>
</table>
Note: Every cooling load in Table 4-1, Table 4-2 and Table 4-3 is calculated based on the level of the parameter concerned with all others at the middle level.

Second, when all parameters concerned are at middle level, the cooling load densities are 89.13 W/m² for the octagon model, 82.92 W/m² for the rectangular model, and 81.62 W/m² is for the square model. All the cooling load densities are in the recommended range of cooling load density from 80 W/m² to 100W/m² in the Shi Yong Gong Re Kong Tiao She Ji Shou Ce in Chain [37] and also in the recommended range of cooling load density from 75 W/m² to 94 W/m² in the book of HVAC Equations, Data, and Rules of thumb [38]. This means that cooling load densities for these models in this paper are reasonable and close to the actual value.

Third, the sensitivity for each parameter for different form models is presented in Table 4-1, Table 4-2 and Table 4-3. From those three tables, it can be seen that the sensitivity order for different form models is the same. The order is ventilation, window-wall ratio (WWR), shading coefficient (SC), U-value of the external wall, indoor air temperature setting, small power equipment density and lighting power density. The five top sensitivities and the range of difference in cooling load density for each parameter for the three models are summarized in Table 4-4.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Octagon model</th>
<th>Square model</th>
<th>Rectangular model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Sensitivity</td>
<td>Range</td>
</tr>
<tr>
<td>First</td>
<td>Ventilation</td>
<td>51.42</td>
<td>48.51</td>
</tr>
<tr>
<td>Second</td>
<td>WWR</td>
<td>9.65</td>
<td>48.25</td>
</tr>
<tr>
<td>Third</td>
<td>SC</td>
<td>30.42</td>
<td>43.46</td>
</tr>
<tr>
<td>Fourth</td>
<td>U-value of ex-wall</td>
<td>5.9</td>
<td>8.42</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Fifth</td>
<td>Indoor air temperature setting</td>
<td>10.79</td>
<td>4.32</td>
</tr>
</tbody>
</table>

Fourth, the biggest sensitivity of the parameter is ventilation. All three of the ventilation sensitivities are around 50. One reason for such a high sensitivity is that the hotel needs a large amount of air to build the comfortable environment. Another reason is the average air humidity in Hong Kong in the hottest month is higher. This increases the cooling load greatly and consumes a large amount of energy to dehumidify the air to the indoor design condition. The latent load of the ventilation can be calculated by the following equation.

Table 4-5 presents the latent load from the HTB2 simulation program and manual calculations at three level ventilation rates for the octagon model. It can be seen that the results from the HTB2 simulation program and manual calculations are slightly different. This is because the climate condition of the latent load calculated by the HTB2 is slightly different with the design climate conditions which are collected from the ASHRAE handbook [36]. The different cooling load density between high level ventilation rate and low level ventilation rate in Table 4-1 is for the total cooling load density. The cooling load density in Table 4-5 is just the latent load caused by ventilation. Regarding the sensible load caused by the ventilation, the different cooling load densities between high level ventilation rate and low level ventilation rate in Table 4-1 and Table 4-5 are reasonable.
Table 4-2 Latent load caused by ventilation in HTB2 and manual calculation

<table>
<thead>
<tr>
<th>Air change rate per hour</th>
<th>HTB2 result for one zone</th>
<th>Manual calculation result for one zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.44</td>
<td>13.81 W/room</td>
<td>15.44 W/room</td>
</tr>
<tr>
<td>0.9</td>
<td>32.12 W/room</td>
<td>31.80 W/room</td>
</tr>
<tr>
<td>1.5</td>
<td>53.37 W/room</td>
<td>53.00 W/room</td>
</tr>
</tbody>
</table>

Fifth, the second and third sensitivities of the parameters are window to wall ratio (WWR) and Shading coefficient (SC). This is because the cooling load in the hottest month is mainly caused by the heat gain from windows [21]. The cooling load transferred by the window includes thermal conduction, convection and solar radiation. Normally, the U-value of window glass is in the 4 and 5 w/(m*K) range which is two or three times more than U-value of ex-wall, so the cooling load transferred though heat transfer by window is larger than heat transfer transferred by ex-wall. Furthermore, solar radiation is also another factor which great contributes to cooling load. Therefore, the window to wall ratio and shading coefficient play significant roles in cooling load.

As mentioned previously, when the three models have same floor area 800m², the ex-wall and window area are different. The biggest one (360 m²) is for the octagon model, the middle one (210 m²) is for the rectangular model, and the smallest one (198m²) is for the square model. Although the WWR and SC have the same values in three models, the window areas are different. That leads to the sensitivities of WWR and SC in three models being different. The bigger area of windows, the bigger sensitivities of WWR and SC are. In table 4.4, the WWR and SC for octagon form
model are 48.25 and 43.46, for rectangular form model are 23.25 and 16.67 and for square form model are 23.1 and 16.41. The difference in area of windows between the rectangular form model and the square form model is just 22m² that is far smaller than the difference of area of windows between the octagon form model and the rectangular form model which is 150m². Therefore the difference of WWR and SC between the rectangular form model and the square form model is smaller than the difference of WWR and SC between the octagon form model and the rectangular form model.

This suggests the designer should use as smaller window area and shading coefficient of the glass as possible and add external or internal shading to reducing the cooling load transferred by the window.

Sixth, all three of the sensitivities for U-value of ex-wall are more than 8. The difference in cooling load density at low level of U-value of ex-wall and high level of U-value of ex-wall for the octagon form model, rectangular form model and square form model are 5.9, 6.09 and 5.79. This means the heat transfer through the ex-wall contributes significant part of cooling load. Additionally, the different construction material have different heat storage capacity and time delay which influence the peak cooling load greatly. However, the HTB2 could not simulate the cooling load by the ex-wall parameter independently. In this study, only one popular group of ex-wall construction material was considered. Therefore, this study could not analysis how the heat transfer through the ex-wall influence the cooling load and develop the rules of thumb for cooling load at this factor.
Seventh, all three of the sensitivities for indoor air temperature are around 4. The differences in cooling load density at low level and high level of indoor air temperature setting for the octagon form model, the rectangular form model and the square form model are 10.79 W/m², 11.29 W/m² and 9.8 W/m². These big differences cooling load densities at different levels of indoor temperature setting is because that the driving force of cooling load is the temperature difference. When the other parameters at same level, the greater the temperature difference is, the higher the cooling load.

Eighth, the orientation is another important factor influencing the cooling load. Table 4-6 is the sensible cooling load density for each zone for the octagon form model at all parameters at middle level. From Table 4-6, it can be seen that the orientation influence the cooling load greatly for each zone. The orientation corresponding the highest cooling is 180⁰. Next one is 135⁰.

<table>
<thead>
<tr>
<th>Orientation</th>
<th>180⁰</th>
<th>270⁰</th>
<th>0⁰</th>
<th>90⁰</th>
<th>225⁰</th>
<th>135⁰</th>
<th>45⁰</th>
<th>315⁰</th>
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<tr>
<td>Cooling load Density W/m²</td>
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<td>38.32</td>
<td>48.49</td>
<td>40.22</td>
<td>49.30</td>
<td>46.00</td>
<td>38.04</td>
</tr>
</tbody>
</table>

The orientation factor influencing the cooling load can be simulated by the different length of side of the rectangular form. The square form model can be treated as one specific form of rectangular form. From Table 4-2 and Table 4-3, the peak cooling load densities for the rectangular form model and the square form model at all
parameters at middle level are 82.92 W/m² and 81.62 W/m². The values of these two cooling load densities are close.

Therefore, the orientation influences the cooling load greatly for each zone, but has little influence on the cooling load density for the whole floor area.

As regards the discussion above, the findings indicate that the factors of ventilation, window to wall ratio, shading coefficient and indoor temperature setting have greater influence on cooling load than other factors and available for developing the rules of thumb for cooling load by using HTB2. Therefore, they are chosen as the key factors to form the rules of thumb for air conditioning system cooling load in hotel in Hong Kong.

4.2 Developing rule of thumb for cooling load estimation

After identified the four key factors and their available range, cooling load density was calculated by HTB2. The rules of thumb for cooling load for the octagon form model, the rectangular form model and the square form model were summarized in Table 4-7, Table 4-8 and Table 4-9, respectively.
<table>
<thead>
<tr>
<th>Indoor air temperature</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
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<td>108.21</td>
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### Table 4-9 Cooling load density for square form hotel building

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</tr>
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</tr>
</tbody>
</table>
Note: The first levels of Table 4-7, Table 4-8 and Table 4-9 present different level of ventilation rates; the second levels are the indoor air temperature; the left side is window to wall ratio and the right side is shading coefficient for each table. The cooling load in bold represents the average level of cooling load when all parameters in the medium level.

By the method of interpolation the data in Table 4-7, Table 4-8 and Table 4-9, HVAC Engineer could find the reasonable rules of thumb for air conditioning system cooling load for hotel buildings based on the specific condition without worry about the cooling load being overestimated or underestimated.

Since all these key factors are independent, a method called multiple regressions can be utilized for analysis these key factors. It is a procedure used to analysis the data with two or more independent variables. It generates an equation like that:

\[ Y = aX_1 + bX_2 + cX_3 + \ldots + mX_n \]

Where X1, X2, X3 and Xn are variables

In this paper, Y is the cooling load of the building, X1 is ventilation rate, X2 is window/ wall ratio, X3 is shading coefficient of window and X4 is the indoor air temperature setting. When we input all the data in the table, the software Excel will generate an equation with these four key factors. The equations for the three models are summarized in Table 4-10.
Table 4-7 Multiple regressions equation for three models

<table>
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<tr>
<th>Model</th>
<th>Equation</th>
<th>P</th>
<th>Adjusted $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Octagon</td>
<td>$Y = 52.19 \times X_1 + 43.72 \times X_2 + 47.07 \times X_3 - 4.39 \times X_3 + 113.90$</td>
<td>$1.6 \times 10^{-56}$</td>
<td>0.97</td>
</tr>
<tr>
<td>Square</td>
<td>$Y = 27.07 \times X_1 + 17.92 \times X_2 + 48.74 \times X_3 - 4.09 \times X_3 + 120.65$</td>
<td>$1.3 \times 10^{-73}$</td>
<td>0.99</td>
</tr>
<tr>
<td>Rectangle</td>
<td>$Y = 27.07 \times X_1 + 17.92 \times X_2 + 48.74 \times X_3 - 4.09 \times X_3 + 120.65$</td>
<td>$1.3 \times 10^{-73}$</td>
<td>0.97</td>
</tr>
</tbody>
</table>

"Beside the equation, some other parameters were generated at the same time to indicate the performance of these equations. There are two most useful parameters called adjust $R^2$ and p-value. $R^2$ is the multiple coefficient of determination which is used to measure whether the equation match the data well. The value of $R^2$ more close to 1, the equation matches the data better. P-value is a measure of the overall significance of the multiple regression equation. The P-value is more close to 0, the variables of this equation is more significant" [1].

The adjust $R^2$ of these three generated equations are 0.97, 0.99 and 0.97 which very close to 1. The P-value of these three generated equations are $1.6 \times 10^{-56}$, $1.3 \times 10^{-73}$ and $1.3 \times 10^{-73}$. These mean that the equations match the equations well and the variables of these equations are quite significant. Engineers can find out rules of thumb for the cooling load more accurately by using those equations.
Chapter 5  Conclusion

5.1  Major findings and contribution of this study

The main objective of this study is to identify the key factors influencing the cooling load, and propose new rules of thumb for hotel buildings in Hong Kong. First, the range of needed parameters for cooling load calculation was collected and determined from ASHRAE, HK-BEAM, HK-COP and other relevant papers. Second, three types of popular form models were identified, namely the octagon form model, the rectangular form model and the square form model. Third, when inputting all needed parameters and the models into HTB2 program, the cooling load was produced. Fourth, by comparing the sensitivity of each parameter, four key factors were determined for developing the rules of thumb. They are ventilation, window wall ratio, shading coefficient and indoor air temperature setting. Finally, the rules of thumb and three equations were identified for the three models. By using the three equations in Table 4-10 and the method of interpolation the data in Table 4-7, Table 4-8 and Table 4-9, HVAC Engineer could find the reasonable rules of thumb for cooling load for hotel buildings based on the specific condition without worrying about the cooling load being overestimated or underestimated.
5.2 Limitations of this study and suggestions for further research

One limitation of this study is that the weather information used in this study was from year of 1992 in Hong Kong. Because of the greenhouse effect and climate change the weather conditions are different from years of 1992. This leads to the cooling load calculated in this study being different from the real situation and reduces the quality of the rules of thumb. Further study should use the latest weather information to simulate the cooling load.

Another limitation of this study is that only one popular group of ex-wall construction material was considered to simulate the cooling load. Heat transfer through the ex-wall contributes a significant part of cooling load. Additionally, the different construction materials have different heat storage capacity and time delay which influence the peak cooling load greatly. However, the HTB2 could not simulate the cooling load by the ex-wall parameter independently. In this study, only one popular group of ex-wall construction material was considered. Therefore, this study could not analyze how the heat transfer through the ex-wall influences the cooling load and develops the rules of thumb for cooling load at U-value of ex-wall factor. Further study should consider different types of ex-wall to simulate the cooling load.

The third limitation of this study is that HTB2 could not simulate the cooling load for independent parameter. The main objective of this study is to identify the key factors
influencing the cooling load, and propose new rules of thumb for hotel building in Hong Kong. Because HTB2 program could not simulate the cooling load for independent parameter, further analysis of how the independent parameter influences the cooling load is difficult by using HTB2 program. The sensitivity method was adopted to discover the key factors in this study. Further study should use other available simulation programs to simulate the cooling load in independent parameter and analyze the differences in cooling load generated.

Another limitation of this study is that only the guest floors are chosen to develop the rules of thumb for cooling load. Normally, a hotel building can be divided into two parts according to the different usage. One part is guest floors; another part is non-guest floors which would include all area except guestrooms. Because the factors in non-guest floors are different for different hotel class, cannot be properly taken into account. In this study, only the guest floors are chosen to develop the rules of thumb for cooling load. The further study should complete the rules of thumb for the non-guest floors.
Reference

Commercial Building in Hong Kong.” HK Polytechnic University, The

pp9-457

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Appendix A  An example for HTB2 Simulation

In this study, there is more than 300 times to running HTB2 at different parameter conditions for determining the key factors influencing cooling load and proposing new rules of thumb for hotel building. This appendix is an example for HTB2 simulation. The running model is the Octagon form model. The WWR is 0.4, the U-value of ex-wall is 2.53 W/m²*K, the Ventilation rate is 0.9 times/hour, the indoor temperature setting is 24.5 °C, the lighting power density is 17.5 W/m² and the small power density is 15 W/m² for running conditions.

The files include:

- The top level file - MOD.TOP
- The building file – MOD.BLD
- The construction file – MOD.CON
- The layout file – MOD.LAY
- The standard material file – MOD.LBY
- The services file – MOD.SRV
- The heating file – MOD.HTR
- The lighting file – MOD.LGT
- The small power file – MOD.SPW
- The occupant file – MOD.OCC
- The ventilation file – MOD.VNT
- The Sunday, Saturday and Weekday diary file – MOD.DRY
Appendix A-1 Top level file

* top level run file for model hotel building

!RUNID  Model HK hotel Building

* configure model as standard...
!ENABLE DIARY INPUT
!ENABLE FABRIC
!ENABLE HEATING
!ENABLE VENTILATION
!ENABLE LIGHTING
!ENABLE METEOROLOGICAL
!ENABLE OCCUPANCY
!ENABLE WATER
!ENABLE SMALL POWER
!ENABLE RADTRAN STAR
!ENABLE SOLAR

* set up run parameters
!SET TIMESTEP = 120.0
!SET SLICES = 3
!SET RUNLENGTH = 365,01
!SET AIR REFERENCE = 20.0
!SET VIRT REPORT = 0
!SET GROUND FACTOR = 1.0
!ENABLE GROUND TEMP
* chose output files and data, output from start of run
!OUTPUT INFO = 'MODBLD.INF'
!ENABLE ZNFILE OUTPUT

!ENABLE BLOCK OUTPUT
!OUTPUT BLOCK FILE = 'MODBLD.BLK'

* connect to further files
!DEFINE BUILDING FILE = 'MODBLD.BLD'
!DEFINE SERVICES FILE = 'MODBLD.SRV'
!DEFINE DIARY FILE = 'MODBLD.DYL'
!DEFINE METEOR FILE = 'HK.MET'
Appendix A-2 Building file

!PROJECTID Model HK hotel Building
* Model HK hotel Building
  * id     vol m3    code no.
!LOCATION = 22.3  -114.2
!TIME ZONE = -120.0
!SKYLINE = 20.0
!DEFINE SPACE = 'N40F'
  !VOLUME = 350
!END
!DEFINE SPACE = 'E40F'
  !VOLUME = 350
!END
!DEFINE SPACE = 'S40F'
  !VOLUME = 350
!END
!DEFINE SPACE = 'W40F'
  !VOLUME = 350
!END
!DEFINE SPACE = 'NE40F'
  !VOLUME = 350
!END
!DEFINE SPACE = 'NW40F'
  !VOLUME = 350
!END
!DEFINE SPACE = 'SW40F'
  !VOLUME = 350
!END
!DEFINE SPACE = 'SE40F'
  !VOLUME = 350
!END
Appendix A-3 Construction file

!MATERIALS FILE = 'STDMAT.LBY'
!CONSTRUCTION FILE = 'MODBLD.CON'
!LAYOUT FILE = 'MODBLD.LAY'

* construction definition file for model HK hotel building

!MATERIALS USER FILE = 'HKMATS.TXT'

!CONSTRUCTION '1 external wall'
!TYPE OPAQUE
!PARTS
* from outside in
* (using std ottv props.)
* part  material  width  slices
*     :       :       :       :
  _1  =  @1  0.025  0  * granite panel
  _2  =  -1  0.050  0  * normal cavity
  _3  =  @2  0.100  0  * concrete  2243 kg/m3
  _4  =  @8  0.020  0  * plaster
}
!END

!CONSTRUCTION '2 glazing'
!TYPE TRANSPARENT
!PARTS
* part  material  width  slices  absorp
*     :       :       :       :
  _1  =  @10  0.006  0  1.00  * window glass
}
!END

!CONSTRUCTION '3 internal core wall'
!TYPE OPAQUE
!PARTS
* part  material  width  slices
*     :       :       :
  _1  =  @8  0.020  0  * plaster
  _2  =  @2  0.250  0  * concrete  2243 kg/m3
  _3  =  @8  0.020  0  * plaster
}
!END
!CONSTRUCTION '4 internal partitioning'
!TYPE OPAQUE
!PARTS
  * part  material width  slices
  *      :      :      :      :
  _ 1   =  @9  0.015 0     * plasterboard
  _ 2   =  -1  0.050 0     * cavity
  _ 3   =  @9  0.015 0     * plasterboard
}!END

!CONSTRUCTION '5 flooring'
!TYPE OPAQUE
!PARTS
  * top down
  * part  material width  slices
  *      :      :      :      :
  _ 1   =  @15 0.005 0     * vinyl tiles
  _ 2   =  @4  0.025 0     * screed
  _ 3   =  @2  0.100 0     * concrete
}!END

!CONSTRUCTION '6 roof'
!TYPE OPAQUE
!PARTS
  * top down
  * part  material width  slices
  *      :      :      :      :
  _ 1   =  @4  0.025 0     * screed
  _ 2   =  @5  0.037 0     * p-styrene insulation
  _ 3   =  @11 0.030 0     * asphalt
  _ 4   =  @4  0.025 0     * screed
  _ 5   =  @2  0.100 0     * concrete
}!END

!CONSTRUCTION '7 adiabatic flooring'
!TYPE OPAQUE
!PARTS
  * top down
  * part  material width  slices
  *      :      :      :      :
  _ 1   =  @15 0.005 0     * vinyl tiles
_2 = @4 0.025 0 * screed
_3 = @2 0.100 0 * concrete
_2 = @4 0.025 0 * screed
* _1 = @15 0.005 0 * vinyl tiles
}
!END

!CONSTRUCTION '8 adiabatic ceiling'
!TYPE OPAQUE
!PARTS
* top down
* part material width slices
* : : :
_1 = @2 0.100 0 * concrete
}
!END

* window type definitions

* 6 mm reflective glass (shading coeff 0.45 approx)
!WINDOW = 'REFL6'
!TRANSMISSION =
   .26, .26, .26, .26, .26, .26, .26, .26, .20, .10, .0
!ABSORPTION =
   .40, .40, .40, .40, .40, .40, .40, .40, .30, .30, .0
!EN
Appendix A-4 Layout file

* LAYOUT DEFINITION FILE for Model HK hotel Building
* Only Typical Floor and Topmost Floor modelled

!ELEMENT = '40FNWALL'
!CONSTRUCTION = 1
!AREA = 27
!ORIENTATION = 180.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 1
!ABSORPTION FIRST = 0.6
!ABSORPTION LAST = 0.5
!SHADING = 'NONE'
!END

!ELEMENT = '40FNWIND'
!CONSTRUCTION = 2
!AREA = 18
!ORIENTATION = 180.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 1
!SHADING = 'NONE'
!WINDOW TYPE = 'REFL6'
!PATCH TO #3 FIRST = 1.00
!END

!ELEMENT = '40FNRPART' * 1,5
!CONSTRUCTION = 4
!AREA = 58.9
!TILT = 0.0
!SPACE TO FIRST = 1
!SPACE TO LAST = 5
!ABSORPTION FIRST = 0.5
!ABSORPTION LAST = 0.5
!END

!ELEMENT = '40FNLPART' * 6,1
!CONSTRUCTION = 4
!AREA = 58.9
!TILT = 0.0
!SPACE TO FIRST = 6
!SPACE TO LAST = 1
!ABSORPTION FIRST = 0.5
!ABSORPTION LAST = 0.5
!END

!ELEMENT = '40FEWALL'
!CONSTRUCTION = 1
!AREA = 27
!ORIENTATION = 270.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 2
!ABSORPTION FIRST = 0.6
!ABSORPTION LAST = 0.5
!SHADING = 'NONE'
!END

!ELEMENT = '40FEWIND'
!CONSTRUCTION = 2
!AREA = 18
!ORIENTATION = 270.0
!TILT = 0
!SPACE TO FIRST = 0
!SPACE TO LAST = 2
!SHADING = 'NONE'
!WINDOW TYPE = 'REFL6'
!PATCH TO #3 FIRST = 1.00
!END

!ELEMENT = '40FELPART' * 5,2
!CONSTRUCTION = 4
!AREA = 58.9
!TILT = 0.0
!SPACE TO FIRST = 5
!SPACE TO LAST = 2
!ABSORPTION FIRST = 0.5
!ABSORPTION LAST = 0.5
!END

!ELEMENT = '40ERPART' * 2,8
!CONSTRUCTION = 4
!AREA = 58.9
!TILT = 0.0
!SPACE TO FIRST = 2
!SPACE TO LAST = 8
!ABSORPTION FIRST = 0.5
!ABSORPTION LAST = 0.5
!END

!ELEMENT = '40FSWALL'
!CONSTRUCTION = 1
!AREA = 27
!ORIENTATION = 0.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 3
!ABSORPTION FIRST = 0.6
!ABSORPTION LAST = 0.5
!SHADING = 'NONE'
!END

!ELEMENT = '40FSWIND'
!CONSTRUCTION = 2
!AREA = 18
!ORIENTATION = 0.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 3
!SHADING = 'NONE'
!WINDOW TYPE = 'REFL6'
!PATCH TO #3 FIRST = 1.00
!END

!ELEMENT = '40FSRPART'  * 8,3
!CONSTRUCTION = 4
!AREA = 58.9
!TILT = 0.0
!SPACE TO FIRST = 8
!SPACE TO LAST = 3
!ABSORPTION FIRST = 0.5
!ABSORPTION LAST = 0.5
!END

!ELEMENT = '40FSLPART'  * 3,7
!CONSTRUCTION = 4
!AREA = 58.9
!TILT = 0.0
!SPACE TO FIRST = 3
!SPACE TO LAST = 7
!ABSORPTION FIRST = 0.5
!ABSORPTION LAST = 0.5
!END

!ELEMENT = '40FWWALL'
!CONSTRUCTION = 1
!AREA = 27
!ORIENTATION = 90.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 4
!ABSORPTION FIRST = 0.6
!ABSORPTION LAST = 0.5
!SHADING = 'NONE'
!END

!ELEMENT = '40FWWIND'
!CONSTRUCTION = 2
!AREA = 18
!ORIENTATION = 90.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 4
!SHADING = 'NONE'
!WINDOW TYPE = 'REFL6'
!PATCH TO #3 FIRST = 1.00
!END

!ELEMENT = '40FWWRPART'
!CONSTRUCTION = 4
!AREA = 58.9
!TILT = 0.0
!SPACE TO FIRST = 7
!SPACE TO LAST = 4
!ABSORPTION FIRST = 0.5
!ABSORPTION LAST = 0.5
!END

!ELEMENT = '40FWLRPART'
!CONSTRUCTION = 4
!AREA = 58.9
!TILT = 0.0
!SPACE TO FIRST = 4
!SPACE TO LAST = 6
!ABSORPTION FIRST = 0.5
!ABSORPTION LAST = 0.5
!END

!ELEMENT = '40FNEWALL'
!CONSTRUCTION = 1
!AREA = 27
!ORIENTATION = 225.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 5
!ABSORPTION FIRST = 0.6
!ABSORPTION LAST = 0.5
!SHADING = 'NONE'
!END

!ELEMENT = '40FNEWIND'
!CONSTRUCTION = 2
!AREA = 18
!ORIENTATION = 225.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 5
!SHADING = 'NONE'
!WINDOW TYPE = 'REFL6'
!PATCH TO #3 FIRST = 1.00
!END

!ELEMENT = '40FNWWALL'
!CONSTRUCTION = 1
!AREA = 27
!ORIENTATION = 135.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 6
!ABSORPTION FIRST = 0.6
!ABSORPTION LAST = 0.5
!SHADING = 'NONE'
!END

!ELEMENT = '40FNWWIND'
!CONSTRUCTION = 2
!AREA = 18
!ORIENTATION = 135.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 6
!SHADING = 'NONE'
!WINDOW TYPE = 'REFL6'
!PATCH TO #3 FIRST = 1.00
!END

!ELEMENT = '40FSWWALL'
!CONSTRUCTION = 1
!AREA = 27
!ORIENTATION = 45.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 7
!ABSORPTION FIRST = 0.6
!ABSORPTION LAST = 0.5
!SHADING = 'NONE'
!END

!ELEMENT = '40FSWWIND'
!CONSTRUCTION = 2
!AREA = 18
!ORIENTATION = 45.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 7
!SHADING = 'NONE'
!WINDOW TYPE = 'REFL6'
!PATCH TO #3 FIRST = 1.00
!END

!ELEMENT = '40FSIEWALL'
!CONSTRUCTION = 1
!AREA = 27
!ORIENTATION = 315.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 8
!ABSORPTION FIRST = 0.6
!ABSORPTION LAST = 0.5
!SHADING = 'NONE'
!END

!ELEMENT = '40FSIEWIND'
!CONSTRUCTION = 2
!AREA = 18
!ORIENTATION = 315.0
!TILT = 0.0
!SPACE TO FIRST = 0
!SPACE TO LAST = 8
!SHADING = 'NONE'
!WINDOW TYPE = 'REFL6'
!PATCH TO #3 FIRST = 1.00
!END
## Appendix A-5 Standard material file

<table>
<thead>
<tr>
<th>Code</th>
<th>Material Description</th>
<th>Conductivity (W/m°C)</th>
<th>Density (Kg/m³)</th>
<th>Spec. Heat (J/Kg°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>'BRICK (OUTER LEAF)'</td>
<td>0.84</td>
<td>2000.0</td>
<td>680.0</td>
</tr>
<tr>
<td>2</td>
<td>'BRICK (INNER LEAF)'</td>
<td>0.62</td>
<td>1800.0</td>
<td>840.0</td>
</tr>
<tr>
<td>3</td>
<td>'BREEZE BLOCK'</td>
<td>0.44</td>
<td>1500.0</td>
<td>650.0</td>
</tr>
<tr>
<td>4</td>
<td>'VERMICULITE INSULATING BLOCK'</td>
<td>0.27</td>
<td>700.0</td>
<td>837.0</td>
</tr>
<tr>
<td>5</td>
<td>'ASBESTOS CEMENT'</td>
<td>0.50</td>
<td>1500.0</td>
<td>1000.0</td>
</tr>
<tr>
<td>6</td>
<td>'ASBESTOS CEMENT SHEET'</td>
<td>0.36</td>
<td>700.0</td>
<td>1050.0</td>
</tr>
<tr>
<td>7</td>
<td>'BITUMEN FELT'</td>
<td>0.50</td>
<td>1700.0</td>
<td>1000.0</td>
</tr>
<tr>
<td>8</td>
<td>'ROOFING FELT'</td>
<td>0.19</td>
<td>960.0</td>
<td>837.0</td>
</tr>
<tr>
<td>9</td>
<td>'MASTIC ROOFING'</td>
<td>1.15</td>
<td>2325.0</td>
<td>1946.0</td>
</tr>
<tr>
<td>10</td>
<td>'CONCRETE (HEAVY MIX)'</td>
<td>1.40</td>
<td>2100.0</td>
<td>653.0</td>
</tr>
<tr>
<td>11</td>
<td>'CONCRETE (LIGHT MIX)'</td>
<td>0.38</td>
<td>1200.0</td>
<td>653.0</td>
</tr>
<tr>
<td>12</td>
<td>'AERATED CONCRETE'</td>
<td>0.16</td>
<td>500.0</td>
<td>840.0</td>
</tr>
<tr>
<td>13</td>
<td>'AERATED CONCRETE BLOCK'</td>
<td>0.24</td>
<td>750.0</td>
<td>1000.0</td>
</tr>
<tr>
<td>14</td>
<td>'REFACTORY INSULATING CONCRETE'</td>
<td>0.25</td>
<td>10.0</td>
<td>837.0</td>
</tr>
<tr>
<td>15</td>
<td>'VERMICULITE AGGREGATE CONCRETE'</td>
<td>0.17</td>
<td>450.0</td>
<td>837.0</td>
</tr>
<tr>
<td>16</td>
<td>'LIGHT CONCRETE SCREED'</td>
<td>0.41</td>
<td>1200.0</td>
<td>840.0</td>
</tr>
<tr>
<td>17</td>
<td>'CAST CONCRETE SCREED'</td>
<td>1.28</td>
<td>2100.0</td>
<td>1007.0</td>
</tr>
<tr>
<td>18</td>
<td>'GRANOLITHIC SCREED'</td>
<td>0.87</td>
<td>2085.0</td>
<td>837.0</td>
</tr>
<tr>
<td>19</td>
<td>'WHITE RENDER'</td>
<td>0.50</td>
<td>1300.0</td>
<td>1000.0</td>
</tr>
<tr>
<td>20</td>
<td>'CEMENT SCREED'</td>
<td>1.40</td>
<td>2100.0</td>
<td>650.0</td>
</tr>
<tr>
<td>21</td>
<td>'CLAY TILES'</td>
<td>0.85</td>
<td>1900.0</td>
<td>837.0</td>
</tr>
<tr>
<td>22</td>
<td>'CONCRETE TILES'</td>
<td>1.10</td>
<td>2100.0</td>
<td>837.0</td>
</tr>
<tr>
<td>23</td>
<td>'SLATE TILES'</td>
<td>2.00</td>
<td>2700.0</td>
<td>650.0</td>
</tr>
<tr>
<td>24</td>
<td>'PLASTIC TILES'</td>
<td>0.50</td>
<td>1050.0</td>
<td>837.0</td>
</tr>
<tr>
<td>25</td>
<td>'RUBBER TILES'</td>
<td>0.30</td>
<td>1600.0</td>
<td>2000.0</td>
</tr>
<tr>
<td>26</td>
<td>'CORK TILES'</td>
<td>0.08</td>
<td>530.0</td>
<td>1800.0</td>
</tr>
<tr>
<td>27</td>
<td>'ASPHALT/ASBESTOS TILES'</td>
<td>0.55</td>
<td>1900.0</td>
<td>837.0</td>
</tr>
<tr>
<td>28</td>
<td>'P.V.C./ASBESTOS TILES'</td>
<td>0.85</td>
<td>2000.0</td>
<td>837.0</td>
</tr>
<tr>
<td>29</td>
<td>'CEILING TILES MINERAL'</td>
<td>0.03</td>
<td>290.0</td>
<td>2000.0</td>
</tr>
<tr>
<td>30</td>
<td>'CEILING TILES PLASTER'</td>
<td>0.38</td>
<td>1120.0</td>
<td>840.0</td>
</tr>
<tr>
<td>31</td>
<td>'SANDSTONE'</td>
<td>1.83</td>
<td>2200.0</td>
<td>712.0</td>
</tr>
<tr>
<td>32</td>
<td>'GRANITE '</td>
<td>2.90</td>
<td>2650.0</td>
<td>900.0</td>
</tr>
<tr>
<td>33</td>
<td>'MARBLE'</td>
<td>2.00</td>
<td>2500.0</td>
<td>880.0</td>
</tr>
<tr>
<td>34</td>
<td>'PLASTER DENSE'</td>
<td>0.50</td>
<td>1300.0</td>
<td>1000.0</td>
</tr>
<tr>
<td>35</td>
<td>'PLASTER LIGHT'</td>
<td>0.16</td>
<td>600.0</td>
<td>1000.0</td>
</tr>
<tr>
<td>36</td>
<td>'GYPSUM PLASTERBOARD'</td>
<td>0.19</td>
<td>950.0</td>
<td>840.0</td>
</tr>
<tr>
<td>Material</td>
<td>Density</td>
<td>Thickness</td>
<td>Weight</td>
<td></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>---------</td>
<td>-----------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>Perlite Plasterboard</td>
<td>0.180</td>
<td>800.0</td>
<td>837.0</td>
<td></td>
</tr>
<tr>
<td>Gypsum Plastering</td>
<td>0.420</td>
<td>1200.0</td>
<td>837.0</td>
<td></td>
</tr>
<tr>
<td>Perlite Plastering</td>
<td>0.080</td>
<td>400.0</td>
<td>837.0</td>
<td></td>
</tr>
<tr>
<td>Vermiculite Plastering</td>
<td>0.200</td>
<td>720.0</td>
<td>837.0</td>
<td></td>
</tr>
<tr>
<td>Wood Block</td>
<td>0.160</td>
<td>800.0</td>
<td>2093.0</td>
<td></td>
</tr>
<tr>
<td>Medium Hardboard</td>
<td>0.080</td>
<td>600.0</td>
<td>2000.0</td>
<td></td>
</tr>
<tr>
<td>Standard Hardboard</td>
<td>0.130</td>
<td>900.0</td>
<td>2000.0</td>
<td></td>
</tr>
<tr>
<td>Fir (20% moist)</td>
<td>0.140</td>
<td>419.0</td>
<td>2720.0</td>
<td></td>
</tr>
<tr>
<td>Flooring Board</td>
<td>0.140</td>
<td>600.0</td>
<td>1210.0</td>
<td></td>
</tr>
<tr>
<td>Cork Board</td>
<td>0.040</td>
<td>160.0</td>
<td>1888.0</td>
<td></td>
</tr>
<tr>
<td>Chipboard</td>
<td>0.150</td>
<td>800.0</td>
<td>2093.0</td>
<td></td>
</tr>
<tr>
<td>Weatherboard</td>
<td>0.140</td>
<td>650.0</td>
<td>2000.0</td>
<td></td>
</tr>
<tr>
<td>Oak (radial)</td>
<td>0.190</td>
<td>700.0</td>
<td>2390.0</td>
<td></td>
</tr>
<tr>
<td>Plywood</td>
<td>0.150</td>
<td>560.0</td>
<td>2500.0</td>
<td></td>
</tr>
<tr>
<td>Wilton Carpet</td>
<td>0.060</td>
<td>186.0</td>
<td>1360.0</td>
<td></td>
</tr>
<tr>
<td>Synthetic Carpet</td>
<td>0.060</td>
<td>160.0</td>
<td>2500.0</td>
<td></td>
</tr>
<tr>
<td>Wool Felt Underlay</td>
<td>0.040</td>
<td>160.0</td>
<td>1360.0</td>
<td></td>
</tr>
<tr>
<td>Rubber Underlay</td>
<td>0.100</td>
<td>400.0</td>
<td>1360.0</td>
<td></td>
</tr>
<tr>
<td>Urea Formaldehyde Foam</td>
<td>0.030</td>
<td>30.0</td>
<td>1674.0</td>
<td></td>
</tr>
<tr>
<td>Fibreboard</td>
<td>0.060</td>
<td>300.0</td>
<td>1000.0</td>
<td></td>
</tr>
<tr>
<td>Woodwool</td>
<td>0.100</td>
<td>500.0</td>
<td>1000.0</td>
<td></td>
</tr>
<tr>
<td>Glasswool</td>
<td>0.040</td>
<td>250.0</td>
<td>840.0</td>
<td></td>
</tr>
<tr>
<td>Thermalite</td>
<td>0.030</td>
<td>753.0</td>
<td>837.0</td>
<td></td>
</tr>
<tr>
<td>Polyurethane Foam Board</td>
<td>0.030</td>
<td>30.0</td>
<td>837.0</td>
<td></td>
</tr>
<tr>
<td>Siporex</td>
<td>0.120</td>
<td>550.0</td>
<td>1004.0</td>
<td></td>
</tr>
<tr>
<td>PVC</td>
<td>0.160</td>
<td>1379.0</td>
<td>1004.0</td>
<td></td>
</tr>
<tr>
<td>Polystyrene</td>
<td>0.030</td>
<td>25.0</td>
<td>1380.0</td>
<td></td>
</tr>
<tr>
<td>C &amp; CA Polystyrene</td>
<td>0.040</td>
<td>13.6</td>
<td>1380.0</td>
<td></td>
</tr>
<tr>
<td>Window Glass</td>
<td>1.050</td>
<td>2500.0</td>
<td>750.0</td>
<td></td>
</tr>
<tr>
<td>Earth</td>
<td>1.280</td>
<td>1460.0</td>
<td>879.0</td>
<td></td>
</tr>
</tbody>
</table>
Appendix A-6 Services file

* services definition file for Model HK hotel Building

!SERVICEID Model HK hotel Building

!HEATING FILE = 'MODBLD.HTR'
!LIGHTING FILE = 'MODBLD.LGT'
!SMALL POWER FILE = 'MODBLD.SPW'
!OCCUPANCY FILE = 'MODBLD.OCC'
!VENTILATION FILE = 'MODBLD.VNT'

*define output zones
!GROUP ZONE = 'MB40'
   _# 1
   _# 2
   _# 3
   _# 4
   _# 5
   _# 6
   _# 7
   _# 8
}
Appendix A-7 Heating file

* Ideal single space hotel heating system, fully convective,
* heat to 19 oC, cool to 22 oC, control by floor, switched by
* diary.

!HEATSYS 'Ideal heating system #1'
!STAT TYPE IDEAL       * force to maintain air temp.
!POWER OUTPUT = -1     * assumed htg cap.; (unltd. cooling)
!CONVECTIVE CONNECTIONS
  _#1   = 1.0           * convective to space 1
{ }

!SETPOINT HEAT = 22.0
!SETPOINT COOL = 24.5
!SETPOINT RH = 50.0
!STAT AIR CONNECTIONS
  _#1 = 1.0             * stat monitoring space 1
\}
!END

!HEATSYS 'Ideal heating system #2'
!STAT TYPE IDEAL       * force to maintain air temp.
!POWER OUTPUT = -1     * assumed htg cap.; (unltd. cooling)
!CONVECTIVE CONNECTIONS
  _#2   = 1.0           * convective to space 2
{ }

!SETPOINT HEAT = 22.0
!SETPOINT COOL = 24.5
!SETPOINT RH = 50.0
!STAT AIR CONNECTIONS
  _#2 = 1.0             * stat monitoring space 2
\}
!END

!HEATSYS 'Ideal heating system #3'
!STAT TYPE IDEAL       * force to maintain air temp.
!POWER OUTPUT = -1     * assumed htg cap.; (unltd. cooling)
!CONVECTIVE CONNECTIONS
  _#3   = 1.0           * convective to space 3
{ }


!SETPOINT HEAT = 22.0
!SETPOINT COOL = 24.5
!SETPOINT RH = 50.0
!STAT AIR CONNECTIONS
   _#3 = 1.0                  * stat monitoring space 3
/
!END

!HEATSYS 'Ideal heating system #4'
!STAT TYPE IDEAL             * force to maintain air temp.
!POWER OUTPUT = -1           * assumed htg cap.; (unltd. cooling)
!CONVECITIVE CONNECTIONS
   _#4 = 1.0                  * convective to space 4
}

!SETPOINT HEAT = 22.0
!SETPOINT COOL = 24.5
!SETPOINT RH = 50.0
!STAT AIR CONNECTIONS
   _#5 = 1.0                  * stat monitoring space 4
/
!END

!HEATSYS 'Ideal heating system #5'
!STAT TYPE IDEAL             * force to maintain air temp.
!POWER OUTPUT = -1           * assumed htg cap.; (unltd. cooling)
!CONVECITIVE CONNECTIONS
   _#5 = 1.0                  * convective to space 5
}

!SETPOINT HEAT = 22.0
!SETPOINT COOL = 24.5
!SETPOINT RH = 50.0
!STAT AIR CONNECTIONS
   _#6 = 1.0                  * stat monitoring space 5
/
!END

!HEATSYS 'Ideal heating system #6'
!STAT TYPE IDEAL             * force to maintain air temp.
!POWER OUTPUT = -1           * assumed htg cap.; (unltd. cooling)
!CONVECITIVE CONNECTIONS
   _#6 = 1.0                  * convective to space 6
}
!SETPOINT HEAT = 22.0
!SETPOINT COOL = 24.5
!SETPOINT RH = 50.0
!STAT AIR CONNECTIONS
  _#6 = 1.0  * stat monitoring space 6
\)
!END

!HEATSYS 'Ideal heating system #7'
!STAT TYPE IDEAL  * force to maintain air temp.
!POWER OUTPUT = -1  * assumed htg cap.; (unltd. cooling)
!CONVECTIVE CONNECTIONS
  _#7 = 1.0  * convective to space 7
}

!SETPOINT HEAT = 22.0
!SETPOINT COOL = 24.5
!SETPOINT RH = 50.0
!STAT AIR CONNECTIONS
  _#8 = 1.0  * stat monitoring space 8
\)
!END

!HEATSYS 'Ideal heating system #8'
!STAT TYPE IDEAL  * force to maintain air temp.
!POWER OUTPUT = -1  * assumed htg cap.; (unltd. cooling)
!CONVECTIVE CONNECTIONS
  _#8 = 1.0  * convective to space 8
}
Appendix A-8 Lighting file

* Model HK hotel Building lighting

!LIGHTSYS 'perimeter'
!HEAT OUTPUT = 1750  * 17.5 w/m2 for 100 m2
!SPLIT =  0.4 , 0.6  * standard fluorescent

!CONVECTIVE CONNECTIONS

  _#1 = 1.0          * to space 1
  _#2 = 1.0          * to space 2
  _#3 = 1.0          * to space 3
  _#4 = 1.0          * to space 4
  _#6 = 1.0          * to space 6
  _#7 = 1.0          * to space 7
  _#8 = 1.0          * to space 8

}

!RADIANT CONNECTIONS

  _#1 = 1.0          * to space 1
  _#2 = 1.0          * to space 2
  _#3 = 1.0          * to space 3
  _#4 = 1.0          * to space 4
  _#6 = 1.0          * to space 6
  _#7 = 1.0          * to space 7
  _#8 = 1.0          * to space 8

}

!END
Appendix A-9 Small power file

* Model HK hotel Building
* Internal heat gains, fully convective; only one source,
* spread equally to all floors
* On/off controlled in diary

!SMALL POWER 'Model hotel'
!HEAT OUTPUT = 12000 *15w/m2 for 800 m2
!INITIAL FRACTION = 1.0 * assume full output when on.

!CONVECTIVE CONNECTIONS

    #1          = 0.125 * to space 1
    #2          = 0.125 * to space 2
    #3          = 0.125 * to space 3
    #4          = 0.125 * to space 4
    #5          = 0.125 * to space 5
    #6          = 0.125 * to space 6
    #7          = 0.125 * to space 7
    #8          = 0.125 * to space 8
}
!END
Appendix A-10 Occupant file

* Model HK hotel Building occupancy conditions

!OCCUPANCY SPACE = 1
!ACTIVITY LEVEL #1 = 50.0  0.01
!ACTIVITY LEVEL #2 = 70.0  0.01
!END

!OCCUPANCY SPACE = 2
!ACTIVITY LEVEL #1 = 50.0  0.01
!ACTIVITY LEVEL #2 = 70.0  0.01
!END

!OCCUPANCY SPACE = 3
!ACTIVITY LEVEL #1 = 50.0  0.01
!ACTIVITY LEVEL #2 = 70.0  0.01
!END

!OCCUPANCY SPACE = 4
!ACTIVITY LEVEL #1 = 50.0  0.01
!ACTIVITY LEVEL #2 = 70.0  0.01
!END

!OCCUPANCY SPACE = 5
!ACTIVITY LEVEL #1 = 50.0  0.01
!ACTIVITY LEVEL #2 = 70.0  0.01
!END

!OCCUPANCY SPACE = 6
!ACTIVITY LEVEL #1 = 50.0  0.01
!ACTIVITY LEVEL #2 = 70.0  0.01
!END

!OCCUPANCY SPACE = 7
!ACTIVITY LEVEL #1 = 50.0  0.01
!ACTIVITY LEVEL #2 = 70.0  0.01
!END

!OCCUPANCY SPACE = 8
!ACTIVITY LEVEL #1 = 50.0  0.01
!ACTIVITY LEVEL #2 = 70.0  0.01
!END
Appendix A-11 Ventilation file

1
**********
1           * simple acr in spaces
0.1, 1.5, 1.5 * in space 1
50.0        * <- Inf. @ .1 ach & .2 during oce

---------
2
0.1, 1.5, 1.5 * in space 2
50.0

---------
3
0.1, 1.5, 1.5 * in space 3
50.0

---------
4
0.1, 1.5, 1.5 * in space 4
50.0

---------
5
0.1, 1.5, 1.5 * in space 5
50.0

---------
6
0.1, 1.5, 1.5 * in space 6
50.0

---------
7
0.1, 1.5, 1.5 * in space 7
50.0

---------
8
0.1, 1.5, 1.5 * in space 8
50.0

---------
0

* end
Appendix A-12 Diary file

* Model HK hotel Building Saturday Diary
* Heating, cooling & ventilation

00:00:00   !SET LIGHTING STATUS #1 = MANUAL ON
00:00:00   !SET LIGHTING OUTPUT MANUAL #1 = 0.20
00:00:00   !SET SPOWER STATUS #1 = ON
00:00:00   !SET SPOWER OUTPUT #1 = 0.3
00:00:00   !SET OCCUPANCY USAGE #1 = 1
00:00:00   !SET OCCUPANCY USAGE #2 = 1
00:00:00   !SET OCCUPANCY USAGE #3 = 1
00:00:00   !SET OCCUPANCY USAGE #4 = 1
00:00:00   !SET OCCUPANCY USAGE #5 = 1
00:00:00   !SET OCCUPANCY USAGE #6 = 1
00:00:00   !SET OCCUPANCY USAGE #7 = 1
00:00:00   !SET OCCUPANCY USAGE #8 = 1
00:00:00   !SET OCCUPANCY LEVEL #1 = 5
00:00:00   !SET OCCUPANCY LEVEL #2 = 5
00:00:00   !SET OCCUPANCY LEVEL #3 = 5
00:00:00   !SET OCCUPANCY LEVEL #4 = 5
00:00:00   !SET OCCUPANCY LEVEL #5 = 5
00:00:00   !SET OCCUPANCY LEVEL #6 = 5
00:00:00   !SET OCCUPANCY LEVEL #7 = 5
00:00:00   !SET OCCUPANCY LEVEL #8 = 5
00:00:00   !SET VENT STATUS #1 = ON
00:00:00   !SET VENT STATUS #2 = ON
00:00:00   !SET VENT STATUS #3 = ON
00:00:00   !SET VENT STATUS #4 = ON
00:00:00   !SET VENT STATUS #5 = ON
00:00:00   !SET VENT STATUS #6 = ON
00:00:00   !SET VENT STATUS #7 = ON
00:00:00   !SET VENT STATUS #8 = ON
00:00:00   !SET HEATER STATUS #1 = ON
00:00:00   !SET HEATER STATUS #2 = ON
00:00:00   !SET HEATER STATUS #3 = ON
00:00:00   !SET HEATER STATUS #4 = ON
00:00:00   !SET HEATER STATUS #5 = ON
00:00:00   !SET HEATER STATUS #6 = ON
00:00:00   !SET HEATER STATUS #7 = ON
00:00:00   !SET HEATER STATUS #8 = ON

* at 8:00 am
08:00:00   !SET LIGHTING OUTPUT MANUAL #1 = 0.35
08:00:00   !SET SPOWER OUTPUT #1 = 0.35
08:00:00   !SET OCCUPANCY USAGE #1 = 2
08:00:00  !SET OCCUPANCY USAGE  #2 = 2
08:00:00  !SET OCCUPANCY USAGE  #3 = 2
08:00:00  !SET OCCUPANCY USAGE  #4 = 2
08:00:00  !SET OCCUPANCY USAGE  #5 = 2
08:00:00  !SET OCCUPANCY USAGE  #6 = 2
08:00:00  !SET OCCUPANCY USAGE  #7 = 2
08:00:00  !SET OCCUPANCY USAGE  #8 = 2
08:00:00  !SET OCCUPANCY LEVEL  #1 = 1
08:00:00  !SET OCCUPANCY LEVEL  #2 = 1
08:00:00  !SET OCCUPANCY LEVEL  #3 = 1
08:00:00  !SET OCCUPANCY LEVEL  #4 = 1
08:00:00  !SET OCCUPANCY LEVEL  #5 = 1
08:00:00  !SET OCCUPANCY LEVEL  #6 = 1
08:00:00  !SET OCCUPANCY LEVEL  #7 = 1
08:00:00  !SET OCCUPANCY LEVEL  #8 = 1

* at 8:00 pm
20:00:00  !SET LIGHTING OUTPUT MANUAL #1 = 0.9
20:00:00  !SET SPOWER OUTPUT #1 = 0.6
20:00:00  !SET OCCUPANCY USAGE  #1 = 2
20:00:00  !SET OCCUPANCY USAGE  #2 = 2
20:00:00  !SET OCCUPANCY USAGE  #3 = 2
20:00:00  !SET OCCUPANCY USAGE  #4 = 2
20:00:00  !SET OCCUPANCY USAGE  #5 = 2
20:00:00  !SET OCCUPANCY USAGE  #6 = 2
20:00:00  !SET OCCUPANCY USAGE  #7 = 2
20:00:00  !SET OCCUPANCY USAGE  #8 = 2
20:00:00  !SET OCCUPANCY LEVEL  #1 = 5
20:00:00  !SET OCCUPANCY LEVEL  #2 = 5
20:00:00  !SET OCCUPANCY LEVEL  #3 = 5
20:00:00  !SET OCCUPANCY LEVEL  #4 = 5
20:00:00  !SET OCCUPANCY LEVEL  #5 = 5
20:00:00  !SET OCCUPANCY LEVEL  #6 = 5
20:00:00  !SET OCCUPANCY LEVEL  #7 = 5
20:00:00  !SET OCCUPANCY LEVEL  #8 = 5
Appendix B The coefficients of transmission and absorption for different shading coefficient

* 6 mm reflective glass  (shading coefficient 0.25 approx)
!WINDOW  = 'REFL6'
!TRANSMISSION = 
  0.13, 0.13, 0.13, 0.13, 0.13, 0.14, 0.15, 0.16, 0.16, 0.0
!ABSORPTION = 
  0.09, 0.09, 0.09, 0.09, 0.09, 0.09, 0.08, 0.07, 0.03, 0.0
!END

* 6 mm reflective glass  (shading coefficient 0.45 approx)
!WINDOW  = 'REFL6'
!TRANSMISSION = 
  0.26, 0.26, 0.26, 0.26, 0.26, 0.26, 0.26, 0.26, 0.20, 0.10, 0.0
!ABSORPTION = 
  0.40, 0.40, 0.40, 0.40, 0.40, 0.40, 0.40, 0.30, 0.30, 0.0
!END

* 6 mm Reflective glass  (shading coefficient 0.50 approx)
!WINDOW  = 'REFL6'
!TRANSMISSION = 
  0.28, 0.28, 0.28, 0.28, 0.28, 0.28, 0.28, 0.25, 0.25, 0.15, 0.0
!ABSORPTION = 
  0.60, 0.60, 0.60, 0.60, 0.60, 0.60, 0.60, 0.55, 0.44, 0.30, 0.0
!END

* 6 mm reflective glass  (shading coefficient 0.75 approx)
!WINDOW  = 'REFL6'
!TRANSMISSION = 
  0.55, 0.55, 0.55, 0.55, 0.55, 0.53, 0.52, 0.50, 0.41, 0.30, 0.0
!ABSORPTION = 
  0.40, 0.40, 0.40, 0.40, 0.40, 0.40, 0.38, 0.35, 0.10, 0.0
!END

* 6 mm reflective glass  (shading coefficient 0.95 approx)
!WINDOW  = 'REFL6'
!TRANSMISSION = 
  0.78, 0.78, 0.79, 0.79, 0.79, 0.78, 0.76, 0.72, 0.60, 0.38, 0.0
!ABSORPTION = 
  0.15, 0.15, 0.15, 0.15, 0.14, 0.13, 0.13, 0.13, 0.05, 0.0
!END