

# Energy Savings with Energy-Efficient HVAC Systems in Commercial Buildings of Hong Kong

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**Abstract:** Hong Kong has seen a dramatic increase in energy consumption in recent years, particularly electricity use in commercial buildings. The growth of electricity demand in future years is crucial both economically and environmentally. As over half of the electricity in Hong Kong is consumed by commercial buildings, and heating, ventilation and air-conditioning (HVAC) is the largest end-user in such buildings, improving the efficiency of HVAC systems in commercial buildings, is the key measure to take in Hong Kong for sustainable development. In this study, the major factors influencing the electricity use of HVAC systems are studied with the building energy simulation program EnergyPlus, which include chiller efficiency, space cooling temperature, variable vs. constant air flow, fan efficiency, lighting intensity and building envelope. From the analysis of the simulation results, it can be found that substantial energy-saving potential exists through improving the efficiency of HVAC systems in commercial buildings, and a combination of desirable system parameters for energy efficiency of commercial building is proposed.

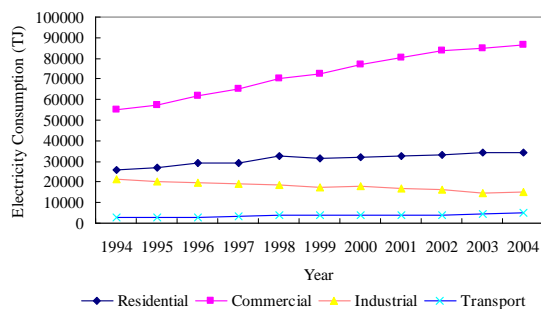
**Key words:** energy saving; HVAC Systems; commercial buildings

## 1. INTRODUCTION

Hong Kong SAR is an international financial trading and service centre in the world. Its economy has risen rapidly for the last two decades. Along with the population and economic growth, and the associated expansion of the building stock, Hong Kong has seen a dramatic increase in energy consumption in recent years, particularly electricity use in commercial and residential buildings. Fig.1 shows the electricity consumption in the commercial, residential, industrial and transport sectors from 1994 to 2004 in Hong Kong<sup>[1]</sup>. It can be seen that the electricity use in commercial and residential buildings rose fast in the last decade, especially in the commercial buildings. In the commercial sector, electricity use rose from 54789 terajoule in 1994 to 86670 terajoule in 2004, an increase of 58.2%. This corresponds to an average rate of increase of 5.8% per year. In 2004, electricity use in commercial buildings accounted for 61.4% of the total electricity consumption in Hong Kong.

The growth of the electricity demand in future years is crucial both economically and environmentally. In response to the growing concerns about energy consumption and its implications for the environment, there some measures need taken. As over half of the electricity in Hong Kong is consumed

by the commercial buildings, and HVAC is the largest end-user in such buildings, accounting for 40–60% of the total building electrical demand in commercial buildings, improving the efficiency of using electricity in commercial buildings, especially the portion that is used for HVAC, is a key measure to take in Hong Kong for environmental protection and sustainable development.



**Fig.1 Electricity consumption in the commercial, residential, industrial and transport sectors from 1994 to 2004 in Hong Kong**

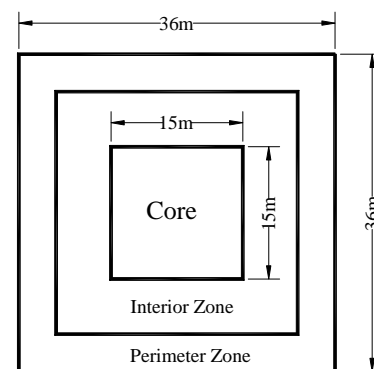
With the aim to explore and examine the energy-related design factors and to identify important parameters influencing commercial building energy consumption in Hong Kong, the commercial building model is set up and alternative design options for building envelope construction and energy-related system in commercial buildings will be studied with the aid of building energy simulation programme.

## 2. REFERENCE COMMERCIAL BUILDING

Majority of commercial buildings in Hong Kong are high rise. Two types of common constructions are found in Hong Kong, the old design is with concrete frame and load-bearing external wall, and the latest one is with steel or concrete frame plus non load-bearing external wall. While concrete wall structures with ceramic tile finish or stucco finish are typical for older buildings, curtain walls are common for commercial buildings since late 1970s. These buildings vary in the types of fenestration, window-to-wall ratio, materials of opaque wall, with or without insulation, and light or heavy weight construction<sup>[2]</sup>.

According to a survey of 64 commercial

buildings in Hong Kong (Chan 1996), the construction characteristics of high-rise commercial buildings in Hong Kong were identified and a reference building was developed as the basis for simulation<sup>[3]</sup>. The reference building is 40-storey high with building parameters representing the average of those that could be expected among the new buildings and the existing ones in Hong Kong, which is a squared office building (36 m by 36 m) with curtain-wall construction and a centralized HVAC system. Fig.2 shows the plan of the model building, which has a 3.2 m floor-to-floor height and a window height of 1.6 m. This represents a window-to-wall ratio (WWR) of 50%. It is taken to be the reference for comparison of the thermal performance of the building envelope designs, energy requirement of air conditioning systems and parametric analysis.



**Fig.2 Layout of the reference commercial building**

Energy required for cooling system in commercial buildings in a sub-tropical climate, as in Hong Kong, is substantial. The HVAC system for the reference building is generally operated in daytime only. The working hours are usually long because it is common to work overtime in Hong Kong. The cooling system of the reference building is scheduled to operate from 8:00a.m to 7:00p.m on weekdays, and from 8:00a.m. to 1:00p.m. on Saturdays, but it is not operated on Sunday.

The occupancy density of the reference building is 7 m<sup>2</sup> per person, which is generally adopted in the design of new local office buildings. The installed light intensity is taken to be 20 W/m<sup>2</sup> that conforms to the local design practice. Amount of heat rejection from office equipment has substantial changes over recent years due to office automation by use of

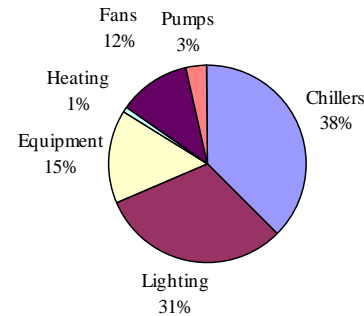
electronic machines. Taking into account the increasing use of electronic equipment in office, the ASHRAE recommendation and the results of local field survey, the equipment heat intensity is taken to be  $12 \text{ W/m}^2$  in the reference building.

### 3. BUILDING ENERGY SIMULATION

The building energy simulation programme used in this project is EnergyPlus, which is a new-generation building energy simulation program<sup>[4]</sup>. On the basis of the characteristics described above, the yearly cooling load of the commercial building has been predicted based on the hourly weather conditions in Hong Kong for year 1989, which was identified to be a representative weather year. To compare the energy effectiveness of these parameters, the reference building described as above is used as a base case. In this base case, cooling temperature is set at  $24^\circ\text{C}$ , and the lighting power density is  $20 \text{ W/m}^2$ . Efficiency of supply fan and return system is 0.52 and 0.45, respectively. VAV system is used. Fig.3 shows the portion of annual electricity consumption for reference commercial building. Chillers consume about 40% of the total annual electricity expenditure, indicating the overwhelming importance of air-conditioning in the subtropics. Together with the HVAC auxiliary (i.e. fans and pumps), air-conditioning accounts for over 50% of the total annual electricity use. Since the local winters are short and mild, energy demand for space heating is not significant. So the major factors influencing the electricity consumption of air-conditioning systems would have a great influence on the total electricity consumption by commercial buildings. These factors include chiller efficiency, space cooling temperature, variable vs. constant air flow, fan efficiency and lighting intensity, and the impacts of these factors are studied in this project.

To investigate the total electricity consumption of the reference buildings, minimum requirements stipulated in the code of practice for energy efficiency, specific design parameters for air-conditioning installations and minimum coefficient of performance for chillers are studied in the simulations. Codes of practice to set out energy efficiency requirements for

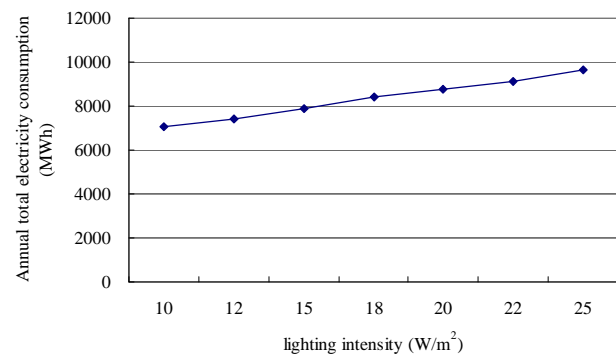
power distribution and utilization in buildings, minimum allowable luminous efficacy for lamp and maximum lighting power density of a particular space are studied. Two types of supply air systems are simulated. They are constant air volume (CAV) system and variable air volume (VAV) system.



**Fig.3 Portion of annual electricity consumption for reference commercial building**

#### 3.1 Lighting Intensity

When taking into account the internal loads, equipment and occupancy are usually beyond the control of the architects and engineers. Therefore, only the electric lighting load is considered in the section of internal load, and the annual electricity consumption for different lighting intensity is shown in Fig.4.



**Fig.4 Annual total electricity consumption against lighting intensity**

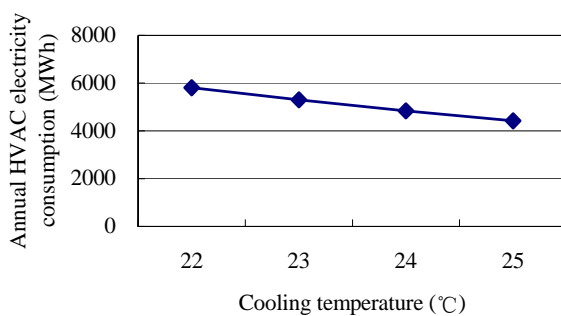
For macroscopic control of lighting energy efficiency stipulated in the Code of Practice for Lighting Installations<sup>[5]</sup>, the maximum allowable lighting power density for office is  $25 \text{ W/m}^2$  which might occur if low efficacy lighting is used. The corresponding normalized annual electricity consumption is  $224.6 \text{ kWh/m}^2$ , which is 9.8% more than the base case. With high efficacy lighting, low lighting power density of  $15 \text{ W/m}^2$  can readily be attained and the normalized electricity consumption

is 184.4 kWh/m<sup>2</sup>, which is 9.8% less than the base case.

Many case-study designs have demonstrated the great energy-saving potential of better and more energy efficient lighting designs, and this should be an important design aspect to address in energy efficiency programmes for commercial buildings.

### 3.2 Space Cooling Temperature

One observation in local commercial buildings is that the air-conditioned space is often cold. This may be because of poor system control, or the temperature setpoint is too low. Fig.5 shows the annual HVAC electricity consumption at different space cooling temperature. If the control works properly and the space cooling temperature is set to acceptable comfort level of 25, the annual electricity consumption for HVAC only are 103.1 kWh/m<sup>2</sup>, which is 8.7% less than the base case. If the cooling temperature is set to 22, simulation result indicates 20% increase of the annual electricity consumption for HVAC than the base case. This indicates that space cooling setpoint temperature has a great influence on energy efficiency in commercial buildings.



**Fig.5 Annual HVAC electricity consumption against cooling temperature**

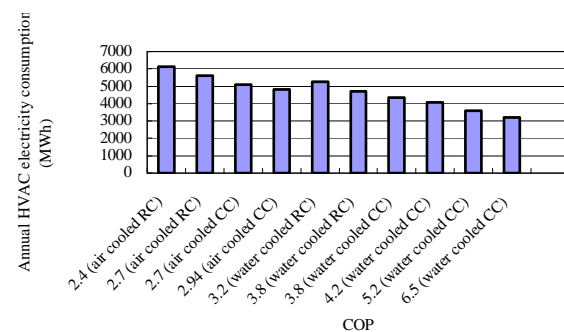
### 3.3 COP

It has been observed in Fig.3 that chillers account for about 40% of the electricity use in the air-conditioning system. The energy performance of chillers has great influence on the energy use, which is largely governed by the coefficient of performance (COP). The simulations based on different COP were carried out, and the results are shown in Fig.6. In

Figure 6, RC stands for reciprocating chiller, and CC stands for centrifugal chiller.

Air cooled reciprocating chiller and water cooled centrifugal chiller are popular for using in commercial buildings in Hong Kong. The simulation results of energy differences for chillers with different heat rejection methods and coefficient of performance are shown in Fig.6. In the base case, the type of chiller is air-cooled centrifugal, having COP of 2.94 at full load design condition. Minimum coefficient of performance of 2.7 is stipulated in the Code of Practice for Energy Efficiency of Air Conditioning Installations for air cooled reciprocating chiller<sup>[6]</sup>, which results in the electricity consumption for HVAC increase by 16.2% than the base case. For water cooled centrifugal chiller, coefficient of performance as high as 6.5 is achievable nowadays with product of latest technology. This will substantially reduce the cooling energy consumption. In this case, the annual total electricity consumption for HVAC is reduced to 74.7 kWh/m<sup>2</sup> with 33.9% reduction compared to the base case. Further improvement can be attained by heat rejection using water cooling tower with variable speed fan.

It appears that improving the energy efficiency of chillers could result in significant energy savings in the commercial sector.

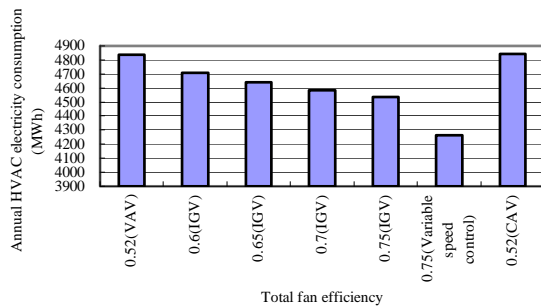


**Fig.6 Annual HVAC electricity consumption against COP**

### 3.4 Fan Efficiency

The operating efficiency of the fan is another concern. In the base case, the air system is VAV with supply fan efficiency of 0.52 and return fan efficiency of 0.45 at design condition of maximum air flow. Fig.7 shows the annual HVAC electricity consumption with different fan efficiency, and IGV

stands for inlet guide vane. An improved yet achievable fan efficiency is 0.75 at the design operating point, with variable speed control by frequency inverter for part load modulation. In this case, the normalized annual electricity consumption for HVAC is 99.5 kWh/m<sup>2</sup>, which is 11.9% less than the base case.



**Fig.7 Annual HVAC electricity consumption against fan efficiency**

From the simulation results as above, it could be found that there exists great energy-saving potential through improving the efficiency of air-conditioning systems in commercial buildings. A combination of desirable system parameters for energy efficiency of commercial building is designed as a VAV system, fan system efficiency of 0.75 at design flow, variable speed control, space temperature of 24 °C, lighting intensity of 15 W/m<sup>2</sup> and using water cooled centrifugal chillers with nominal coefficient of performance equal to 6.5. The annual electricity consumption of this energy efficient building is 5841.6 MWh (i.e., 136.4 kWh/m<sup>2</sup>), which is 33.3% less than the base case. If this efficient building is further enhanced with a desirable building envelope, with OTTV (Overall Thermal Transfer Value) of 20.56W/m<sup>2</sup>, annual electricity consumption will further drop 258.3MWh to 5583.4MWh (i.e., 130.4 kWh/m<sup>2</sup>). This is equivalent to 36.2% improvement comparing to the base case. On the other hand, an energy inefficient building has been identified with undesirable system parameters including a CAV system, fan system efficiency of 0.52, space temperature of 23 °C, lighting intensity of 25W/m<sup>2</sup> and using air cooled reciprocating chillers with nominal coefficient of performance of 2.7. In this case, the normalized annual electricity consumption for HVAC is 257.0 kWh/m<sup>2</sup>, which is 25.7% more than the base

case. In combination with unsatisfactory building envelope design, where OTTV is equal to 38.3W/m<sup>2</sup>, the simulated annual electricity consumption is as high as 269.9 kWh/m<sup>2</sup> which is 31.2% more than the base case. The simulation results also suggest that the combination of desirable system parameters for energy efficiency of commercial building is more energy-sensitive than the building envelope.

#### 4. CONCLUSION

Along with the population and economic growth, and the associated expansion of the building stock, Hong Kong has seen a dramatic increase in energy consumption in recent years, particularly electricity use in commercial buildings. Over half of the electricity in Hong Kong is consumed by the commercial buildings, and HVAC is the largest end-user in such buildings.

Lighting is a key design area to be addressed by the building professions. Through computer energy simulations, it has been estimated that lowering the lighting load from the current 25 W/m<sup>2</sup> for an office to 15 W/m<sup>2</sup>, the total building electricity consumption could be reduced by 9.8%.

Space cooling setpoint temperature has a great influence on energy efficiency in commercial buildings. If the space cooling temperature is set to acceptable comfort level of 25 °C, the annual electricity consumption for HVAC is 8.7% less than the base case.

It appears that improving the energy efficiency of chillers could result in significant energy savings in the commercial sector. For water cooled centrifugal chiller with COP as high as 6.5, the annual total electricity consumption for HVAC is reduced by 33.9% compared to the base case.

The operating efficiency of the fan is another concern. An improved yet achievable fan efficiency is 0.75 at the design operating point, with variable speed control by frequency inverter for part load modulation. In this case, the annual electricity consumption for HVAC is 11.9% less than the base case.

From the simulation results, it can be found that great energy-saving potential exists through improving the efficiency of using electricity in

commercial buildings, especially the portion that is used for HVAC. With the desirable systems, the annual total electricity consumption will be 33.3% less than the base case. If this efficient building is further enhanced with a desirable building envelope, with OTTV (Overall Thermal Transfer Value) of  $20.56\text{W/m}^2$ , there will be 36.2% improvement comparing to the base case. Because the combination of desirable HVAC system parameters for energy efficiency of commercial building is more energy-sensitive than the building envelope, more attention should be focused on the HVAC and lighting designs and the subsequent operation of the building services equipment .

#### ACKNOWLEDGEMENT

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