The Effect of Building Characteristics and Climatic Zone on Sensible and Total Cooling Demand in an Office Building

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Abstract

It is important to make a difference between sensible cooling load and the total cooling load when air-water air conditioning systems are designed. Air-water room air conditioning systems can be designed as sensible cooling or total cooling applications. In the sensible cooling room air conditioning applications the cooling demand is covered with room units. The latent load is compensated in air-handling unit by dehumidifying the supply air flow to required level to avoid condensation on the piping or heat transfer surfaces of the terminal unit in the room space. In this case study, IDA-ICE energy simulation program was used to calculate the required sensible and the total cooling capacities and energy consumption of air-water systems. In the analysis, different window sizes and room orientations were studied. The cooling analysis was carried out in different climate zones in Europe and Asia covering cold, temperate, sub-tropical and tropical conditions. This paper presents the actual sensible cooling demand of an office building with different window sizes. The maximum sensible cooling demand in the perimeter zone could be reduced to level of 120 W/m² in all climate zones. The required sensible cooling load is not much depending on the building location. However, the total cooling capacity and energy demand is much higher in hot and humid conditions than in temperate and cold climates.

Keywords – sensible load; latent load; air-water air conditioning system; chilled beam; office building; climate zone

1. Introduction

The energy consumption of a building depends on the qualities of building envelope and the energy efficiency of the selected HVAC- system. The properties of the windows are the most significant factor on cooling demand in modern offices, where energy efficient light fittings and laptop computers are enabled. [1,2]. With good solar shading, the cooling requirement can be significantly reduced. The reduction of cooling loads also
expands the variety of HVAC-systems, which can be used in buildings. Low
temperature heating and high temperature cooling air-water systems can be
more easily introduced in such buildings [3].

During the design phase, it is important to make a difference between
sensible cooling and total cooling loads, when air-water systems are
considered. In air-water room air conditioning systems, only sensible cooling
load is covered with room units. The latent load is compensated in air-
handling unit by dehumidifying the supply air flow to required level to avoid
condensation in the room space. Thus, the cooling capacity is much lower
than when using e.g. condensing fan-coil units, where the major part of
dehumidification occurs in the fan-coil unit.

In this paper, the required sensible and total cooling capacity and energy
consumption of a chilled beam system were analyzed. The analysis was
carried out in different climate zones in Europe and Asia covering cold,
temperate, sub-tropical and tropical conditions. The breakdowns of the
required sensible and latent cooling capacities are presented in typical design
conditions.

2. Analyzed office building case

In this case study the IDA-ICE energy simulation software was used to
calculate the required cooling capacity and the energy consumption of an
office room. The office room was simulated in six climatic regions: the
Asian locations were Singapore, Seoul and Tokyo and the European
locations were Helsinki, Paris and Rome. The simulated office room area
was 10.8 m² (4.0 x 2.7 x 3 m, L x W x H). The window width was in all
cases 2.5 m and four different heights of the window 1.2, 1.6, 2.0 and 2.8 m
were analyzed. The window sizes are presented in Fig. 1.

![Fig. 1 Analyzed window sizes.](image)
The window was a triple-pane window with the solar heat gain coefficient (SHGC) of 0.4. The overall heat transmission coefficient (U-value) of the window was 1.1 W/m\(^2\)K and the U-value of the external wall was 0.3 W/m\(^2\)K in all cases. The exterior wall was a concrete wall (heavy) and interior walls were plaster board structures (light). No heat transfer between interior walls was assumed. Infiltration rate was 0.15 l/h during the cooling season.

Two occupants were considered to be in the simulated office room during the occupancy period from 9.00 a.m. to 6.00 p.m. The lighting load of 10 W/floor-m\(^2\) and appliance load of 10 W/floor-m\(^2\) were switched on during the occupancy. Fans operate from 7.00 a.m. to 8.00 p.m. providing a constant outdoor airflow rate of 2 l/s,floor-m\(^2\). Room air temperature set point was 24 °C. The supply air temperature of the dedicated outdoor air system was 14 °C between April and August. During September - March, the supply air temperature was 19 °C (except in Singapore the supply air temperature was continuously 14 °C). The minor part of space cooling demand was covered by the enthalpy rate of the cooler supply air flow. The rest of the required sensible cooling capacity was compensated by the enthalpy flow of the chilled water flow in the cooling coil of the chilled beam.

3. The cooling demand

In Asian cities, the required sensible cooling capacities of the office rooms were between 80-140 W/floor-m\(^2\) (Fig. 2). In office rooms facing to the south and to the north, the sensible cooling capacities were at the level of 80 W/m\(^2\). Only when fully glazed exterior wall was introduced (window height of 2.8 m), the required cooling capacity was at the level of 100 W/floor-m\(^2\). In offices facing to the east and to the west, the maximum cooling capacity was 140 W/floor-m\(^2\) with the fully glazed facade. When the window height was 2.0 m and 1.6 m, the required cooling capacity was reduced to 120 W/floor-m\(^2\) and 100 W/floor-m\(^2\).

In European locations, the average cooling demands were higher than in Asian (Fig. 3). In Northern latitudes, the vertical incident angle of the solar radiation is bigger and thus the solar load is higher. The effect of the window height was more significant in European cities than in Asian metropolises. As a rule of thumb, it could be estimated that 40 cm higher full-width window increases the cooling capacity with 20 W per floor-m\(^2\). The maximum cooling power in south rooms varied between 125 to 165 W/floor-m\(^2\). By reducing the window height to 1.6 m, it is possible maintain the set room air temperature using the cooling power of 100-120 W/floor-m\(^2\). In to the east and west facing office rooms, the maximum cooling capacity was 180 W/floor-m\(^2\). When the window height was 1.6 m and 1.2 m, the required cooling capacity reduced to 130 W/m\(^2\) and 100 W/m\(^2\). In the north façade office room, the cooling capacity was 80-100 W/m\(^2\).
Fig. 2  Sensible cooling capacity in Asian cities using different window heights.
Fig. 3 Sensible cooling capacity in European cities using different window heights.
The required cooling capacity of the air handling unit, using the outdoor airflow rate of 2 l/s per floor m², the total cooling capacity (sensible and latent) varied 40–70 W/floor-m² in Europe and 80-90 W/floor-m² in Asia (Fig.4). Ration of the latent load was much higher in Asian cities (54-64 %) than in European cities (29-50 %).

Introducing a window of 1.6 m height in south façade office, the total of cooling capacity of the air handling unit and the chilled beam coil capacity were about the same 130-140 W/m² regardless of the location. (Fig.5). In west façade offices, the cooling capacities were 160-180 W/m². The coil capacity was the most significant portion in the cooling capacities of the office rooms. In Europe, the sensible cooling of the chilled beam coil was 60-75 % of the office room. In Asia, the coil capacity was 40-50 %, respectively.

![Fig. 4 Sensible and latent cooling capacities in air-handling unit with 2 l/s per m².](image)

<table>
<thead>
<tr>
<th>Ratio L/T</th>
<th>Singapore</th>
<th>Seoul</th>
<th>Tokyo</th>
<th>Helsinki</th>
<th>Paris</th>
<th>Rome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latent AHU</td>
<td>55.92</td>
<td>47.82</td>
<td>53.16</td>
<td>11.96</td>
<td>20.39</td>
<td>37.83</td>
</tr>
<tr>
<td>Sensible AHU</td>
<td>36.21</td>
<td>34.91</td>
<td>36.03</td>
<td>28.63</td>
<td>32.63</td>
<td>33.91</td>
</tr>
</tbody>
</table>
4. The required cooling energy consumption

The location had a significant effect on the cooling energy demand in air handling unit (AHU) (Fig.6). In the tropical Singapore, the cooling energy consumption of AHU was slightly more than 430 kWh/m². In Seoul, Tokyo and Rome, the cooling energy consumption of AHU was at the level of 100 kWh/m². Cooling energy demand of AHU was in Paris slightly above 40 kWh/m² and Helsinki only about 20 kWh/m².

In Asian cities, the latent energy was about 55-60 % of the cooling energy consumption in the air handling unit. In European cities, there was larger variation: the ration varied between 30 % (Helsinki) to 50 % (Rome).
Fig. 6  Sensible and latent cooling energy need of air handling unit with 2 l/s per m$^2$.

With 2 l/s per floor-m$^2$ outdoor airflow rate, the energy consumption of the air handling unit and the chilled beam coils was about 510 kWh/m$^2$ in south façade office room and 590 kWh/m$^2$ in west façade office room in Singapore (Fig.7). In Seoul, Tokyo and Rome, the cooling energy need was at the level of 150-180 kWh/m$^2$. The cooling energy consumption was 70-80 kWh/m$^2$ and 40-50 kWh/m$^2$ in Paris and Helsinki.

The latent load was about the half of the total energy consumption for cooling. The coil cooling energy consumption was of the total energy in south façade office 15 % and in west façade office 27 %. Coil cooling was about 45 % in Seoul, 40 % in Rome and 35 % in Tokyo. In Helsinki, the total cooling energy need was 40–50 kWh/m$^2$ in west and south façade offices. The ration of the coil cooling was 45-60 % of the whole cooling energy need.

With the COP of 3.0, the delivered electric energy consumption of chiller (AHU and water coil of chilled beam) was about 180 kWh/m$^2$ in Singapore, 50 kWh/m$^2$ in Seoul, Tokyo and Rome, 25 kWh/m$^2$ in Paris and 15 kWh/m$^2$ in Helsinki.

Fan energy consumption was 15 kWh/m$^2$ with the specific fan power (SFP) of 1.7 kW/m$^3$/s. Thus, fan energy consumption was significant compared with the electric consumption of chiller. On the contrary, the pumping energy of chilled beam system was small. Specific pumping energy consumption was only 0.3 kWh/m$^2$ in Helsinki and Paris and 2.0 kWh/m$^2$ in Rome, Seoul, Tokyo and Singapore.
Fig. 7. Cooling energy consumption of air handling units and water cooling of chilled beams southern and western offices with 1.6 m height of window and the airflow rate of 2 l/s per m².

5. Discussion and conclusions

When an air conditioning system is sized, it is important to calculate the actual cooling demand by using dynamic energy simulation program. If the effect of the thermal mass is not taken into account, the whole system is over-sized. In the cooling demand, window properties are playing a significant role. If there is no solar shading or window with good solar heat gain coefficient (SHGC), the required cooling capacity can easily be 1.4-1.6 times higher than with the state-of-the-art windows.

On the contrary of the local building codes in this study, the same U-values were used in simulations. However, it should be noted that heat
transfer through structures is not so significant because of quite minor temperature difference between room space and ambient temperatures.

When windows having SHGC of 0.4 is used, the required cooling capacity of the perimeter zone could be reduced to the level of 120 W/m² in Asian cities. In European and even Nordic conditions, the required maximum cooling capacity is higher than in Asian cities because of the lower solar angle. To reach the level of 120 W/m², the height of the full-width window should not be higher than 1.6 m.

It is interesting to notice that the total cooling capacity of air handling unit and room system is about the same level in all analyzed cities. In Asian and south European cities where the solar load is lower than in the northern region, the latent load is respectively higher. It is important to notice that the total heat load is the basis for chiller sizing and room system air conditioning system with dry cooling principle like chilled beam shall always be sized based the sensible load of the room space. On the contrary when sizing e.g. split- system or fan coil- room system, where the dehumidification partly or totally occurs in the room space, the also the latent load is taken into account.

In cooling energy need, the cooling of the chilled water for the room system is playing the most significant role. Only in Singapore and Tokyo, the energy need for dehumidification is higher than chilled water cooling for the room system. In Nordic climate, the room system chilled water cooling dominates and it may be more than half of the required total cooling energy consumption.

When the delivered cooling energy consumption is considered, the cooling energy need is divided by the coefficient of performance of the chiller system. Typically, COP of a chiller is between 3-4. Also, the fan and pump energy consumption shall be taken into account in the total energy consumption. In the total energy consumption, the fan energy is a significant to consider but in the contrary pumping energy is typical quite small.

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References