Sustainable Office Building: Should I Focus on HVAC-system Design or Building Envelope

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Summary

This paper presents energy simulation case study of an office building located in temperate climate taking into account the energy consumption of HVAC-system and lighting. Windows have good solar shading. Air handling unit is designed with specific fan power of 1.8 and total heat recovery efficiency of 60 %. Active chilled beams are used as terminal unit and there is demand-based ventilation in meeting rooms.

The annual energy consumption is 50 kWh/m^2. Lighting uses 31 kWh/m^2 of energy, which could be reduced to less than half with more efficient lights and controls. Second biggest energy user is fans (7.7 kWh/m^2). This is about 3 % less than in a similar building with constant airflows in all spaces. Cooling energy need is 3.4 kWh/m^2. Building needs 5.6 kWh/m^2 of energy to heat the primary air at desired temperature. It would be almost ten times more without heat recovery and with constant airflow rates. The annual space heating energy need is small (2 kWh/m^2 and less than 5 % of total energy use). Even with poorer envelope it would be less than 10 kWh/m^2. During occupied hours the internal heat loads are more than heat losses and building requires cooling.

Another important observation is related to room air temperature. Terminal units are designed to keep the room air temperature at 25 ^{O}C during summer. Room air temperature is under 25 ^{O}C only 900 h (office hours 8-18) and under 23 ^{O}C less than 50 h. Most of the winter time the room air temperature is higher than standards request.

In a sustainable office building the efficiency of HVAC-system is more important than the design of building envelope. The most important factors in energy consumption are the control of lighting system, solar shading of windows, demand based ventilation and efficient heat recovery. The sustainable building design requires different kind of selection of terminal units, if the room air temperature is chosen to be in lower level during winter and intermediate season

Keywords: Energy efficiency, indoor environment quality, HVAC-system design, chilled beams

1. Introduction

Sustainable building does not only provide wellbeing for users and healthy indoor environment but also takes into account various environmental aspects. From environmental issues the building's energy efficiency and use of renewable energy sources are one of the most important, however there are many other issues to be considered, like use of land, location of building (e.g. near the public transportation), reduction of pollutions during construction and life time of building, and use of materials.

Focus on energy saving and use of renewable energy sources are identified as a major source to improve environmental focus and reduce carbon emissions in construction industry. The energy efficiency of buildings is greatly affected by air conditioning and ventilation systems.

The energy consumption of building depends on the design of building envelope, selected HVAC-systems and the maintenance of them. The quality of windows pays an important role, when building is designed. Solar shading is another important issue, where architects can greatly affect the quality of building and it's energy efficiency. With good solar shading the cooling requirement can be reduced close to internal load level e.g. 40 – 50 W/floor-m^2. This also expands the variety of HVAC-systems, which can be used in building. Low temperature heating and high temperature cooling systems (like slab cooling, chilled ceiling and chilled beams) can be used in such a buildings. Also full-air systems, like displacement ventilation, become more feasible.

Sustainable solutions matches each space with a suitable system e.g. full-air systems to areas where main heat loads are from people (e.g. auditorium) where as in office environment it is more economical to transfer heat using water as media. Target is to design solutions, which can be adjusted according the use of space to meet the different indoor climate conditions over the life cycle of building and use products, which are adaptable to various conditions and designed to create complete solutions.

Good indoor climate can be achieved with less energy by selecting such a room systems which allows optimization of energy efficient cooling and heating.

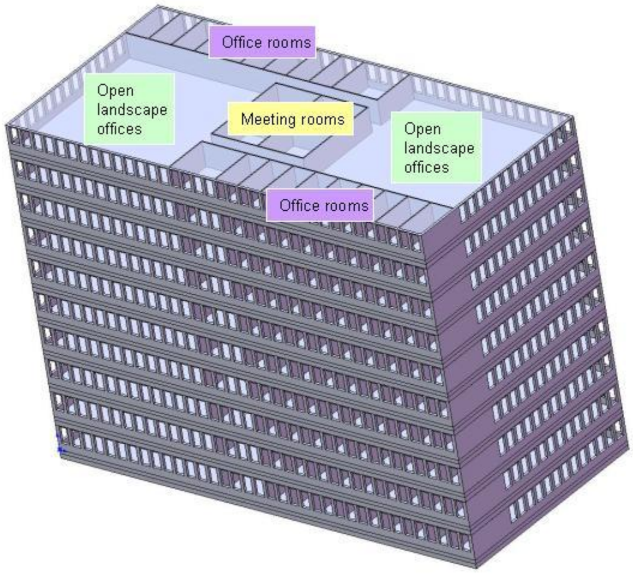
Lower cooling and heating requirements allows also the better utilization of renewable energy sources like ground water heat pumps, outdoor air (free cooling), solar panels, bio energy, wind, etc. There are several primary energy sources available to generate heat, but cooling energy is mainly produced using electricity, which typically have high primary energy coefficient. This is why in primary energy studies it is important to minimize the demand for cooling.

2. Design criteria of a case study

In this case study the IDA-ICE energy simulation program was used to calculate the annual energy need of building. To evaluate the energy saving potential, two different kinds of buildings were used. Reference building has structures, which are typically used in Central-European climate conditions today. In advanced building thermal conductivity of external structures has been improved as well as solar shading of window.

Several HVAC-systems were used for room air conditioning and ventilation: fan coil unit with constant air volume, variable air volume system, traditional active chilled beams with constant air volume, and variable active chilled beams with variable air volume. The design parameters were also modified, so all together more than 40 different simulations were made. In this paper the results of one simulation is presented in details and then compared to the other simulation results.

2.1 Building design



The simulation was made using 11000 m^2 office building (10 floors), each floor with a mixture of different type of spaces: landscape offices 610 m^2 (55 %), office rooms 242 m^2 (22 %), meeting rooms 162 m^2 (15 %), and other (rest rooms, etc) 95 m^2 (8 %).

The main facades were towards north-west and south-east. Window height was 1.8 m and width 1.2 m, one window in each 1.35 m module, so window-floor ratio was 25 % in external offices.

Energy simulation was made using Paris-Orly weather data.

Fig. 1. Case study building located in temperate climate.

Design values of a case study building are as follows:

- External wall 0.3 W/K,m^2
- Infiltration 0.165 dm^3/s,m^2
- Window 1.1 W/K,m^2
- Window g-value 0.48
- Solar shading External overhang of 500 mm

2.2 HVAC-system design

Air handling unit is designed so, that specific fan power SFP is 1.8 kW/m^3,s and total heat recovery efficiency is 60 % by using a plate heat exchanger. Dedicated outdoor air system was used with primary air volumes of 1.5 l/s,m^2 in offices and 4.2 l/s,m^2 in meeting rooms. Static ductwork pressure was constant. EU 7 filters were used in supply and EU 3 in exhaust. Night purge ventilation was utilized. Cooling water temperature of a cooling coil in air handling unit was 12 ^{O}C and supply air temperature was 16 ^{O}C. Primary air was dehumidified in air handling unit to be dry enough to handle all latent loads.

There was two chillers with air cooled condensers in the building: one for air handling units with evaporation temperature of 2 ^{O}C and another one for chilled beam system with evaporation temperature of 10 ^{O}C. Condensing boilers were used to produce warm water.

Active chilled beams are used as terminal unit. Demand based ventilation is used in meeting rooms (15 % of floor area) by selecting specific chilled beams, which are developed for variable airflows. Inlet water temperature to chilled beams was 15 ^{O}C. Room conditions were controlled using PI-controller with room air temperature set values of 20.5 / 25 ^{O}C.

2.3 Cooling Demand of a Building

Different areas of a building require different cooling capacity of terminal unit. Required cooling need is simulated using energy simulation software IDA-ICE. Case study building is divided into several operational areas based on their internal design values (use of space, air flow rate, internal loads) and orientation (solar load). Cooling needs in different parts of a building (Fig. 2) are presented in Table 1.

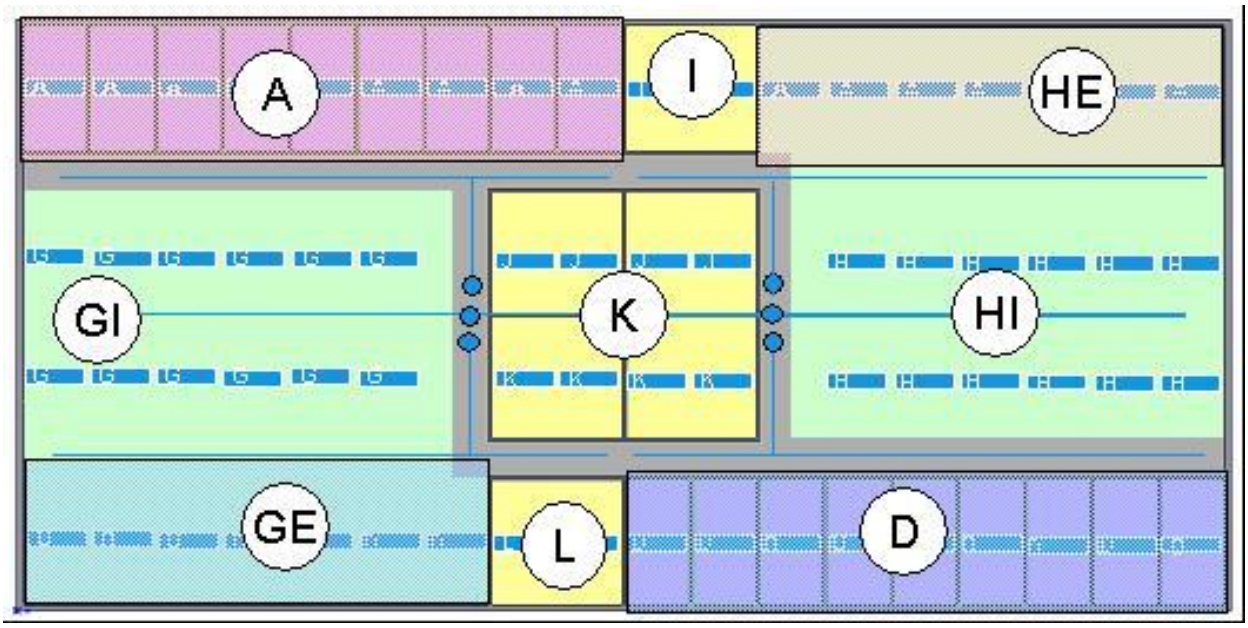


Fig. 2. Building is devided to several operational zones: office rooms (A, D), landscape offices (H, G), and meeting rooms (I, K, L).

Table 1. Cooling needs in different parts of building.

Space	**Area (m^2)**	**Advanced (W/m^2)**
Office space A	12.9	58
Office space D	12.9	63
Meeting room I	27.2	80
Meeting room L	27.2	88
Meeting room K1	27.2	25
Landscape office H	292	25
Landscape office G	290	28

3. Energy Simulation Results

The annual energy consumption of a building is 49 kWh/m^2 as net delivered energy and it is presented in table 2.

Table 2. Energy simulation results as annual net delivered energy (kWh/m^2,a)

Heating	Spaces	2.0
	Ventilation	5.6
	Heating total	**7.6**
Electricity	Cooling (incl. dehumidification)	3.4
	AHU fans	7.4
	Condenser fans	0.3
	All pumps	0.1
	HVAC Total	**11.2**
	Lighting	31.1
	Electricity total	**42.3**
TOTAL		**49.9**

In this case study lighting uses annually 31 kWh/m^2 of energy representing 60 % of total net energy consumption. With more efficient lights (like LED) and better controls (day light and occupancy) this could be reduced to less than half.

Second biggest energy user is fans. They use annually 7.7 kWh/m^2, which is15 % of total energy consumption. This is about 30 % less than in a similar building with constant airflows in all spaces.

Cooling energy need is 3.4 kWh/m^2 (7 %). 75 % of that is used to dehumidify the primary air before it is supplied to the space, This is important due to use of chilled beam system, which operates with dry coil and therefore demands dry enough room air.

Additional energy needed to heat the primary air is low due to heat recovery. This building needs annually only 5.6 kWh/m^2 to keep the primary air at desired temperature. Without heat recovery and with constant airflow rates in all spaces, it could be almost ten times more.

In this kind of building the annual space heating energy need is very small, being 2 kWh/m^2 and less than 5 % of total energy use. Even with poorer envelope (U-values of 0.43 and 2.6) it would still be less than 10 kWh/m^2. During occupied hours the internal heat loads are still more than heat losses and building requires cooling.

All these alternations results the variation between 20…90 kWh/m^2,a and this case study building was 50 kWh/m^2,a. This case study building represents a very good building in terms of tightness and thermal insulation. The further energy saving potential of HVAC- and lighting system is therefore approximately 30 kWh/m^2,a whereas better building structures could only reduce maximum 2 kWh/m^2,a (heating of spaces).

4. Duration of Room Air Temperature

In this case study the room air temperature is under 25 ^{O}C only 900 h during year (office hours 8-18) and under 23 ^{O}C only less than 50 h. Most of the winter time the room air temperature is higher than standards request. The temperature duration curve is presentied in Fig. 3.

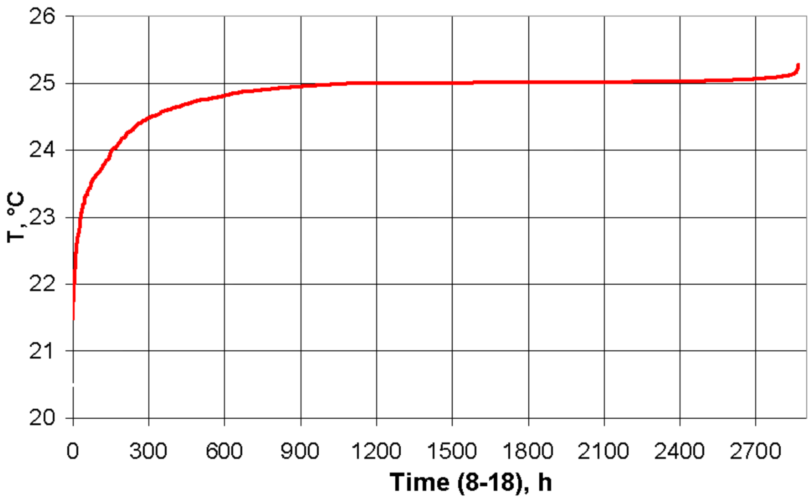


Fig. 3. Duration of room air temperature in south façade.

5. Conclusions and Discussion

This case study demonstrates that in a commercial office building, where internal heat loads and ventilation rates are high, the efficiency of HVAC-system is more important than the design of building envelope, if building structures are alreydy designed and executed well. The further improvement of structures has only a small influence of annual energy consumption (less than 5 %). The most important factors in energy consumption are the sophisticated control of lighting system, solar shading of windows, demand based ventilation and efficient heat recovery. HVAC-system and lighting represent the saving potential of 60 %.

Another important observation in this case study is the room air temperature. Terminal units are designed to keep the room air temperature at 25 ^{O}C, when cooling is needed. However, in all international standards there is a request to keep the room air temperature during wintertime in 21 ^{O}C. The sustainable building design requires different kind of selection of terminal units, if the room air temperature is chosen to be in lower level during winter and intermediate seasons. In this case, the terminal unit's cooling capacity should be designed for winter season's room air temperature.

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