Energy Efficient HVAC System and Building Design

ENTROPIC

ECOLOGY INDOORS

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SUMMARY

This paper presents energy simulation case studies of office buildings located in France. It takes into account the energy consumption of HVAC-system. Two different kinds of buildings have been used. Reference building has external structures of a typical new building in Paris today. In advanced building external walls and windows have lower U-value and improved tightness. Windows have also better shading coefficient and external overhang of 500 mm for solar shading. Different kind of HVAC-system components have been simulated both in reference and advanced building in order to find the lowest possible energy consumption. Result shows that with right HVAC-system and building design can reduce energy consumption 75 %.

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 also 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 primary energy studies it is important to minimize the demand for cooling.

DESIGN CRITERIA OF SELECTED CASE STUDIES

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, and lighting system has been improved.

Five different 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 in two different kind of system.

Building and HVAC-system design values

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 hight 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. Other building and system design parameters are presented in Tables 1. and 2. Energy simulation was made using Paris-Orly weather data.

Table 1. Design values of reference and advanced building.

	Reference building	Advanced building
External wall W/K,m^2	0,43	0,3
Infiltration $dm^3/s,m^2$	0,33	0,165
Window W/K,m^2	2,6	1,1
Window g-value	0,48	0,31
Solar shading	No	External overhang of 500 mm

Terminal units have been selected using manufacturers product data. Fan coil unit, VAV-terminal unit and traditional active beam were selected taking into account the comfort conditions in the space (velocity in occupied zone < 0,25 m/s). Variable active chilled beams were selected for demand-based ventilation cases (system 4 and 5), because they allow reducing airflow rate from maximum without creating velocity problems into occupied zone.

Table 2. Design values of different HVAC-systems.

	System 1	System 2	System 3	System 4	System 5
Room terminal unit	Fan coil unit	VAV-terminal unit	Traditional active chilled beam	Variable active chilled beam	Variable active chilled beam
Heat recovery	Hydronic (40%)	Hydronic (40%)	Hydronic (40%)	Hydronic (40%)	Regenerative (80%)
Air flow control	Constant air volume	Variable air volume	Constant air volume	Demand based	Demand based
Duct work design	Balanced	Balanced	Balanced	Constant pressure	Constant low pressure
Chiller design temperature	2 ^{O}C	2 ^{O}C	2 ^{O}C	2 ^{O}C	2 ^{O}C / 10 ^{O}C
Chilled water temperature	12 ^{O}C	-	15 ^{O}C	15 ^{O}C	15 ^{O}C
Room air temperature	24 ^{O}C	24 ^{O}C	24 ^{O}C	24 ^{O}C	25 ^{O}C
Supply air temperature	20 ^{O}C	15 ^{O}C	16 ^{O}C	16 ^{O}C	16 ^{O}C
Air flow rate: offices	1,5 l/s,m^{2}	1…7,5l/s,m ^{2}	1,5 l/s,m^{2}	1,5 l/s,m^{2}	1,5 l/s,m^{2}
Air flow rate: meeting room	4,2 l/s,m^{2}	1,2..9,2l/s,m^{2}	4,2 l/s,m^{2}	0...4,2 l/s,m^{2}	0...4,2 l/s,m^{2}
AHU design pressure loss	790 / 530 Pa	1100/ 750 Pa	790 / 530 Pa	790 / 530 Pa	470 / 330 Pa
SFP	2,0	2,8	2,0	2,0	1,2
Artificial lighting	15 W/m^{2}	15 W/m^{2}	15 W/m^{2}	15 W/m^{2}	6 W/m^{2}
Lighting control	Time 8 - 20	Time 8 - 20	Time 8 - 20	Time 8 - 20	Daylight, occupancy, time 8 - 18

Cooling need in different parts of 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. 1) are presented in Table 3. In this case study the reference building requires a terminal unit that can supply 80 W/m^{2} of cooling into an office space and respectively in advanced building 63 W/m^{2}.

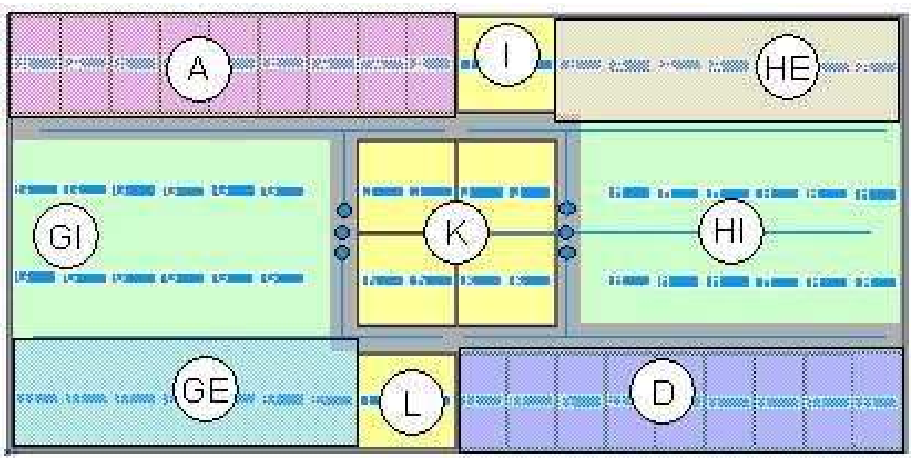

Figure 1. Building is devided to several operational zones: office rooms (A, D), landscape offices (H, G), and meeting rooms (I, K, L).

Table 3. Cooling needs in different parts of building.

Space	Area (m^2)	Reference (W/m^2)	Advanced (W/m^2)
Office space A	12,9	77	58
Office space D	12,9	80	63
Meeting room I	27,2	98	80
Meeting room L	27,2	104	88
Meeting room K1	27,2	67	25
Landscape office H	292	43	25
Landscape office G	290	43	28

ENERGY SIMULATION RESULTS

The energy consumption of the building was simulated using IDA-ICE software. The delivered energy consumption of HVAC-system is presented in table 4.

The annual energy consumption of reference building is almost 100 kWh/m^2 of net delivered energy. Approximately 5 % total energy saving can be achieved by varying the room terminal unit from fan coil unit to VAV-terminal unit or active chilled beam. By introducing the demand-based ventilation into meeting rooms (15 % of floor area) using active chilled beams as a terminal unit, the energy saving increases to 15 % (15 kWh/m^2,a). By designing the whole building and system differently, significant savings can be achieved. Total annual energy consumption can be as low as 22 kWh/m^2 as net delivered energy, which is 50 kWh/m^2 as annual primary energy (gas 1,2, electricity 2,5).

Lighting represents in all studied cases 44...53 % of total net energy consumption. Heating of primary air in air handling unit is 21...26 % in those cases, where heat recovery efficiency was 40 %, but only 3 % in case where heat recovery efficiency was 80 %. Fan energy in reference building with fan coil unit system is 15 % of total energy need, but because in advanced building with system 5 the overall energy need is so low, the relative importance of fan energy is much bigger (23 %). Pumping energy in all studied cases is very low, less than 1 % of total energy need.

Table 4. Energy simulation results as delivered energy (kWh/m^2,a).

	Reference Building								Advanced	
	System 1 (Fan coil)		System 2 (DOAS VAV)		System 3 (Chilled beam)		System 4 (Chilled beam)		System 5 (Chilled beam)	
Space heating	6,9	7 %	0	0 %	6,2	7 %	5,9	7 %	3,4	16 %
Heating of air	24,7	25 %	24,3	26 %	21,9	24 %	17,6	21 %	0,6	3 %
Heating total	31,5	32 %	24,3	26 %	28,1	31 %	23,5	28 %	4,0	18 %
Cooling	7,6	8 %	6,4	7 %	8,6	9 %	8,2	10 %	2,7	12 %
El. reheating	0	0 %	5,5	6 %	0	0 %	0	0 %	0	0 %
Fans:AHU/FC	14,4	15%	12,8	14 %	10,4	11 %	6,4	8 %	5,0	23 %
Condenser fan	0,5	1 %	0,3	0 %	0,6	1 %	0,6	1 %	0,2	1 %
Pumps	0,6	1 %	0,5	1 %	0,7	1 %	0,7	1 %	0,01	0 %
Lighting	43,7	44 %	43,7	47 %	43,7	47 %	43,7	53 %	10,0	46 %
Electricity tot.	66,8	68 %	69,2	74 %	64,0	69 %	59,6	72 %	17,9	82 %
TOTAL	**98,3**		**93,5**		**92,1**		**83,1**		**21,9**	
	100 %		**95 %**		**94 %**		**85 %**		**22 %**	

4. CONCLUSIONS

This paper presents the possibilities to reduce energy use of an office building by changing design criteria of building and HVAC-system. The primary air volume (fan energy as well as heating and cooling of supply air) is one of the most important HVAC-system design considerations in terms of energy use. Heating of spaces in office type of building is not the first priority when designing energy efficient buildings. Solar shading, lighting levels and control of lighting and shades are important areas to pay attention, because they reduces the energy consumption of lighting system as well as the energy consumption of cooling system.

Different selection strategies of chilled beam have also a significant influence on both room conditions and energy use. Demand based ventilation integrated into a chilled beam system is an easy way to save energy, but variable air volume must be taken into account when selecting the beam model.

Total energy saving potential of HVAC-system is over 70 % by actions that are simultaneously improving also comfort conditions. These are e.g. improved solar shading, better U-value of windows, demand based ventilation and improved heat recovery.