Sustainable Chilled Beam Design

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ABSTRACT

Chilled beam technology is seen as a very sustainable technology providing both excellent indoor conditions but also an energy efficient lifetime. This is a case only when different aspects of sustainability are taken into account in entire design process. It is important to optimise architectural design of building, HVAC-system design, and terminal unit selection according to indoor environmental conditions, energy use of building as well as investment and life cycle costs.

This paper presents studies of a chilled beam technology in a typical office building. It takes into account the total energy consumption of HVAC-system, lighting and equipments and discusses the possibilities to reduce energy use by changing design criteria. As an example, the primary air volume (fan energy as well as heating and cooling of supply air) is one of the most important design considerations in terms of energy use. Control of lighting is the other area to pay attention. On the other hand the pumping energy is relatively small part of total energy consumption. Different selection strategies of chilled beam have also a significant influence on both room conditions and energy use.

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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 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-m2. 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.

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.

1.1. Sustainable Design Process

Sustainable design process starts with a consideration of various performance objectives of interest to building stakeholders. While primary attention is generally given to space requirements and construction costs, a wide spectrum of objectives need to be considered at this stage, including energy-efficiency, life-cycle economics, occupant comfort and productivity, and building functionality and adaptability. The intent of client briefing phase is to define the desired performance for facility and systems so that design and operation decisions can be made to achieve this performance.

It is recommended to select and validate the room system (and if possible the solution supplier as well) before the actual design starts. This way the design can be based on the optimum performance of each selected component, and the problems of generic design can be avoided.

In design phase it is important to pay attention not only to system and product operation in single operating points (e.g. cellular office in maximum cooling and maximum heating), but also analyse the operation in various usage situations (e.g. intermediate seasons, open plan office and meeting room operation).

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 optimisation of energy efficient cooling and heating.

1.2. Chilled Beam System Design

In order to be able to manage indoor environment efficiently through the lifetime of building, it also requires changes in room unit design. There are new features in chilled beam technology to enable both easy changes in operation point and also good indoor conditions in varying circumstances.

When a chilled beam system is designed and chilled beams are selected, there are several aspects to be considered. The main target is to achieve excellent indoor climate conditions in spaces for the whole life cycle of the building, even if there is a continuous need to make changes in the space usage or layout.

Designing and selecting chilled beams in traditional way allows indoor climate target to be met in the design conditions, but future changes in use or layout may influence the performance of products. This strategy results in lowest possible investment cost, but changes during operation are costly and often requires a project to select new operation points for chilled beams.

In practice this means that each chilled beam is optimized to one operation point by selecting nozzle size, length and active length individually room by room. This means various kinds of chilled beams in each project making selection and installation work labour consuming. After each change either during the design and installation process or after building is taken into use, this same selection work needs to be done.

If air flow rates need to be adjusted in the space, the changes requires hours of work first typically by plugging the nozzles or releasing the nozzles and after that balancing the ductwork. In the case of relocated wall the changes may even be bigger and the whole unit need to be either changed or relocated as well. Traditional chilled beams cannot be easily used with variable air flow rates due to too low chamber pressure with small air flow rates or respectively too high chamber pressure with maximum air flow.

1.3. Adaptable Chilled Beam Technology

Adaptability of active chilled beams ensures not only effective design and installation process but also easy changes over lifetime. In adaptable design chilled beams are selected so that nozzle size, length and effective length are the same for all beams. Both the throw pattern and air flow rate is adjusted in building site during commissioning using two new patented technologies: Velocity Control and Air Quality Control unit, which are integrated into an active chilled beam.

Velocity Control (Fig. 1) is used for adjusting room air velocity conditions and throw pattern of chilled beam either when room layout changes (e.g., in cases where the partition wall is located near the chilled beam) or when local, individual velocity conditions need to be altered. Velocity Control damper is a manual induction rate adjustment with three different positions. It is recommended to design the chilled beam in the "normal" position in order to allow both throttle and full functions later on in the building's life cycle.

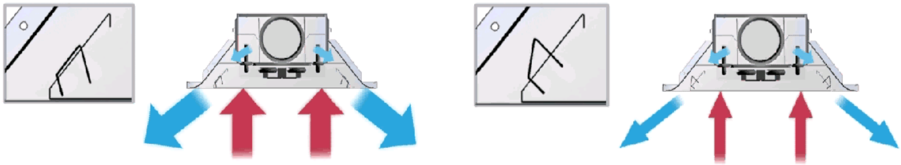

Figure 1. Velocity control is located into a supply air slot of an active chilled beam, where it adjusts both the induction rate of a chilled beam and a slot opening. This guarantees a good throw pattern also with reduced amount of induced air.

The Air Quality Control unit (Fig. 2) position and selection of chilled beam nozzle size are used for adjusting the airflow rate in the space. Airflow balancing is not needed because of constant pressure duct systems are used. Several nozzle sizes are available, to enable attaining the minimum supply airflow rate of the chilled beam in a typical room module.

The primary airflow rate of each beam is adjusted using the Air Quality Control unit during the installation and commissioning. There is no need to change or plug nozzles of the chilled beam. Motorized Air Quality Control unit also allows adjustment of the airflow rate of a chilled beam - e.g., to meet the ventilation requirements of meeting rooms.

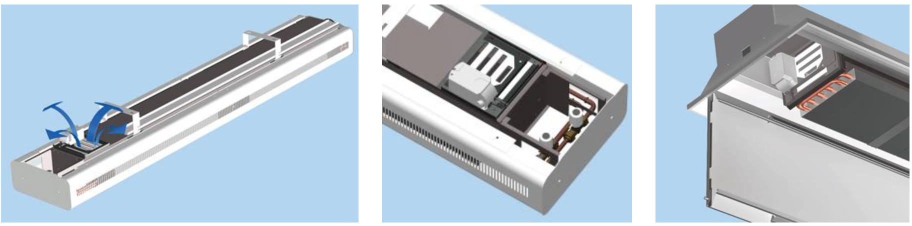

Figure 2. Air quality Control unit is integrated into chilled beam to adjust the required extra air flow rate of a chilled beam. Minimum airflow requirement is supplied through nozzles. In case of a high maximum airflow rate, Air Quality Control unit on the top or inside of a chilled beam can be motorized (e.g. meeting rooms).

The typical Scandinavian office building's (Fig. 3) columns spacing is 8,1 m and it is divided into 6 modules (à 1,35 m). If active chilled beam is installed into every second module perpendicular to perimeter wall, it means that there may become two module rooms with one beam, three module rooms with one beam and three module rooms with two beams. In this kind of installation there is different airflow rates in each beam and also different kind of throw pattern is needed (Table 1).

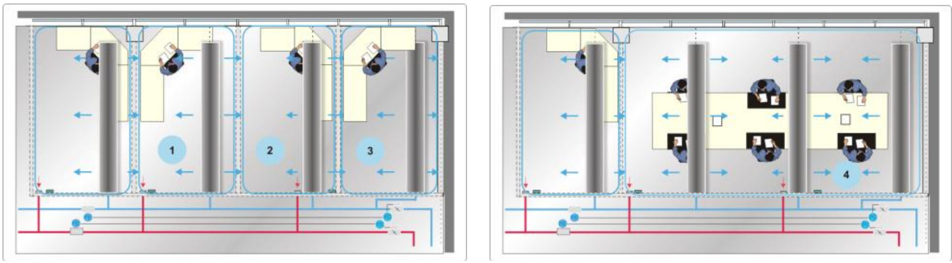

Figure 3. Typical floor layout where both Velocity Control and Air Quality Control are used to adjust the operation of each chilled beam to provide right air volume and throw pattern both as an office room (beams 1, 2, and 3), open-plan office (beams 1,2, and 3), and as a meeting room (beam4).

Table 1. Adjustments of Air Quality Control unit and Velocity Control unit in the example case.

	Velocity Control positions		Nozzle airflow rate (qv_1)		Airflow rate of Air Quality Control (qv_2)		Total airflow rate (qv_1+qv_2)	
	left	right	l/s	m^3/h	l/s	m^3/h	l/s	m^3/h
Office	full	throttle	15	54	5	18	20	72
Open-plan	normal	normal	15	54	5	18	20	72
Meeting room	normal	normal	15	54	0...45	0...160	15...60	54...216

2. CASE STUDY OF AN OFFICE BUILDING USING ACTIVE CHILLED BEAM TECHNOLOGY

The energy efficiency of sustainable building design and adaptable chilled beam technology was evaluated. IDA-ICE energy simulation program was used to calculate the annual energy need of building. To evaluate the energy saving potential, two different cases were simulated:

1. reference building with traditional active chilled beams (cooling + heating),
2. advanced building with adaptable active chilled beams (cooling + heating).

2.1. 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 Table 2. and a system schematic diagram of reference case in Fig. 4. Simulation was made using Paris-Orly weather data.

Table 2. Design values of reference and advanced simulation cases.

		Reference case	Advanced case
Building envelope	External wall W/K,m^2	0,43	0,3
	Window W/K,m^2	2,6	1,1
	Window g-value	0,48	0,31
	Solar shading	no	External, overhang of 500 mm, 200 mm above
	Infiltration dm^3/s,m^2 (4 Pa)	0,33	0,165
Heating and cooling systems	Boiler plant	Condensing boiler	
	Chiller plant with air cooled condensers	One common chiller (2^{O}C)	2 separate chillers: beams (10^{O}C), AHU (2^{O}C)
	Inlet water temperature	Chilled beams 15 ^{O}C, AHU 7 ^{O}C	
	Active chilled beams	Traditional	Adaptable
	Room control	P	PI
	Room temperature set value	20,5 / 24 ^{O}C	20,5 / 25 ^{O}C
Air handling unit	Airflow rates	Dedicated outdoor air system 1,5 l/s,m^2 in offices, 4,2 l/s,m^2 in meeting rooms	
	Airflow design	Constant airflow in all spaces	Constant airflow in offices, variable in meeting rooms
	Ductwork	Balanced	Constant low pressure
	AHU sizing: SFP kW/m^3,s	1,9	1,6
	Heat recovery	Hydronic (40%)	Plate exchanger (60%)
	Filtration	EU7 in supply and EU 3 in exhaust	
	Night purge ventilation	no	yes
Lights	Lighting loads W/m^2	15	12
	Controls	Time	Time, daylight

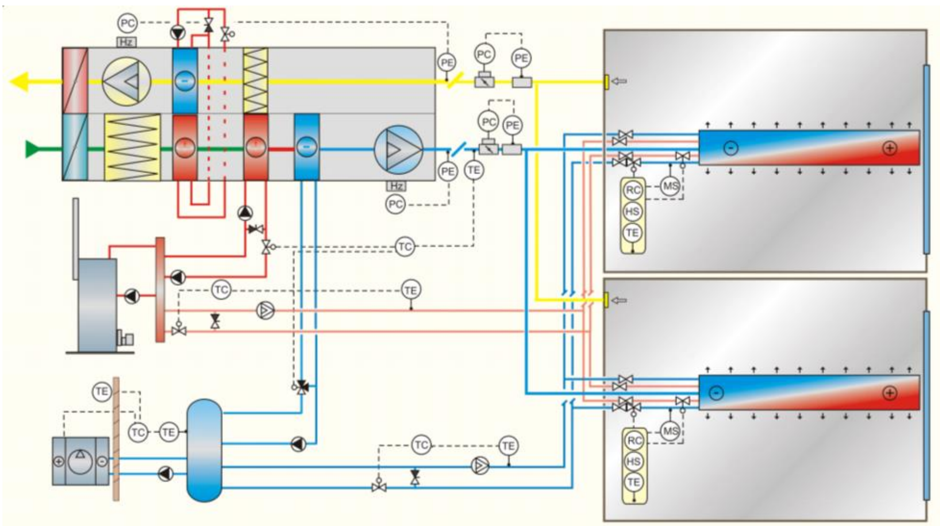

Figure 4. System schematic diagram of a reference case.

2.2. Chilled Beam Selection

Different areas of a building requires different performance values from a chilled beam. Before making a beam selection, we need to analyse how much cooling (Table 3.) is needed in different parts of a building (Fig. 5). After that we can choose such a chilled beam that its operation area is able to fulfil different needs. In this case study the reference case requires a chilled beam that can supply 80 W/m^2 of cooling into an office space and respectively in advanced case 63 W/m^2.

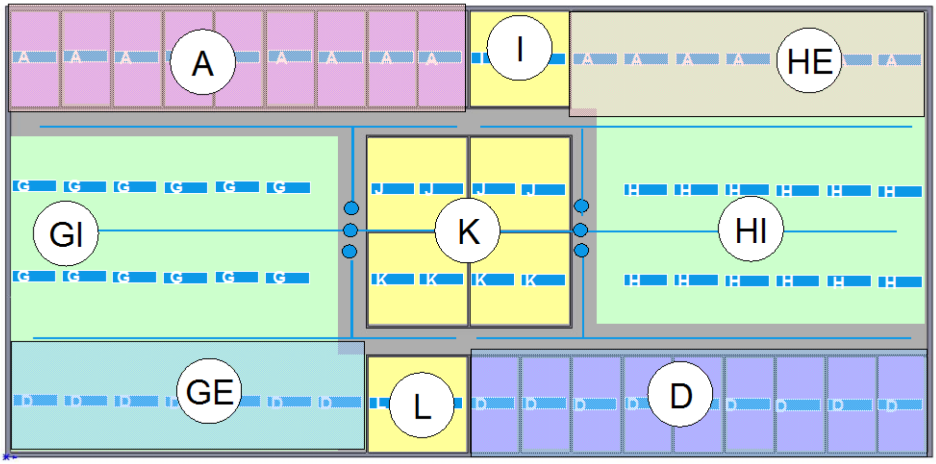

Figure 5. Building is devided to several operational zones: office rooms (A, D), landscape offices (H, G), and meeting rooms (I, K, L).

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

The reference case requires two different kinds of chilled beam. The smallest nozzle size (A-nozzle) is required in offices to supply 1,5 l/s,m^2 of primary air. In the meeting room the primary air volume is much larger (4,2 l/s,m^2). Therefore larger nozzle size is selected (D-nozzle). Even then the velocity increases in the occupied zone (0,20 -> 0,35 m/s), the chamber pressure is slightly increased (119 -> 132 Pa), and noise level increases (21 -> 33 dB(A)). Chilled beam selections are presented in Fig. 6 and 7. Effective length of 2300 mm is required in order to achive high enough cooling capacity.

Cooling	CBC/A-S2N-2600-2300		2007.10
Room:		Supply air flow rate:	2 x 19 l/s
Room size:	9.8 x 2.6 x 2.8 m		(8.3 l/(sm), 1.5 l/(sm2))
Occupied zone:	h=1.8 m / dw=0.1 m	Supply air temperature:	16.0 °C
Room air:	25.5 °C / 50 %	Total pressure drop:	119 Pa
Heat gain:	-	Total sound pressure level:	21 dB(A)
Installation height:	2.80 m	Primary air capacity:	429 W (2 x 215 W)
Inlet water temperature:	15.0 °C	Total cooling capacity:	2110 W (2 x 1055 W)
Outlet water temperature:	19.0 °C		459 W/m, 83 W/m2
Water flow rate:	0.100 kg/s (2 x 0.050 kg/s)	Dew point temperature:	14.3 °C
Coil capacity:	1681 W (2 x 841 W)	Velocity control:	side=3, middle=3
	365 W/m	Flow damper opening:	-
Water pressure drop:	2.3 kPa	L_d:	-

Max. jet velocities	v1	v3		
Nozzle jet	~0.20 m/s	~0.20 m/s		
Nozzle jet, isothermal	~0.20 m/s	~0.15 m/s		
dt (nozzle jet-room air)	-0.6 °C	-0.7 °C		

Heat sources and their location may influence the velocity and direction of the jet

vlim = 0.15 m/s

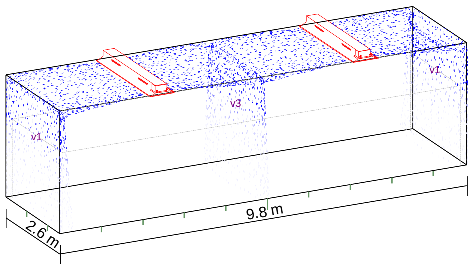

Figure 6. Chilled beam selection for reference office case. Velocity V1 presents the room air velocity near wall in an office space and velocity V3 presents the velocity in landscape office between the beams.

Cooling	CBC/D-S2N-2600-2300		2007.10
Room:		Supply air flow rate:	2 x 53 l/s
Room size:	9.8 x 2.6 x 2.8 m		(23.0 l/(sm), 4.2 l/(sm2))
Occupied zone:	h=1.8 m / dw=0.1 m	Supply air temperature:	16.0 °C
Room air:	25.5 °C / 50 %	Total pressure drop:	132 Pa
Heat gain:	-	Total sound pressure level:	33 dB(A)
Installation height:	2.80 m	Primary air capacity:	1197 W (2 x 598 W)
Inlet water temperature:	15.0 °C	Total cooling capacity:	3276 W (2 x 1638 W)
Outlet water temperature:	20.0 °C		712 W/m, 129 W/m2
Water flow rate:	0.100 kg/s (2 x 0.050 kg/s)	Dew point temperature:	14.3 °C
Coil capacity:	2080 W (2 x 1040 W)	Velocity control:	side=3, middle=3
	452 W/m	Flow damper opening:	-
Water pressure drop:	2.3 kPa	L_d:	-

Max. jet velocities	v1	v3		
Nozzle jet	~0.35 m/s	~0.25 m/s		
Nozzle jet, isothermal	~0.35 m/s	~0.25 m/s		
dt (nozzle jet-room air)	-0.6 °C	-0.6 °C		

Heat sources and their location may influence the velocity and direction of the jet

vlim = 0.15 m/s

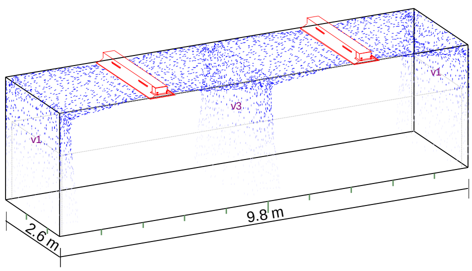

Figure 7. Chilled beam selection for meeting room in reference case.

In the advanced case only one chilled beam model is selected. This beam is able to fulfil both office space and meeting room requirements. The smallest nozzle size (A-nozzle) is sufficient to supply 1,5 l/s,m^2 of primary air for offices and by opening the Air Quality Control unit also the higher primary air volume of 4,2 l/s,m^2 can be handeled in the meeting rooms. Chilled beam selection for advanced meeting room is presented in Fig. 8. In advanced case the better room conditions can be provided in different operating situations compared to reference case with cheaper life time costs i.e. there is no need to change beams in future even the use of space is changed.

Use of variable air volume is possible when using adaptable chilled beams with Air Quality Control unit. Then the comfort conditions can be provided both with maximum and minimum airflow rate. If the big nozzle size is used with low air volume in the traditional beam, the supply air jet detachs from a ceiling surface and creates unexpected velocities in the occupied zone.

Cooling	CDC-S2N-2600-2300+AQ(24.3)		2009.06
Room:		Supply air flow rate	2 x 53 l/s / 2 x 16 l/s
Room size:	9.8 x 2.6 x 2.8 m	total/nozzle(s):	(23.0 l/(sm), 4.2 l/(sm2))
Occupied zone:	h=1.8 m / dw=0.1 m	Supply air temperature:	16.0 °C
Room air:	25.5 °C / 50 %	Total pressure drop:	100 Pa
Heat gain:	-	Total sound pressure level:	33 dB(A)
Installation height:	2.80 m	Primary air capacity:	1197 W (2 x 598 W)
Inlet water temperature:	15.0 °C	Total cooling capacity:	2304 W (2 x 1152 W)
Outlet water temperature:	21.6 °C		501 W/m, 90 W/m2
Water flow rate:	0.040 kg/s (2 x 0.020 kg/s)	Dew point temperature:	14.3 °C
Coil capacity:	1107 W (2 x 554 W)	Velocity control:	side=3, middle=3
	241 W/m	Flow damper opening:	-
Water pressure drop:	0.4 kPa	L_d:	2.2 m

Max. jet velocities	v1	v3		
Nozzle jet	~0.25 m/s	~0.25 m/s		
AQ diffuser jet	~0.25 m/s	~0.20 m/s		
Nozzle jet, isothermal	~0.25 m/s	~0.20 m/s		
dt (nozzle jet-room air)	-1.1 °C	-1.3 °C		

Heat sources and their location may influence the velocity and direction of the jet

vlim = 0.15 m/s

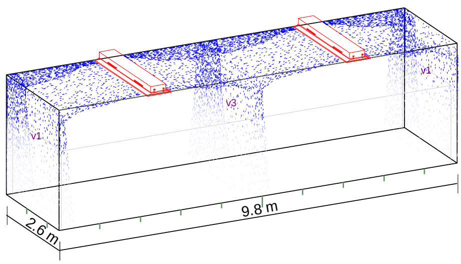

Figure 8. Chilled beam selections for meeting room in advanced case. Velocity V1 near the wall has reduced from 0,35 m/s (Fig 7.) to 0,25 m/s as well as the velocity between the chilled beam rows.

2.3. Energy Simulation Results

The energy consumption of the building was simulated using IDA-ICE software. In both reference and in advanced case the highest monthly energy consumptions (Fig. 9.) were in January, August and December. However, in advanced case the level was lower especially during summer months due to lower need for space cooling.

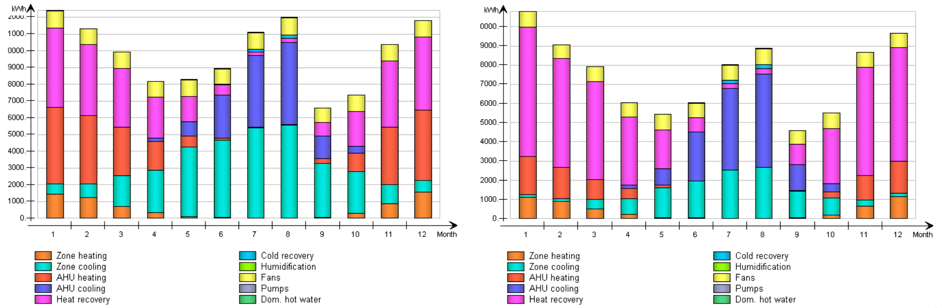

Figure 9. Monthly energy consumption breakdown in reference case (left) and in advanced case (right).

In this study, the delivered energy saving potential of HVAC-system is over 60 % with relatively easy and well-known actions. The delivered energy consumption of HVAC-system is presented in table 4. The biggest reduction 16,3 kWh/m^2,a (74%) is in heating of ventilation due to better heat recovery and demand based ventilation in meeting rooms. Demand based ventilation and lower SFP reduces fan energy 40 % (4,4 kWh/m^2,a). Better insulation and more tight walls and windows reduces the heating of spaces 66 % (4,1 kWh/m^2,a). Improvement in the solar shading among other things reduces cooling of spaces 5,2 kWh/m^2,a. At the same time the pumping energy is also reduced by 86 %, but being less than 1 % of total energy consumption of HVAC-system, is not necessarily the main item when energy savings are considered. Heating of spaces is 6,2 kWh/m^2,a in reference case. The improved insulation and better windows reduces it by 66 %. But heating is only 7 % of total energy consumption of building in reference case.

However, the lighting has the most remarkable saving potential. The electricity consumption of lighting in reference case was 43,7 kWh/m^2/a, almost as much as the heating (gas) and electricity of HVAC-system.

Table 4. Delivered energy consumptions of building.

	Reference case kWh/m^2/a	Advanced case kWh/m^2/a
Heating of spaces	6,2	~~3,5~~ / 2,1
Heating of ventilation	21,9	~~7,3~~ / 5,6
Cooling of spaces	6,0	~~4,9~~ / 0,8
Cooling of ventilation	2,6	~~2,7~~ / 2,7
Fan energy	11,0	~~8,8~~ / 6,6
Pumps	0,7	~~0,2~~ / 0,1
HVAC-SYSTEM TOTAL	**48,4**	**~~27,4~~ / 17,9**

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. It offers easily over 20 kWh/m^2,a saving potential. Heating of spaces is less than 10 % of total energy use. Control of lighting is an importan area to pay attention.

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 sellecting the beam model.

Total energy saving potential of HVAC-system is over 60 % by actions that are simultaniously improving also comfort conditions. These are e.g. improved solar shading, beter U-value of windows, demand based ventilation and improved heat recovery.

REFERENCES

Kosonen, Virta, Taking flexibility into account in designing beam systems, 9th REHVA world congress CLIMA 2007 in Helsinki.

Kosonen, Hagström, Laine and Martiskainen, A life cycle costs study of an office building in Scandinavian conditions: a case study approach, Healthy Buildings 2003.

Ruponen, Streblow, Mustakallio, Room velocity control for room ventilation device, 8th REHVA world congress CLIMA 2005 in Lausanne.

Virta (ed.), Butler, Gräslund, Hogeling, Kristiansen, Reinikainen, Svensson, Chilled Beam Application Guidebook, Rehva Guidebook N.o 5, ISBN 2-9600468-3-8.

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