A life-cycle costs study of an office building in Scandinavian conditions: a case-study approach

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ABSTRACT

It is common that the first cost is the main criterion when making choices between different systems. However, it is possible to demonstrate that a lower initial investment can turn out to be more costly from the whole life-cycle viewpoint. With life-cycle cost (LCC) calculations, it is possible to get a better overview of the total cost. LC costs of typical systems (fan-coil, constant airflow rate, variable air volume and ventilated beams) were analysed and compared in a case-study office building. The LC cost of the system combination where air–water based ventilated beams is utilized in office rooms, variable air volume system in conference rooms and canteen and respectively constant airflow rate in other public areas, was the lowest. The analysis depicts that it is possible to enhance energy efficiency and reduce environmental impact using demand-based air-conditioning without deteriorating the indoor environment.

INDEX TERMS

Demand-based air-conditioning; Life-cycle cost; Life-cycle assessment

INTRODUCTION

The building industry continues to see a growing interest in creating solutions that consider the priorities of indoor air quality and energy conservation. Additionally, there is an obvious link with indoor climate and productivity. Recent studies have shown the link between indoor air quality to thermal comfort, productivity and health issues (Wyon, 1996; Wargocki *et al.*, 1999). Thus, it was possible to demonstrate that an investment to a better air-conditioning system is profitable already with very modest productivity improvements (Hagström *et al.*, 2000).

The need to consider the ‘quality’ of the space is encompassed within the publication ‘Ventilation for Buildings—Performance requirements for ventilation and air conditioning systems’ (CEN, 1998). This sets a range of technical target values that need to be agreed between the designer and the client. Thus, end-users will become much more aware of what can be expected.

In the building process, it is still common that the first cost is the main consideration when making choices between different systems. A lower initial investment can turn out to be more costly from the whole life-cycle viewpoint if the operation costs and the influence on productivity of workers are not taken into account. The system selection should be conducted based on the space type and actual time schedule of usage. The concept of demand-based air-conditioning on is required for energy efficiency when internal loads and contaminants levels vary considerably. Typical spaces to apply demand-based air-conditioning concepts are, e.g. lobby areas, auditoriums and conference rooms. On the other hand, offices have high cooling load and only moderate outdoor airflow rate demand. In offices, a ventilated beam system offers a comfortable indoor environment with competitive life-cycle costs. Using a demand-based concept, where variable airflow rate is utilized in spaces where ventilation demand vary

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significantly and an air–water ventilated beam system is used in offices, it is possible to enhance the indoor environment in a life-cycle cost-efficient manner.

In this paper, the life-cycle cost of typical air-conditioning systems in European conditions are studied using a case-study approach. The case-study office building is located in Stockholm, Sweden. A comparative analysis on the life-cycle assessment is carried out to get a more generic view of the environmental impacts of a building's energy use with different systems.

A CASE-STUDY BUILDING

The building is located in Stockholm, Sweden. The total area of the south-north oriented building is 6715 m^2 and the total volume is 23 905 m^3. In the building, there are seven floors, 155 office rooms, 13 open offices, 14 meeting rooms and a kitchen with an adjoining dining area.

The design room and the supply air temperatures are 24C and 17°C in summer and 21 and 18°C in winter, respectively. The air-conditioning system operates from Monday to Friday between 7:00 a.m. and 6:00 p.m. The *U*-values of the building structures are:

- exterior wall 0.25 W/m^2 K,
- roof 0.16 W/m^2 K,
- ground floor (against ground) 0.25 W/m^2 K,
- triple glazed low-emissivity windows 0.37 W/m^2 K.

The analysed air-conditioning systems are: (1) constant airflow rate (CAV) which fulfils the target room temperature; (2) minimum just code-approved constant airflow rate (CAV$_{min}$); (3) Fan-Coil (CAV together with reheating in meeting rooms and canteen); (4) variable airflow rate (VAV); (5) ventilated beams (CAV together with reheating in meeting rooms and canteen) and (6) Demand-Based-Indoors concept (DBI) where ventilated beams are used in office rooms and a VAV system is public areas. The cooling capacity of the systems is done by a dynamic energy simulation software using Stockholm's hourly weather data.

The heat loads consists of people, lighting and equipment loads. The occupant density (person per m^2) is 0.05 in the kitchen, 0.1 in the offices and the canteen and 0.3 in the meeting rooms. Altogether approximately 600 persons are working in the building, the heat gain of the lighting is 20 W/m^2 in the meeting rooms and 15 W/m^2 in other spaces. The equipment heat gain is 40 W/m^2 in the kitchen, 15 W/m^2 in the offices and 5 W/m^2 in meeting rooms. The calculated cooling capacities and airflow rates are shown in Table 1.

Table 1 The requested supply airflow rates in the different spaces and the additional cooling capacities per room area (φ_w) of the air–water systems

Space	DBI		VAV	Fan-coil		Beam		CAV	CAV$_{min}$
	q_v l/s m^2	φ_w W/m^2	q_v l/s m^2	q_v l/s m^2	φ_w W/m^2	q_v l/s m^2	φ_w W/m^2	q_v l/s m^2	q_v l/s m^2
Open office	2	31.4	2.0/6.4	2	40.8	2	31.4	6.2	1.5
Office south	2	71.0	2.0/11.1	2	92.3	2	71.0	11.1	1.5
Office north	2	32.3	2.0/6.3	2	42.0	2	32.3	6.3	1.5
Meeting room	1.8/6	–	1.8/6	6	–	6	–	6	4
Canteen	3/10	–	3/10	10	–	10	–	10	10
Kitchen	10	–	10	10	–	10	–	10	10
Corridor	1	–	1	1	–	1	–	1	0.5

RESULTS

Energy Consumption and Internal Thermal Conditions

Annual heating and cooling energy consumptions of the analysed air-conditioning systems are shown in Figure 1. From the systems that fulfil the target room temperature, constant airflow system (CAV) has the highest energy consumption. VAV and DBI systems have significantly lower consumption. It should be noted that using the system of minimum constant airflow rates (CAV_{min}) it is not possible to maintain the target room temperature. The room temperature is at an unacceptable level (over 30^{o}C) during design conditions. The analysis depicts that it is possible to maintain target conditions in an energy efficient manner. Figure 2 shows the room temperatures of DBI and CAV_{min} concepts during design conditions.

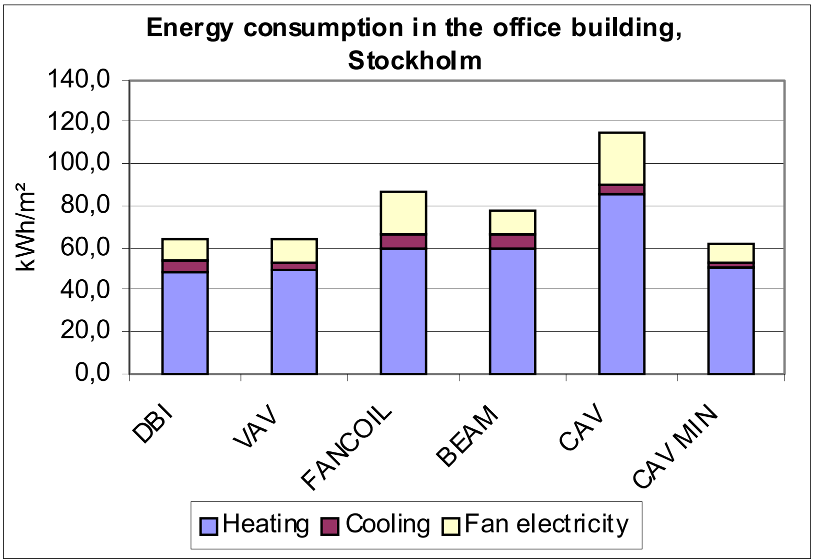

Figure 1 Annual energy consumption in a case-study building.

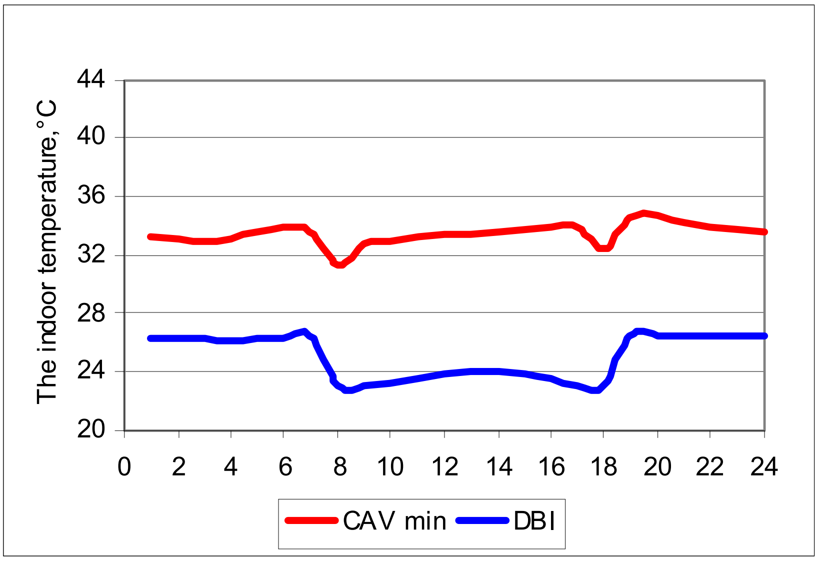

Figure 2 Room temperatures of DBI and CAV_{min} concepts during design conditions. The minimum airflow rate concept that minimizes energy consumption leads to unacceptable high room temperature.

Life-Cycle Costs

Life-cycle cost (LCC) calculations were conducted for comparing technical systems. The LC calculations included the investment, energy and maintenance costs. The components and systems included in the analysis cover:

- Central Air Handling, Cooling and Heating units.
- Mechanical networks (ductwork, heating and cooling pipework).
- Room equipment (Cooling Beams, Fan Coils, VAV-units, radiators, Diffusers and Valves).
- Building Automation and Electricity of the HVAC systems.

The investment and maintenance cost calculations are carried out using a software that is supported by a statistical database. In the calculation method, preventive periodical maintenance including the labour and material costs is also taken into account. Calculations were conducted for a life-cycle of 15 years. The net interest rate is set to be 7.0%. The net present values are shown in Figure 3.

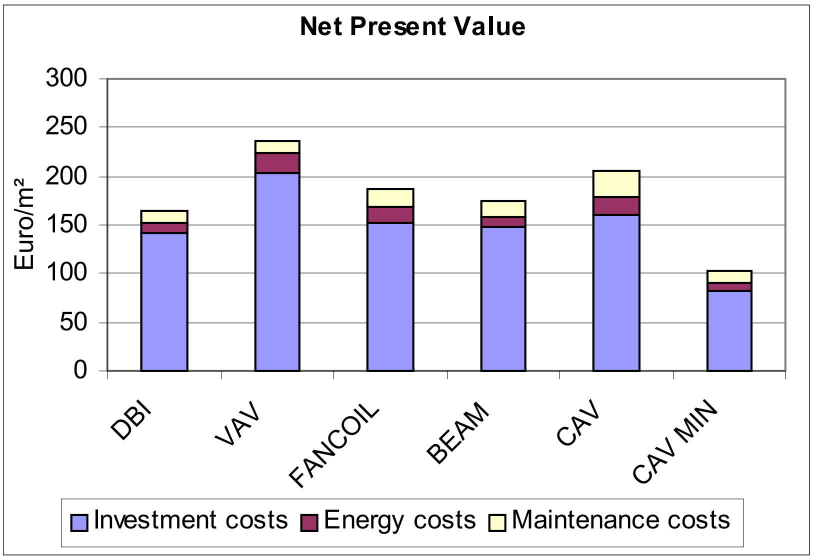

Figure 3 The net present value of the analysed systems.

It should be noted that the investment cost is significant in the breakdown of the net present value. Independent of the system, energy and maintenance costs together is about 1/3 of the total LC costs. From the systems that are able to maintain target indoor conditions, the DBI concept has the lowest net present value. The ventilated beam system has the second lowest costs. All-air systems (VAV and CAV) have significantly higher net present values than air–water concepts because of the larger air-handling units and ductworks. Also, the space demand of technical systems is much larger with all-air systems.

The minimum airflow rate concept has the lowest present net value. That ostensibly lower initial investment can turn out to be more costly if the influence on productivity of workers is even roughly estimated. Typically 90% of the annual cost of an office building is related to personnel working. Thus, a modest 1–3% drop in office work productivity is economically more significant than the differences of the total net present value of the mechanical systems. In the case-study, the difference between the net present values of DBI concept and CAV_{min} is 62 EUR/m^2. Even 1% of loss in productivity can correspond to a loss of 270 EUR/m^2 during the contemplation period of 15 years. In other words, the loss could be more than four times higher than the savings in the investment.

Environmental Impact of Building's Energy Use

The LCA defines the environmental impacts of the building, its systems and use. LCA calculations were used for comparing these different technical solutions from the perspective of environmental impacts of the energy use only. Calculations were made for a life cycle of 50 years.

The calculations take into account the emissions that have an impact on climate change and use the characterization factors for a period of 100 years. The emissions are given in CO_2-equivalents. The calculation tool uses the emissions having an impact on acidification and ozone depletion and the corresponding weighting factors as given in the DAIA (Decision Analysis Impact Assessment) and Ecoindicator95 characterization methods.

In the weighting phase of the LCA the classified indicator values are combined to a total indicator value. Weighting the classified results using a certain method means that the corresponding characterization method has been used. The calculation tool uses DAIA and EPS (Environmental Priority Strategy) methods for weighting.

Environmental impact of energy use is based on the average environmental profiles of Finnish energy production in 1998. The source information varies according to the locality (Figure 4).

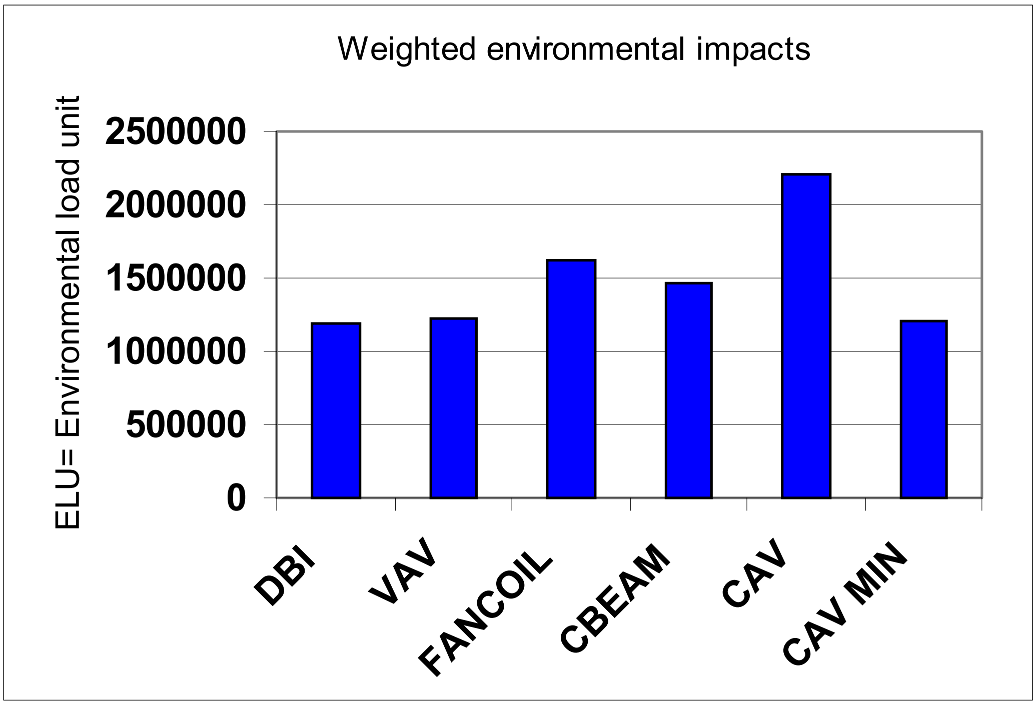

Figure 4 Weighted environmental impacts on analysed systems.

As the net present value of the DBI concept, the weighted environmental impact of the DBI concept is the lowest. The weighted environmental impact of DBI is lower than CAV_{min}, whose indoor environmental quality does not fulfil the target conditions. This demonstrates that the selection of the demand-based system also reduces effectively the environmental impacts of the mechanical system.

CONCLUSION

The life-cycle cost of the Demand-Based-Indoors concept, where air–water based ventilated beams is utilized in office rooms, variable air volume system in conference rooms and canteen and respectively constant airflow rate in other public areas, was the lowest.

The system selection should be conducted based on the space type and actual time schedule of usage. With the Demand-Based-Indoors concept, it is possible to enhance energy efficiency and reduce environmental impact without deteriorating the indoor environment. The weighted environmental impact is also lowest with the Demand-Based-Indoors concept.

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