OPTIMUM VENTILATION AND AIR FLOW CONTROL IN BUILDINGS

17th AIVC Conference, Gothenburg, Sweden, 17-20 September, 1996

(Title)

Energy Efficiency in Office Buildings

An Energy and System Analysis Study

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SYNOPSIS

While the use of heat energy has decreased since the middle of the 1970's the use of electricity in the Swedish stock of commercial buildings has increased dramatically. In the average Swedish office building, roughly 30 % of all electricity is used for heating, ventilation and air-conditioning (HVAC). Another 30 % is used for lighting, 20 % for office machines, and about 20 % for other loads.

In order to study the use of electricity in Swedish office buildings in detail, the Swedish Council for Building Research initiated four monitoring and building simulation projects in 1989. The project buildings represent different ages and different HVAC technologies.

Based on a combination of hourly monitored data during four years, building simulations using the DOE2 program have been carried out. In two of the buildings, energy conservation measures have been implemented too.

An interesting aspect in our study is the so called load factor. Load factors for lighting and other electric loads are evaluated. Taking this into account, you can optimize the design of the air flow rates and the cooling systems and reduce the investment and operational costs for the HVAC systems. Thanks to a correct HVAC design you may also reduce the negative impact on the environment by less use of CFCs etc.

Our studies indicate that the load factor variation in Swedish office buildings, during a day or a week, diverge substantially from the schedule for lighting and office machines etc. according to the ASHRAE 90.1-1989 Standard [6]. Regarding office machines etc., the installed power density also diverges to a great extent.

In order to classify ventilation systems with respect to energy efficiency, some different key values are defined. One is the so called SFP value (Specific Fan Power). In some Swedish projects, the goal has been to reach a level of 1.5 kW/(m^3/s) or less. However, it is not easy to reach that level in existing buildings. SFP values for Swedish office buildings based both on rated and measured data are presented in this paper.

By implementing appropriate energy conservation measures (ECM), the use of electricity and heat energy may be considerable reduced and also lead to a better indoor climate. However, it is important to have an overall view of the building and its systems and to take all effects of interacting ECMs and systems into account.

1 INTRODUCTION

While the use of heat energy has decreased since the middle of the 1970's, the use of electricity in the Swedish stock of commercial buildings has increased dramatically. This increase was most pronounced in the 1980's.

The use of electricity in the Swedish commercial building sector amounts to about 25 TWh annually. In the average Swedish office building roughly 30 % of all electricity is used for HVAC. Another 30 % is used for lighting, 20 % for office machines, and about 20 % for other loads [1].

In order to study the use of electricity in Swedish office buildings in detail, the Swedish Council for Building Research initiated four intensive monitoring and building simulation projects in typical office buildings in 1989. These buildings, owned by four Swedish insurance companies, represent different HVAC technologies. Two of them are representative of the early 1980's and the other ones of the late 1980's.

During this before-after study period, we also investigated some twenty other office buildings with respect to the energy use both in total and for different loads such as for lighting, office machines etc. The HVAC system, control system and lighting system were also studied. Several energy and power measurings as well as other kinds of measurements were carried out.

Detailed results from these studies have up till now mainly been published by the Swedish Council for Building Research [2,3]. However, the results have also been used recently in a licentiate thesis as well as in a doctoral thesis, both at Chalmers University of Technology in Gothenburg [4,5].

2 LOAD FACTOR STUDIES

2.1 Definition

An often neglected thing when designing HVAC systems for office buildings is the so called **load factor**. This factor we define as the quotient between the electrical power used at a given moment and the total power installed (rated) e.g., for part of or the whole office building.

The load factor can be said to be compounded of two parts. The first part is the difference between rated power and real power in use for each machine etc. The second part is the fact that all machines and lighting etc. in an office floor etc. are never used simultaneously.

Another expression that will be used in this paper is the **installed power density**. When talking about installed power density for lighting or receptacle (office machines etc.) or both together, we mean the power installed (rated) e.g., for part of or the whole office building, divided by the floor area of immediate.

2.2 Correct Load Factor Consideration Leads to Environmental Benefits

When designing HVAC systems it is very important to consider the load factor in a correct manner. By taking the load factor into account, you can **optimize the design** of the air flow rates as well as the cooling systems. Thus you can reduce the investment and operational costs for the HVAC systems as well as the environmental influence.

You obtain environmental benefits in two ways. First, a correct designed HVAC system will use less energy than an oversized one. Secondly, this will lead to less use of CFCs etc., which will be demonstrated shortly in section 3.3.

2.3 Decreasing Load Factors

Our studies have shown that the load factors in office buildings are often much lower than most consultants and building engineering experts think. Furthermore, the load factors in Swedish office buildings have tended to decrease during the last few years. This fact has been possible to estabilish as a result of our monitoring project running for several years. There is no reason why our results would not be valid also for office buildings in other countries.

In **Figure 1** results from the four main buildings in our investigation are shown. The load factors in this figure are counted for single office floors and represent **maximum** values during several years of monitoring. The values include lighting and all electrical office machines etc. and are representative of about 700 m^2 in each building.

Office building	Lorensberg	Svaneholm	Stampen	Lagern
Year 1990/1991	48 %	60 %	40 %	47 %
Year 1995	22 %	33 %	Not investigated	Not investigated

Figure 1 Maximum load factors for single office floors in four typical Swedish office buildings

Office buildings in common are getting more and more equipped with electrical office machines. This is the main reason why the remarkable load factor decrease in the Lorensberg and the Svaneholm office buildings. The great drop for the Lorensberg office building is also a result of the installed occupancy sensor-controlled lighting system.

When the number of personal computers, printers etc. increase, the difference between the total summed up rated power and the power in use also increase i..e., the load factor becomes lower. One reason for this is that all machines and lighting are never used simultaneously.

Based on investigations in several office buildings during a number of years, we also state that the difference between the rated power and the real operating power for each single machine today is often greater than it used to be. Often the operating power is about 30 % of the rated one.

Our detailed studies in the four office buildings have also showed that there normally is a difference regarding the load factor level between summer and winter time. In the summer the load factors often are somewhat lower, mainly due to the fact that all office staff does not need to use the lighting all day. Of course vacations also to some extent have an influence on the level of the load factor.

Considering load factors, one must also be aware that they will probably increase even more in the future, although most office buildings already today are very well equipped. This statement is based on two trends seen today. First, most office machines become more and more energy efficient in standby periods, thanks to power sleep modes, Energy Star demands, etc. Secondly, the use of office lighting controlled by occupancy sensors will probably become more frequent. Both these circumstances will increase the difference between the installed rated power and the real power demand, and through this the load factor, will be reduced.

Recently, a new project has been started in order to study load factors, not only for single office floors but also for entire office buildings. In the entire office buildings, the load factors are probably even lower than has been shown in this paper. We intend to find out the normal level of total load factors as well as their schedules.

2.4 Comparisons Regarding Installed Power Densities and Load Factors

In this section, results regarding installed power densities and load factors from our four building projects are compared with the ASHRAE 90.1-1989 Standard [6].

	Installed power density [W/m²]				
Office building	Lorensberg	Svaneholm	Stampen	Lagern	ASHRAE
Office room lighting[1]	16.9	22.1	17.0	12.6	19.4
Office machines etc	21.2	16.0	26.6	20.5	8.1

[1] In new Swedish office buildings the installed power density for office lighting is often less than 10 W/m² incl. losses

Figure 2 Installed power densities for single office floors in four typical Swedish office buildings (**before** ECMs) compared with the ASHRAE Standard

From measured load factor schedules and the installed power density values in **Figure 2**, we can calculate what we may call **power density schedules**. An analogous calculation may also be done based on shedules and power density values according to the ASHRAE Standard.

In **Figure 3**, power density schedules for office machines etc. based on the four project offices, as well as based on the ASHRAE Standard for an average working-day may be seen. In **Figure 4**, a similar comparison is shown, but this time regarding density schedules for office lighting.

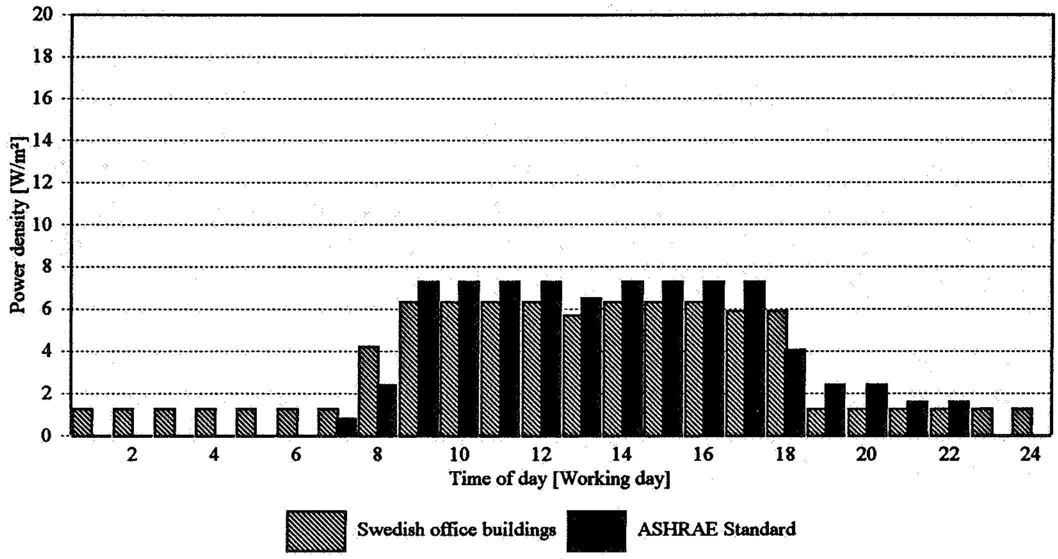

Figure 3 Power density schedules for office machines

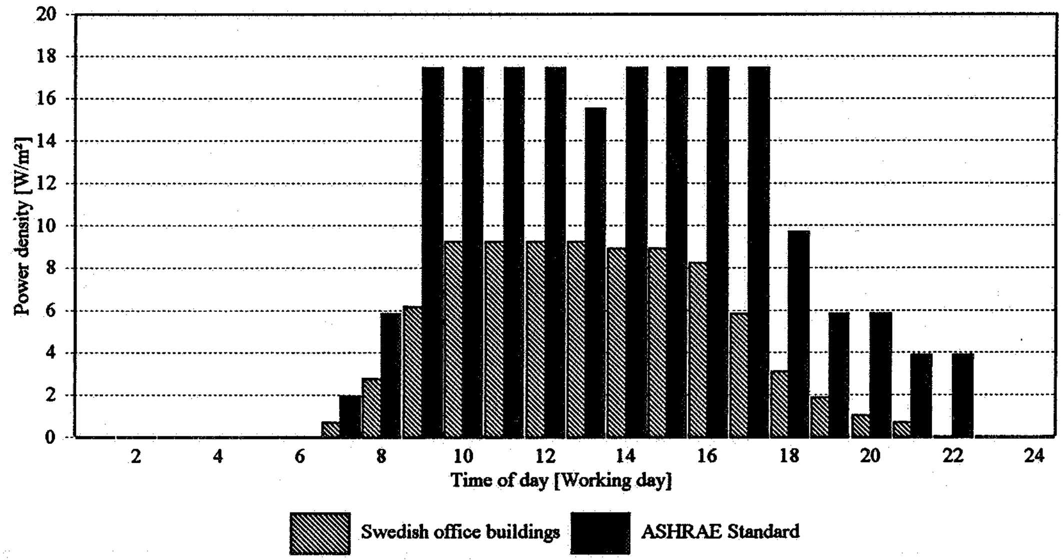

Figure 4 Power density schedules for office lighting

Two main conclusions may be drawn from the results shown in **Figure 3** and **Figure 4**.

Firstly, despite substantial differences regarding installed power density as well as the load factor schedules, the two power density schedules for office machines etc. become quite similar. The daily energy use will be nearly the same in both cases [5].

Thus, regarding **receptacles** (office machines etc.) the ASHRAE values may be used also for Swedish office buildings. Please note that in this case **both** the ASHRAE load factor schedule **and** the ASHRAE installed power density must be used.

On the other hand, the second main conclusion is that a utilization of installed power density, and schedule for **lighting** according to the ASHRAE Standard will result in a power density schedule that does not at all correspond to our experiences based on conditions in Swedish office buildings.

In Sweden therefore, a HVAC system fully designed and based on the ASHRAE Standard would probably become oversized.

3 DOE2 SIMULATIONS

3.1 Why Simulate?

When for instance an office building is to be built or rebuilt, it is very often advantageous to carry out computer simulations. Hereby different possible HVAC systems may be analyzed. This is a way to optimize the design and to reduce the life cycle costs for the system choosen. In a rather cheap way you will also get a prediction of the energy and power demands for the building.

3.2 Simulations for the Svaneholm Office Building and Measuring Results

There are several different building energy simulation programmes on the market today. We have used the well known and in many studies validated DOE2-program (version 2.1D) [7].

Based on a combination of hourly monitored data during four years, building simulations of the effect of different possible energy conservation measures (ECMs) have been carried out for the Svaneholm office building [1,2]. The monitored data represent the most important end-users of electricity such as ventilation, cooling, lighting, computers, etc.

One of our goals was to analyze the real result of the energy savings besides learning more about the system effect of different ECMs.

In **Figure 5,** the results of some of these simulations are shown. The use of electricity as well as of energy for heating could be considerably reduced if both studied measures were to be implemented. Measure no 1 stands for "Installation of energy efficient lighting", and measure no 2 for "More energy efficient HVAC system".

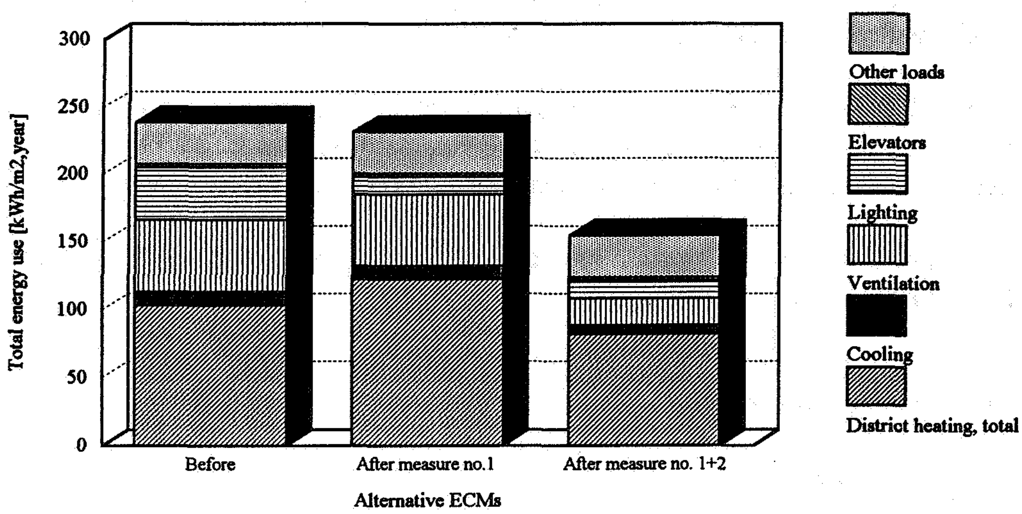

Figure 5 DOE2 simulations of energy use for the Svaneholm office building

These simulations were carried out based on real load factors, determined through the measurings mentioned above in combination with inventories. When simulating buildings to be built, of course you do not have any load factor information etc. for the building. This is one of the reasons why it is of great interest to establish what might be called schedules of normal load factor for different kinds of buildings.

Today in the Svaneholm building, the ECMs have been implemented to a great extent. By means of long time monitoring, we have been able to see that the accordance between simulations and real outcome is very good regarding energy use as well as power use. Although all ECMs are not yet completely carried out, we have reached about 90 % of the predicted energy savings.

In **Figure 6** and **Figure 7, power profiles** are shown for comparable weeks before and after the implemented ECMs. The y-axis represents power and the x-axis represents time. Consequently the different areas in the figures represent the energy use.

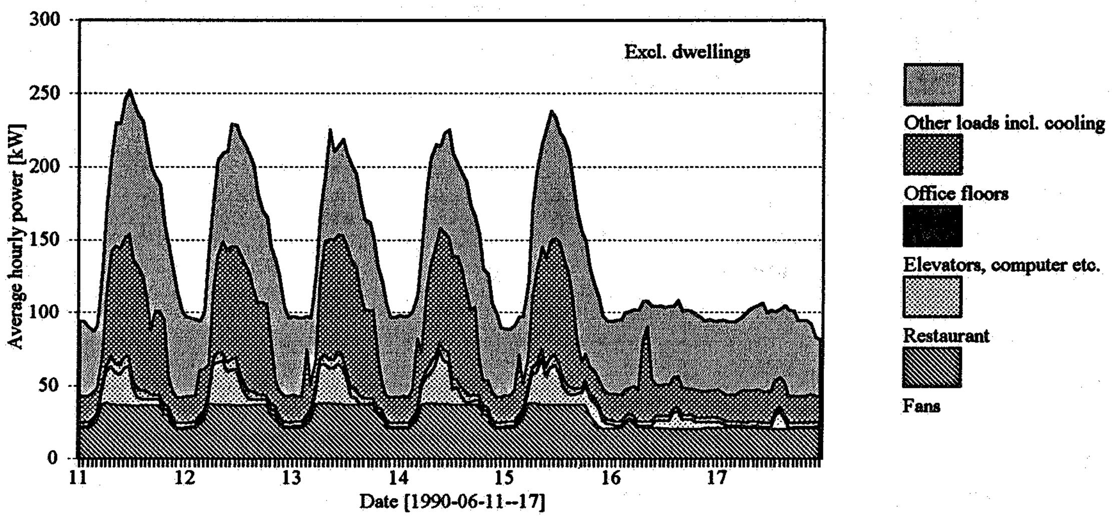

Figure 6 Power profile for the Svaneholm office building **before** implemented ECMs

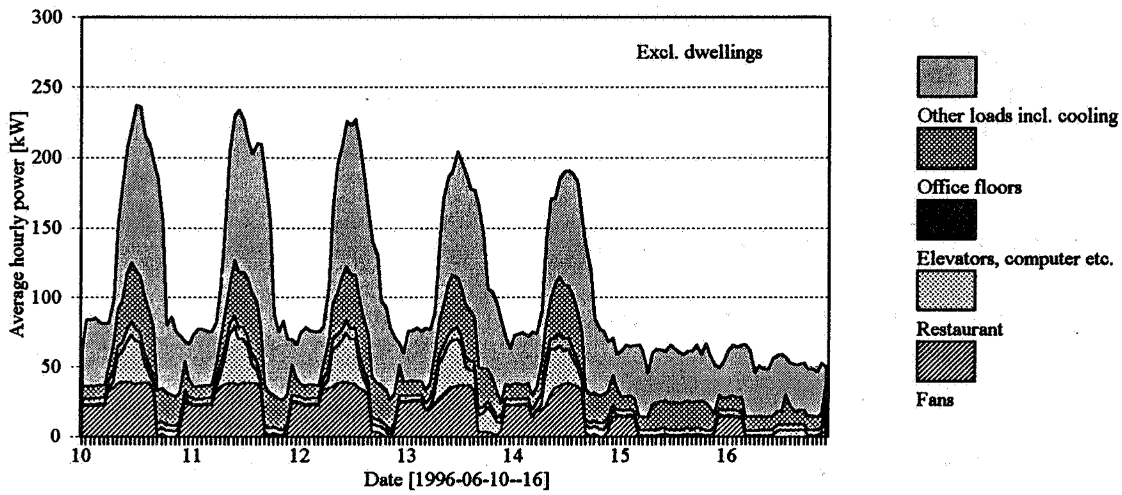

Figure 7 Power profile for the Svaneholm office building **after** implemented ECMs

A comparison between these two figures shows that the energy and power used for **Office floors** (i.e. lighting and plug loads as PCs etc) as well as for **Fans** are substantially reduced. However, it should be noted that all HVAC measures were not yet implemented when the power profile in **Figure 7** was plotted. Due to circumstances not connected to the project, the power use for **Other loads** has increased.

3.3 A Short Example of Load Factor Influence

To show the influence of the load factor level and its time variation some other DOE2 simulations for the Svaneholm office building were carried out. In the basic simulation (left column in **Figure 5**) a load factor schedule based on real measurements was used. In a second serie of simulations a load factor schedule according to the ASHRAE 90.1-1989 Standard [6] was used. In both cases the same criteria for satisfactory indoor climate was set.

The ASHRAE simulations indicated that more energy was to be used for ventilation as well as for the cooling system. The electric power demand for cooling equipment was about 10 kW higher according to the ASHRAE simulation. The HVAC system would probably become oversized if it was designed in accordance with the ASHRAE schedule. This example demonstrates the importance of using correct and relevant load factors when simulations are to be carried through and, above all, when HVAC systems are to be designed in reality.

As mentioned before, correct design of the HVAC systems does not only result in reduced investment and operational costs, but also in environmental benefits such as less use of CFCs etc.. The difference regarding the demand for cooling between the ASHRAE simulation and the basic simulation for the Svaneholm building corresponds to a difference concerning the CFC volume of about 10 kg.

Of course, a use of relevant load factor schedules is also very important when ECM simulations is to be done, as e.g. those shown earlier in **Figure 5**. Often, the same type of ECM lead to quite different energy savings if the simulations are based on different load factor schedules. The higher an office's internal loads (lighting, office machines etc.) are, the more important is a correct load factor assumption.

4 SPECIFIC FAN POWER MEASUREMENTS

In order to classify ventilation systems with respect to energy efficiency, different factors are used. One is the so called SFP value (Specific Fan Power). The SFP value is defined as the total fan motor power installed divided by the total air flow through the building.

In some Swedish projects the goal has been to reach a SFP level of 1.5 kW/(m³/s) or less. However, it is not easy to reach that level in existing buildings even when extensive renovation work is to be carried out.

In **Figure 8,** SFP values for the four buildings in our main project are presented.

	Specific Fan Power [kW/(m^3/s)]			
Office building	Lorensberg	Svaneholm	Stampen	Lagern
Rated data	3.7	3.6	5.2	2.9
Measured	2.2	2.6	4.6	2.8

Figure 8 SFP values for the four Swedish project office buildings **before** ECMs

A comparison between the figures above and Swedish (as well as American) limits regarding SFP values shows that most SFP values considerably exceed these limits. However, this result was also expected, since the four buildings are not built according to current standards.

Figure 8 also indicates a fact that we have seen in many offices that we have studied. There are often great differences between SFP values based on rated data (motor power and air flow) and SFP values based on measured data.

The above values may be classified as high compared to the levels that we discuss today. However, with the exception of the Stampen value the SFP values for the four project buildings are not extremely high. In **Figure 9,** SFP values for seventeen Swedish office buildings that we also have studied are shown as a comparison.

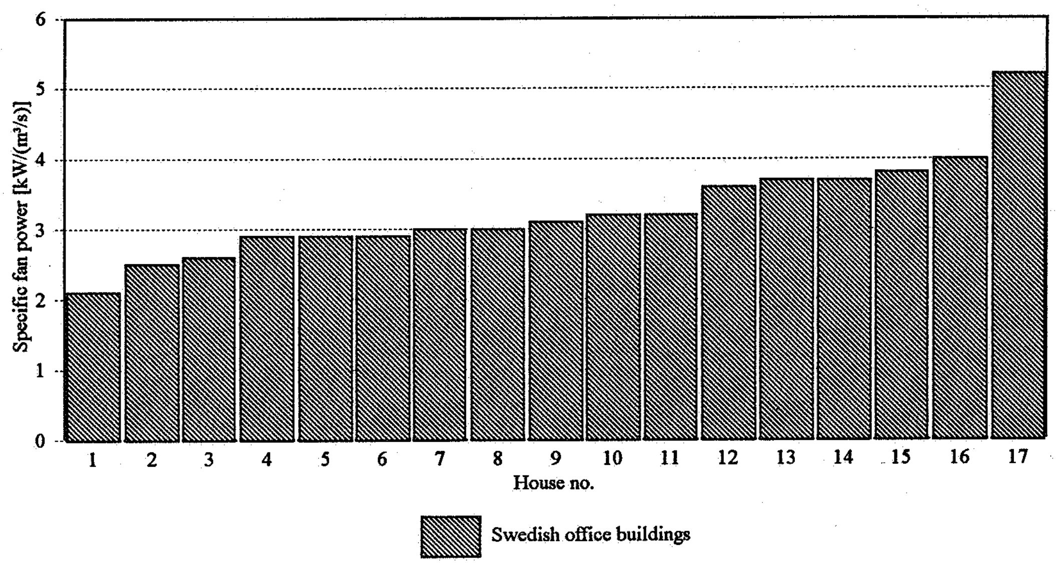

Figure 9 SFP values based on rated data in seventeen Swedish office buildings

5 AN OVERALL VIEW IS IMPORTANT WHEN PLANNING ECMs

By implementing appropriate ECMs the use of electricity and heat energy may be considerably reduced and also lead to a better indoor climate. However, it is important to have an overall view on the building and its systems and take all effects of interacting ECMs and systems into account.

The result of the DOE2 simulation shown in **Figure 5** above demonstrates this . When only lighting measures (Measure no 1) were carried out, a great reduction of the use of electricity was obtained - but **more** energy had to be supplied for heating. However, when also HVAC measures (Measure no 2) were carried out, the heat energy use as well was reduced considerably.

ACKNOWLEDGEMENTS

Bengt Dahlgren AB would like to thank the Swedish Council for Building Research (BFR) for funding the main part of our research as well as the Swedish National Board for Industrial and Technical Development (NUTEK) for funding most of the implementation of the energy conservation measures. We are also very grateful to the four biggest insurance companies in Sweden who own the project buildings, for all their support and pleasant collaboration during several years.

REFERENCES

1. NILSON, A. and HJALMARSSON, CH.
"Energy Use in Swedish Office Buildings."
The European Directory for Energy-Efficient Buildings, James & James Science Publishers Ltd, 5 Castle Road, London NW1 8PR, UK, 1994.

2. NILSON, A. and HJALMARSSON, CH.
"The End-Use of Electricity in Four Office Buildings - Measurements, Analysis and Experiences"
R56:1993, Swedish Council for Building Research, Stockholm, Sweden, 1993. (In Swedish[1].)

3. NILSON, A., HJALMARSSON, CH. and UPPSTRÖM, R.
"Energy Use and Indoor Climate in Office Buildings - A Follow-up Study of Four Buildings by Measurements and Questionnaires"
Swedish Council for Building Research, Stockholm, Sweden, to be published in the autumn of 1996. (In Swedish[1].)

4. REN, J.X.
"Night Ventilation for Cooling Purposes, Analysis Based on a Monitored Office Building"
Document D31:1995 (Licentiate thesis), Department of Building Services Engineering, Chalmers University of Technology, Gothenburg, Sweden, 1995.

5. JAGEMAR, L.
"Design of Energy Efficient Buildings, Applied on HVAC Systems in Commercial Buildings"
Document D34:1996 (Doctoral thesis), Department of Building Services Engineering, Chalmers University of Technology, Gothenburg, Sweden, 1996.

6. ASHRAE.
"Energy Efficient Design of New Buildings, Except New Low-Rise Residential Buildings"
ASHRAE/IES Standard 90.1-1989.
American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA, USA, 1989.

7. DOE2 BASICS. Simulation Research Group, Centre for Building Science, Applied Science Division, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720, USA, 1991.

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[1] A summary report based on reference 2 and reference 3 will be published in English in the autumn of 1996