Volume 38 No. 4 1991 ISSN 0306–2619

(25)

APPLIED ENERGY

Editor

S. D. PROBERT

ELSEVIER APPLIED SCIENCE

Applied Energy **38** (1991) 283–291

Is Space Heating in Offices Really Necessary?

Stig-Inge Gustafsson & Björn G. Karlsson

IKP/Energy Systems, Institute of Technology, S 581 83 Linköping, Sweden

ABSTRACT

New office buildings in Sweden are thoroughly insulated due to the Swedish building code. This code, however, does not consider the type of activity occurring in the building. This means that the heating equipment is designed as if no activity at all is going on. In modern offices there is a lot of equipment installed which uses electricity. This electricity is converted into heat which can be utilized for heating the premises, mostly in a direct way but also by the use of exhaust-air heat-pumps or heat exchangers. This paper deals with a modern office building plus office hotel complex located in Linköping, Sweden, about 200 km south of Stockholm. The tenants deal with the design of hard- and software for computers. The lighting and computers in the building use electricity which converts into heat. In this paper, it is shown that this electricity is all that is needed during normal conditions, i.e. when people work in the building. The building is also equipped with a district-heating system, which is designed as if no activity goes on in the building, so subsequently the heating equipment is larger than it need be. In this special case, it might have been better to install an electric heating device for hot-water heating and very cold winter conditions, instead of using district heating. This is so even if district heat is about half the unit price compared with that due to the dissipation of electricity. At present, when district heating is used, no measures for saving heat can be profitable due to the low district-heating price. The fact is that the tenants complain of too much heat instead of too little: the prevailing indoor temperature was about 24°C in January 1990 even though 20°C would have been sufficient. There is subsequently a need for a properly working regulation system. The one currently in use is designed to a modern standard, but is not able to maintain temperatures at a modest level.

Applied Energy 0306-2619/91/$03·50

INTRODUCTION

Early in 1990, the Swedish State Power Board financed an enquiry into many different industries to determine how to reduce the need for electric power before the Swedish nuclear power plants are phased out in the year 2010. One of these examinations dealt with a modern office building where research and design of both hard- and software for computers is undertaken. The offices are also equipped with an excessive amount of lighting which consumes electricity, and a ventilation system using big fans for the transportation of clean and used air in and out of the building. A monitoring program was developed in order to find out how much, for what, and when electricity and heat are used in the building. The monitoring occurred for about three weeks in January because there was a need for measures during winter conditions. Unfortunately the month of January 1990 was extremely mild and the subsequent results must be considered with this in mind.

THE BUILDING

The building contains about 5200 m^2 of floor area of which 4800 m^2 are used by the tenants. The total transmission factor has been calculated, and is shown in Table 1.

In Linköping the design outside temperature, according to the Swedish Building Code, is $-19°C$, while the inside temperature is set to $+20°C$. This means that the thermal load because of transmission is about 85 kW.

VENTILATION

The ventilation equipment is designed to distribute about 26 000 m^3/h and the thermal load, due to the code, has been calculated to be 112 kW or 2574 W/K. It has been assumed that the HVAC system is equipped with an air-to-air heat exchanger with an efficiency of about 70%. The values for air flow and efficiency, calculated as in Ref. 1, have been confirmed by the measurements. There is also a regulation system that turns off the fans when nobody is working in the building. If the temperature is higher than a certain value, the fans are turned on automatically as long as this temperature prevails. The building is constructed using concrete floors with pipe-formed cavities: the ventilation flow is transferred through these cavities and fans distribute heat from high-temperature parts of the building to places with low temperatures.

TABLE 1
Transmission Factors for Different Building Components

	Area [m^2]	*U-value*[a] [$W/m^2 K$]	*Area × U-value* [W/K]
Attic floor	1 340	0·15	201·0
External walls	2 565	0·20	513·0
Base floor	1 340	0·30	402·0
Windows	538	2·0	1 076·0
Total			2 192·0

[a] See Ref. 1.

CLIMATE CONDITIONS

In order to calculate an energy balance over one year for the building, it is necessary to use information about the mean outdoor temperature. The Swedish Meteorological and Hydrological Institute has compiled temperatures for 1989, and mean values for a 30-year period, for the Malmslätt site which is not far away from Linköping (see Table 2).

The reason for choosing 1989 as the considered year is that it is the most recent for which the actual consumptions of district heat and electricity are known. The temperatures for 1989 result in the number of degree hours shown in Table 3 if it is assumed that one degree hour is generated as long as the outdoor temperature is colder than the desired inside temperature. The desired inside temperature is set to 24°C because the measurements showed that that was the actual mean temperature during the monitoring period. The monitoring programme showed that the ventilation system was used far more than expected. This may be due to a new computerized system having been installed. However, it is expected that the system was used in the same

TABLE 2
Outdoor Temperatures in the Neighbourhood of Linköping, Sweden

	1989	*Means for 1931–1960*		*1989*	*Means for 1931–1960*
January	3·9	−2·9	July	17·5	17·7
February	3·4	−3·0	August	14·8	16·4
March	4·0	−0·1	September	11·0	12·2
April	5·7	5·3	October	7·0	7·1
May	12·1	11·0	November	2·1	2·7
June	15·3	15·4	December	−1·3	0·0

TABLE 3
Degree Hours for the Ventilation System and the Climate Envelope

Month	*Hours*	*Temperature difference (°C)*	*Ventilation*[a] *(h °C)*	*Envelope (h °C)*
January	744	20·1	10 130	14 954
February	672	20·6	10 382	13 843
March	744	20·0	10 080	14 880
April	720	18·3	9 223	13 176
May	744	11·9	5 997	8 853
June	720	8·7	4 384	6 264
July	744	6·5	3 276	4 836
August	744	9·2	4 636	6 845
September	720	11·7	5 897	8 242
October	744	16·3	8 215	12 127
November	720	21·9	11 037	15 768
December	744	25·3	12 751	18 823

[a] Calculated as 504 h × temperature difference.

way as during the first weeks of 1990: this means that the equipment is running from 8 am to 12 pm during workdays and from 2 pm to 12 pm during Saturdays and Sundays. At other times it is turned off. Thus the ventilation system operates about 504 hours each month. Using these values leads to the data in Table 3.

HOT-WATER HEATING

There is also a need for hot-water heating in the building. No special monitoring of this heat has been made but the magnitude of heating for this purpose can be found by examining the district heating measurements during summertime, i.e. when no space heating at all is supposed to be necessary. In this way, it can be found that about 5 kW is applicable as a mean value for a whole month.

FREE HEAT

There is also a lot of 'free' heat in the building, from solar radiation, heat from persons and from appliances. The solar radiation has been calculated for the four different orientations of the windows by use of a computer program.[2] The values are presented in Table 4. These values are to be

TABLE 4
Solar Radiation through Triple-Glazed Vertical Windows in kWh/m² for Different Orientations in Linköping, Sweden, Lattitude 58·3°N

Month	*North*	*East*	*South*	*West*
January	1·1	3·9	21·3	3·9
February	2·6	10·3	34·5	10·3
March	6·9	26·6	54·7	26·6
April	10·8	39·1	51·5	39·1
May	16·2	55·9	58·3	55·9
June	17·3	57·2	56·8	57·2
July	17·1	57·2	57·7	57·2
August	13·4	47·0	54·8	47·0
September	8·6	32·0	53·6	32·0
October	4·2	16·1	43·5	16·1
November	1·3	4·9	22·2	4·9
December	0·6	2·1	14·7	2·1

multiplied by the appropriate areas of the windows for the different orientations, in order to ascertain the heat gains (see Table 5).

The free heat from people visiting and working in the building is assumed to be of the magnitude of 100 W for each person. It is also assumed that there are about 75 people in the premises. Free heat from appliances and lighting is the overwhelming part of the free gains in the building. The electricity meters

TABLE 5
Energy Balance in kWh for the Office Hotel in Linköping, Sweden

Month	*Losses from*			*Supplies from*			
	Transmission	*Ventilation*	*Hot water*	*Solar*	*People*	*Appliances*	*District heating*
January	32 779	26 074	3 720	3 476	5 580	50 478	3 720
February	30 343	26 723	3 360	6 730	5 040	45 565	3 360
March	32 617	25 945	3 720	13 632	5 580	50 478	3 720
April	28 881	23 740	3 600	16 983	5 400	50 708	3 600
May	19 406	15 436	3 720	22 739	5 580	54 350	3 720
June	13 731	11 284	3 600	23 091	5 400	52 597	3 600
July	10 600	8 432	3 720	23 152	5 580	54 350	3 720
August	15 004	11 933	3 720	19 647	5 580	54 350	3 720
September	18 066	15 178	3 600	15 114	5 400	52 597	3 600
October	26 582	21 145	3 720	9 398	5 580	54 713	3 720
November	34 563	28 409	3 600	3 850	5 400	53 300	4 022
December	41 260	32 821	3 720	2 115	5 580	55 077	15 029
Total	303 832	247 120	43 800	159 927	65 700	628 563	55 531

in the building have been read at about four-monthly intervals and the bills have been sent to the tenants. Using these billing statistics, the amounts of free energy are presented in Table 5.

ENERGY BALANCE

The discussion above shows the basis for calculating how much heat should be supplied to the building. The values are shown in Table 5 and the technique is presented in more detail in Ref. 2. From the Table, it is obvious that only a very small amount of space heating is necessary to be drawn from the district-heating system. In November and December a total of 11 731 kWh is assumed to be used for this purpose. Through the whole year, a total of 55 531 kWh has been calculated to be supplied and this is about 11 kWh/m^2. The billing statistics show that in fact 220 400 kWh were delivered, or about four times more than was needed. Note also that an indoor temperature of 24°C was used in the calculations, while 20°C is a more common reference temperature.

ANALYSIS

It should have been possible to heat the office hotel in Linköping solely with free heat from appliances, solar radiation and from people, at least if a desirable indoor temperature of 20°C was used. Why, then is there such a big discrepancy between the calculated and the monitored values? Some possible explanations are:

—errors in the values assumed for the thermal envelope of the building;
—errors in the values for the ventilation flows;
—too few degree hours;
—too small an assumed hot-water consumption;
—too high assumptions for the free gains from the appliances, people and solar insolation.

The thermal status of the building has been calculated by use of the construction data and the area of the envelope. Two different calculations have been made, by the designer of the HVAC system and by the authors of this paper. Both calculations show the same magnitude of thermal losses. There is also a risk of bad workmanship when the building was constructed. The owner of the office hotel, however, has competent personnel who inspected in detail the building during construction, and subsequently.

The capacity of the ventilation equipment has been measured with a Pitot tube and the air flow was found to be very close to the design value. The heat exchanger's performance could be poor but temperature measurements on each side of the exchanger showed that the values seemed to be better than the ones assumed. There is also a possibility that the ventilation system is used far more than anticipated, but this is unlikely.

The number of degree hours used in this investigation is derived from calculations based on official statistics from the Swedish Meterological and Hydrological Institute. The Malmslätt site where the measurements are actually undertaken is only about 10 km from the location of the office hotel. The hot water use might be underestimated. The value used comes from a mean value for six months during the summer and it seems unlikely that this can be the cause of all the encountered differences.

Instead, it seems that the building cannot use all of the free energy available to the premises even if it is specially designed for doing so. The free energy comes principally from the electricity used for lighting and running the computers. The value is metered using ordinary electrical meters which serve for billing the utility. There is thus no severe risk of errors in the electrical metering.

Further, it might be supposed that a lot of the equipment is in fact located outside the building and subsequently the free gains will not be available. Such equipment exists, e.g. some cooling devices and outside lighting. Two of the ventilation fan motors are also located in such a way that most of the free heat from them will disappear directly to the ambient outside air.

This analysis led to a repeat calculation of the energy balance for the building, but with the assumption that about 10 kW, which was found to be applicable, of free power never being available in the building. These calculations show that the use of district heating is supposed to be doubled, to about 120 000 kWh each year, or about half the real consumption. However, monitoring in the building makes it possible to investigate if free energy is utilized in the way it is supposed to be.

UTILIZATION OF FREE ENERGY

It is obvious (see Fig. 1) that the district heating supplied goes down when the electricity use increases. The district heating, however, does not decrease as much as expected. Looking at the second peak in the figure, at about 97 hours, the electricity peak is about 50 kW while the decrease in district heating is only about 20 kW. The minimum use of district heat is about 20–30 kW irrespective of how much electricity is utilized. The decrease in district-heat usage during day-time could also depend on the outdoor

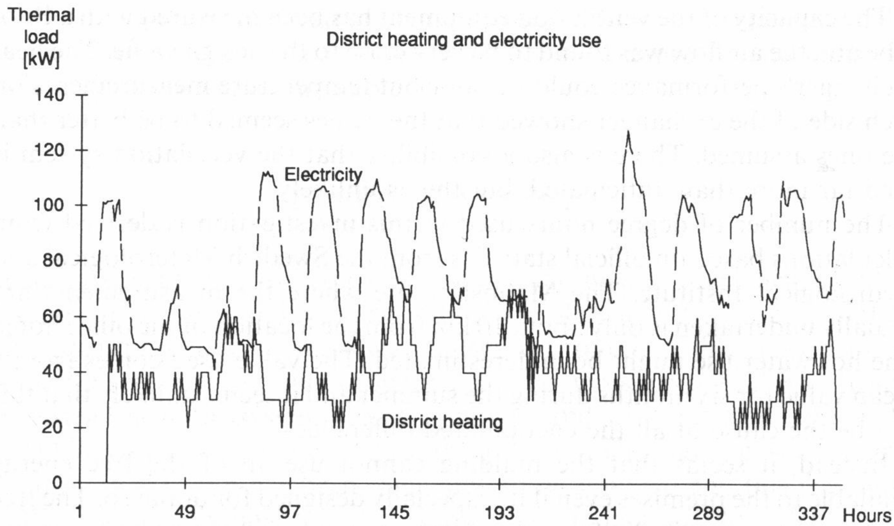

Fig. 1. District heating and electricity use for two successive weeks during January 1990.

temperature which usually increases during the day. In Figs 2 and 3 the outdoor temperature and the district heating load are depicted.

After the first peak in the temperature curve, at about 10 hours, the temperature falls from 5·5 to about 1·5°C. At the same time the district heating load increases from about 30 to 70 kW.

There is an influence of the outdoor temperature upon the district-heating load but it also seems that a temperature fall of about 4°C results in a relatively large increase in the district-heating load: about 20 kW would be expected. Another means of determining the significance of the free heat in the building is to examine whether the building has a long time constant.

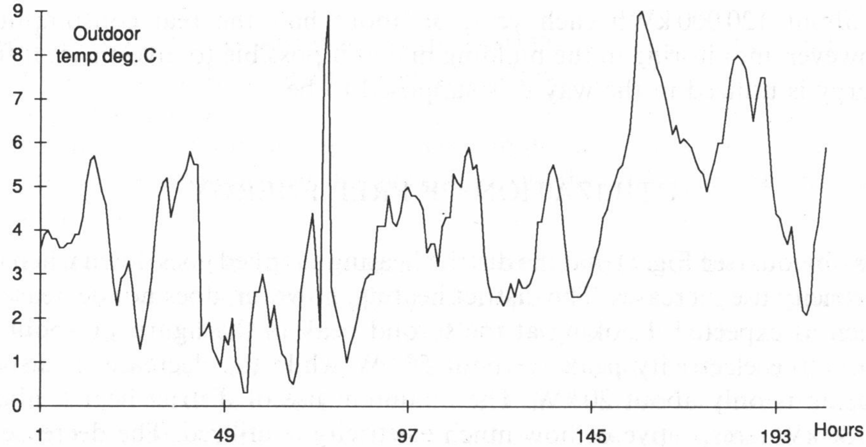

Fig. 2. Outdoor temperature in Linköpong for two weeks during January, 1990.

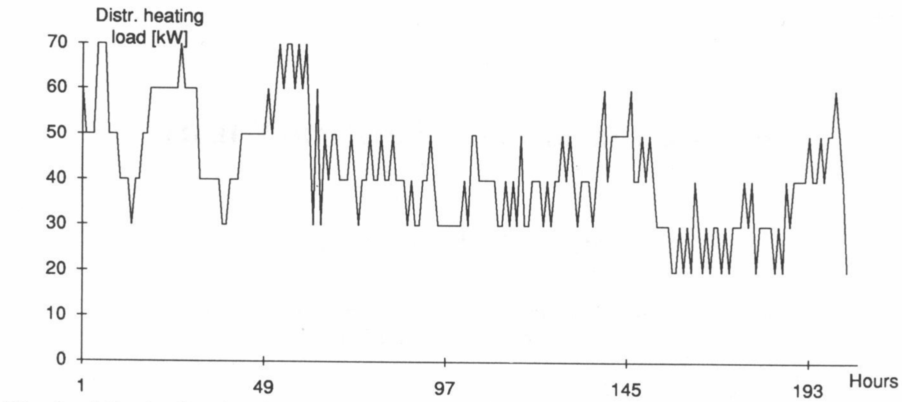

Fig. 3. District heating load in the considered office/hotel, Linköping Sweden during two weeks in January, 1990.

(The time constant of the building shows how fast the temperature in the building can be increased or decreased.[1]) If the outside temperature falls there should be a certain time gap before the district-heating load increases. As can be seen from the curves, no such gap exists. The district-heating load increases simultaneously as the outdoor temperature decreases.

CONCLUSIONS

This investigation of an office building in Linköping, Sweden, implies that it should be possible to utilize the free energy from people, solar insolation and appliances so that no space heating at all would be necessary. The investigation also showed that the building at present could not harness fully the free energy in the desired way. This would be so even if the building were better designed. The building is thoroughly insulated and a very heavy concrete construction is used for the floors; further, the ventilation flow is led through cavities in these floors, but this does not seem to influence the rate of energy use significantly. The investigation also shows the importance of regularly checking the rate of energy use in a building in a simple way. Otherwise it is very difficult to reveal if any inadequacies exist in the building or in the system for energy regulation.

REFERENCES

1. Holman, J. P., *Heat Transfer*, 6th printing. McGraw-Hill International Book Co, New York, 1985.
2. Gustafsson, S. I. & Karlsson, B. G., Life-cycle cost minimization considering retrofits in multi-family residences. *Energy & Buildings*, **14**(1) (1989) 9–17.

APPLIED ENERGY

VOL. 38 NO. 4 1991

(Abstracted/indexed in: *Applied Mechanics Reviews; Chemical Abstracts; Current Contents; Energy Information Abstracts; Engineering Abstracts; Geo Abstracts; GEOBASE; Science Citation Index*)

CONTENTS

ELSEVIER APPLIED SCIENCE