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32.

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Climate Influence on District Heating and Electricity Demands

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ABSTRACT

This paper describes the district heating and electricity load of Kalmar, Sweden. Unfortunately, it has not been possible to examine one full year because the monitoring of the energy use for district heating and electricity, and the outdoor temperature, did not exactly overlap. However, more than 7200 h, of the 8760 in a full year, have been examined. It is shown that the district heat load has a far higher correlation with the outdoor temperature (a coefficient of 0·89), than has the electricity load (0·33). Thus, it is much easier to predict the influence of, e.g. an insulation retrofit for the building stock where district heating is used compared with electricity space heating. It is also shown how an estimate can be made of the thermal transmission factor for the total building stock.

INTRODUCTION

When energy-system mathematical models for the behaviour of municipal combined heat and power (CHP) networks are developed, it is important to introduce presumed district heating and electricity loads that closely reflect reality. Because of constraints in monitoring and calculation time, it is not financially viable to employ real values for each hour of the year. Therefore simplifications are introduced. In some papers[1,2] dealing with the CHP network in Malmö, Sweden, a mixed integer model has been adopted. The model is used for optimization of the CHP system and to find out if it is better to produce more heat and electricity or to implement thrift measures that will decrease the energy need. In these papers, the district heating load was assumed to be reflected by a gigantic fictitious building. The load was

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calculated by the use of this building and the monthly mean values for the outdoor temperature. It was ascertained that the estimated overall use of district heating for one year was consistent with reality. The building could be modified by the application of extra insulation or other energy retrofits. The electricity load had been monitored and split up in the same segments as for the electricity time-of-use tariff. However, it was not possible to split up the load for different users and therefore, assumptions had to be made as to how a building retrofit would affect the electricity load. One more reason for examining real load data is because of the growing interest in energy-storage equipment. If a heat accumulator is to represent a profitable investment, usually it must be used as often as possible, with short intervals between charging and discharging. It soon became obvious that more knowledge about real loads for both district heating and electricity was essential in order to devise better models. The municipality of Kalmar in the south of Sweden has provided monitored data that show the outdoor temperature, as well as the district heating and the electricity loads for each hour during one year. Unfortunately, the data series are not exactly overlapping and further, some error in the temperature measurements made some parts of the raw data impossible to use. However, almost 7300 h from the years 1990 to 1991 are covered by unbroken series.

SOME STATISTICAL MEASURES

It would be cumbersome to present the total input data, containing about 24 000 values, in a paper like this. Thus some statistical measures have been calculated and are presented in Table 1. The 'best fit' equation, due to the method of least squares, shows the loads in MW as a function of the outdoor temperature in degrees Celsius. It is assumed that the building stock is to be heated up to 20°C and thus all the outdoor temperatures have been subtracted from that value. The expressions used are:[3]

$$b = [n\sum xy - \sum x \sum y]/[n\sum x^2 - (\sum x)^2] \tag{1}$$

$$b_0 = y_{mean} - bx_{mean} \tag{2}$$

In the same way, the correlation coefficients are calculated in order to determine the relative influences of the temperature on the loads. The coefficients are calculated as:[3]

$$r = [n\sum xy - \sum x \sum y]/\{[n\sum x^2 - 1(\sum x)^2][n\sum y^2 - (\sum y^2)]\}^{0 \cdot 5} \tag{3}$$

The standard deviations have been calculated as:[3]

$$s = \{[\sum(x_i - x_{mean})^2]/(n-1)\}^{0 \cdot 5} \tag{4}$$

TABLE 1
Derived Information for the District Heating Load, Electricity Load and Outdoor Temperature

Variable	*Mean*	*Standard deviation*	*Correlation*	*'Best-fit' equation*
20°C, outdoor temperature t	8·95	6·855	—	—
District heating load	19·26	11·689	0·895	$Q_{dh} = 5{\cdot}6 + 1{\cdot}525t$
Electricity load	41·96	12·663	0·326	$Q_e = 36{\cdot}6 + 0{\cdot}602t$

As can be seen in Table 1, the mean of the district heating load is about half that for the electricity load. The standard deviations are about the same magnitude and thus it could be assumed that they vary to about the same extent.

The correlation coefficients show that the district heating load has a much higher correlation (0·895) with the outside temperature, that that for the electricity load (0·326). If the 'best fit' expressions are used, it could therefore be assumed that a higher accuracy prevails if the district heating load is calculated by use of the expression in Table 1 than if the electricity load is calculated by use of the corresponding equation.

CLOSER STUDY OF THE DATA SET

In Fig. 1, the electricity and district heating loads during one week, and how they vary with the outdoor temperature, are presented. It is obvious that the district heating load has a closer correlation with the outdoor temperature

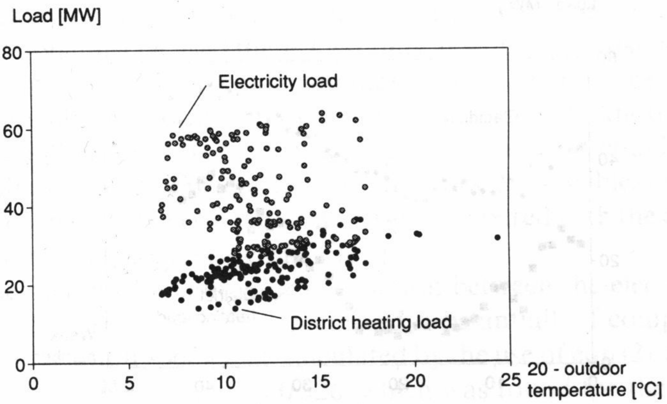

Fig. 1. District heating and electricity loads in Kalmar; 14:00 h on 19 March 1990 to 13:00 h on 26 March 1990.

than the electricity load, as indicated by the statistical measures in Table 1. However, it seems that the standard deviation should be much larger for the electricity load, if only Fig. 1 is considered. This is because the load is more widely scattered. One reason for this is that the electricity load could vary to the same extent around its average mean value 41·96 MW as the district heating load does around 19·26 MW if the total measuring period is considered. It is not possible to show all the 14 000 values, but in Fig. 2 the average loads for 43 consecutive weeks are presented. From the figure, it is obvious that the district heating load varies more due to the time of the year than does electricity load. The standard deviations for the two loads calculated on the weekly average values in Fig. 2 are 10·685 for the district heating and 7·091 for electricity. These calculations thus show the opposite result compared with the values found in Table 1; the district heating load varying more than the electricity load.

The reason for the disagreement is that the loads vary due to the time of day. In Fig. 3, the loads and outdoor temperature are presented as functions of the hours in one week (19–26 March 1990) and it can be found that the electricity load increases when the temperature gets higher and vice versa. This is so because people start to work in the morning, and this effect on the load is much higher than the climatic influence. The district heating load varies in the opposite direction, i.e. when the outside temperature gets higher, the load will decrease. There is a time lag between fluctuations of the outdoor temperature and of the two loads.[4] When the temperature falls or rises it would take some time before this could be observed in the load values. However, no such lag could be observed in the data set.

From the above discussion, it is clear that it is not easy to find the part of the electricity load that depends only on the climate. If it could be possible to

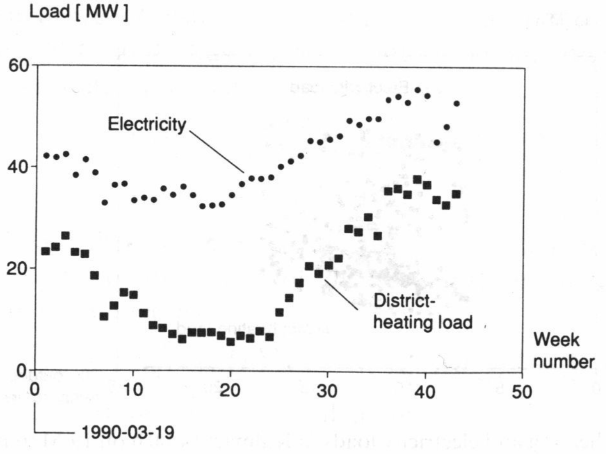

Fig. 2. Average electricity and district heating loads for 43 weeks starting 19 March 1990.

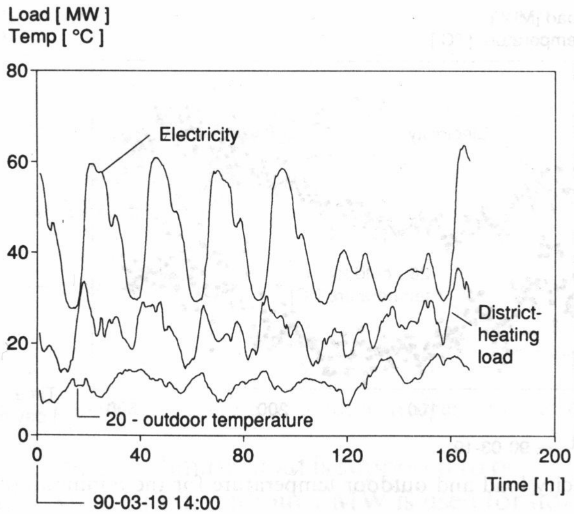

Fig. 3. District heating, electricity load and outdoor temperature for one week starting at 14:00 h on 19 March 1990.

run the values through a filter, taking away the influence that the load will increase just because of the time of day when people start to cook their meal in the morning and to start work, the climatic load effects. Unfortunately, it proved very difficult to find an equation for this even if the amplitude and the frequency are known, i.e. about 30 MW and 24 h. This is in part due to the fact that the increase of the electricity load in the morning has a steeper slope than the decrease in the evening. Ordinary trigonometric functions, and some further combinations of such functions, have been tested but with disappointing results. One more problem is that the amplitude changes very much at the end of each week and therefore some other expression must be used there. Certainly, it would be possible to devise a computer program that could simulate the load, but the effort for this will probably be too much compared with the yield. Another way to decrease the influence of, for example, the industrial load could be to use only the values each day when the load is as low as possible, and use the correlation coefficient to see if it has increased compared with the one for the total database. This is presented in Fig. 4.

As can be seen in the figure, the correlation between the electricity load and the outdoor temperature has increased substantially if compared with Fig. 1. The correlation coefficient, calculated by the use of eqn (3), also shows this, and is now 0·748 instead of 0·326, which was found for the total data population. The climate therefore, has a much larger influence on the values in Fig. 4 than on the values in Fig. 1. The same procedure applied to the

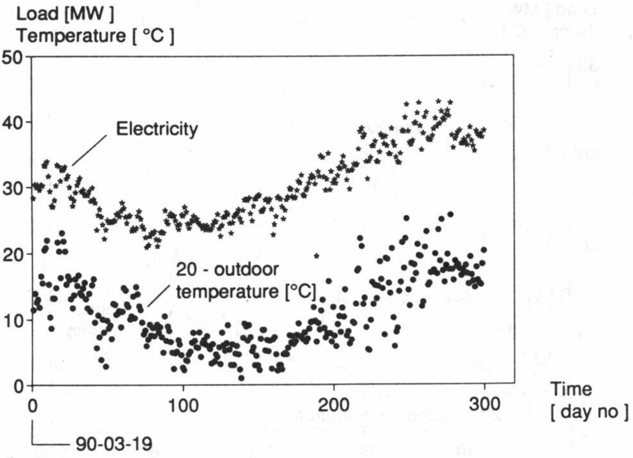

Fig. 4. Electricity load and outdoor temperature for the minimum point each day.

district heating load shows that the correlation will change from 0·895 to 0·892 which means that no further improvement was made. In Fig. 5, the minimum points for the district heating load each day and the corresponding outdoor temperatures are shown. It is important to notice that, even if the outdoor temperature varies considerably, the same variation could not be found in the load. During the summer the load is almost constant—see the values from about day 100 to 180. These show the situation when the outdoor temperature is close to or higher than 20°C and thus the temperature points in Fig. 5 will be located around zero or lower. This effect is not obvious in Fig. 4. Note that the minimum electricity points do not occur at exactly the same times as the minimum district heating points. No temperature values below zero occur in Fig. 4.

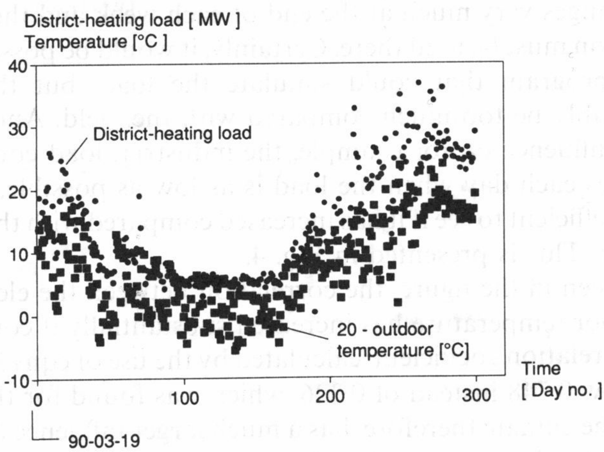

Fig. 5. District heating load and outdoor temperature for minimum daily load.

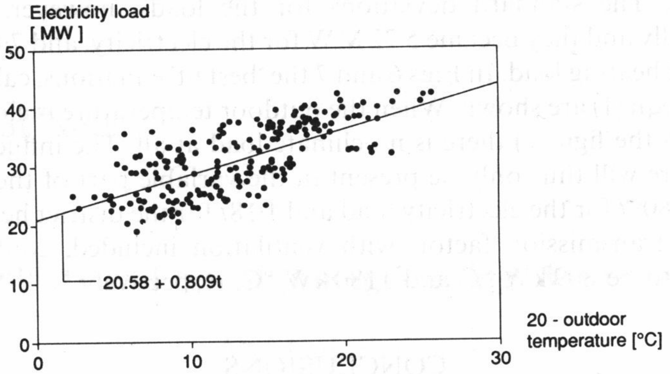

Fig. 6. Electricity load as a function of outdoor temperature, summer excluded.

During the summer, no climatic load is supposed to occur. For the district heating load, this will mean that about 7 MW is used for hot-water heating, which will probably be the sole use of the heat. The electricity load in Fig. 4 has a lowest value of about 21 MW, but it is not possible to say exactly how this electricity is used. Hot-water heating will be a part of the base load, but lighting and other uses for electricity also ensue. However, it could reasonably be assumed that from day 100 to 180, no electricity is used for space heating as was found for the district heating load. In Fig. 6, these values have been excluded from the electricity data set. The corresponding correlation coefficient has been calculated to be 0·707, i.e. slightly lower than for the total number of minimum load days. Therefore, this procedure made the situation worse, instead of better which would be expected. The situation is qualitatively similar for the district heating load—see Fig. 7.

The correlation coefficient for Fig. 7 was found to be 0·851, which is a decrease compared with the situation for the total amount of the minimum

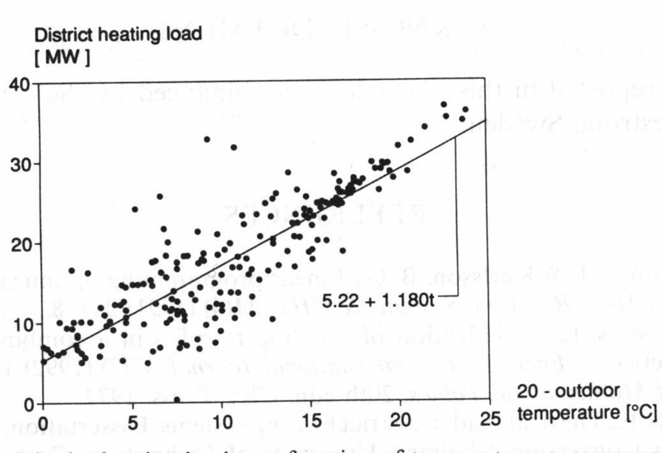

Fig. 7. District heating load as a function of temperature, summer excluded.

load days. The standard deviations for the loads, however, decreased substantially and they became 5·72 MW for the electricity, and 7·86 MW for the district heating load. In Figs 6 and 7 the 'best fit' equations, calculated by the use of eqn (1) are shown. When the outdoor temperature is close to 20°C (i.e. zero in the figures) there is no climate load at all. The influence of the temperature will thus only be present in the variable part of the functions which is $0{\cdot}809t$ for the electricity load and $1{\cdot}18t$ for the district heating load. The total transmission factor, with ventilation included, could thus be estimated to be 809 kW/°C and 1180 kW/°C, respectively.

CONCLUSIONS

By the use of simple statistical measures, the electricity and district heating loads of Kalmar, Sweden, have been examined and their variations correlated with those of the outdoor temperature. From the survey, it is concluded that the district heating load has a higher correlation (0·89) with the temperature compared with that (0·326) for the electricity load, if the hourly values are used. The low correlation for the electricity load could be explained as a result of the major variations occurring during the day. By the use of the minimum values on a diurnal base, the correlation between the electricity load and the outdoor temperature improved substantially, from a correlation coefficient of 0·326 to 0·748. The same procedure implemented for the district heating system load showed instead a slightly lower correlation and was therefore not of any interest. Excluding the values for the summer, when no climate load could be present, also showed a lower correlation than the values where all the minimum days were taken into consideration.

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CONTENTS

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