CLIMATE INFLUENCE ON DISTRICT HEAT AND ELECTRICITY LOADS

Stig-Inge Gustafsson
IKP/Energy Systems, Institute of Technology,
S581 83 Linköping, Sweden

Abstract

When mathematical models of energy systems are designed it is important to know how actions aimed for energy conservation will influence the total energy use. 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 heat and electricity, and the outdoor temeperature, did not exactely overlap. However, more than 7200 hours, 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, 0.89, than has the electricity load, 0.33. Thus, it is much easier to predict the influence of e.g. an insulation retrofit in the building stock where district heating is used compared with electricity space heating, common in Sweden today. It is also shown how an estimate is made for finding a so called transmission factor in W/K for the total building stocks connected to the different energy sources.

INTRODUCTION

When energy system models of municipal combined heat and power,CHP, networks are designed it is important to implement fictious district heating and electricity loads that closely reflects the reality. Because of constraints in monitoring and calculation time, it is not possible to use models dealing with real values each hour during a year. Simplifications must be used instead. In some papers, e.g. Refs. [1] and [2], dealing with the CHP network in Malmö, Sweden, a mixed integer model has been described. 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 conservation measures that will decrease the energy need. In these papers the district heating load was assumed to be reflected by a gigantic fictious building. The load was calculated by use of this building and monthly mean values for the outdoor temperatures. It was ascertained that the estimated overall use of district heat for one year was consistent with the real use. The building could after this be affected by extra insulation or other energy retrofits. The electricity load had been monitored and split up in the same segments as was found in the electricity time-of-use tariff. However, it was not possible to split up the load for different users and therefore, only assumptions could be made 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 be profitable it must be used as often as possible with short intervalls between charging and discharging. It was obvious that more knowledge about real loads for both district heating and electricity was essential in order to design better models. The municipality of Kalmar in the south of Sweden has provided monitored data that shows the outdoor temperature, 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 measurement made some parts of the raw data impossible to use. However, almost 7300 hours from the years 1990 to 1991 are covered in unbroken series.

SOME STATISTICAL MEASURES

Of course it is impossible to present the total input data, containing about 24000 values, in a paper like this. Thus some statistical measures have been calculated and presented in Table 1. The "best fit" equations , due to the method of least squares, shows the loads in MW as a function of the outdoor temperature in degrees Centigrade. 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 which is common when calculating the number of degree hours for a site. The expressions used are, see Ref. [3]:

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

$$b_0 = y_{mean} - b \times x_{mean} \tag{2}$$

In the same way the correlation coefficients are calculated for finding the influence on the loads of the temperature. The coefficients are calculated as, see Ref. [3]:

$$r = \frac{n \sum xy - \sum x \sum y}{\sqrt{[n \sum x^2 - (\sum x)^2][n \sum y^2 - (\sum y)^2]}} \tag{3}$$

The standard deviations have been calculated as, see Ref. [3]:

$$s = \sqrt{\frac{\sum (x_i - x_{mean})^2}{(n-1)}} \tag{4}$$

As can be found in Table 1 the mean of the district heating load is about half the size of the mean for the electricity load.

Variable	Mean	St. deviation	Correlation	Best fit equation
20 °C - outdoor temp	8.95	6.855	-	-
District heating load	19.26	11.689	0.895	$Q_{dh} = 5.6 + 1.525 \times t$
Electricity load	41.96	12.663	0.326	$Q_e = 36.6 + 0.602 \times t$

Table 1: Mean, standard deviation, correlation and "best fit" equation for district heating load, electricity load and outdoor temperature

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 with the outside temperature, 0.895, than 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 Figure 1 the electricity and district heating loads during one week, and how they vary with the outdoor temperature, are presented.

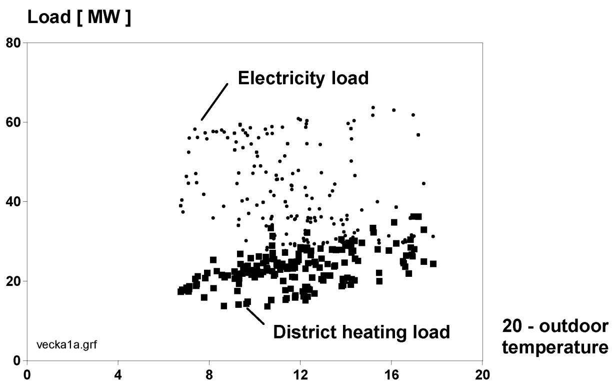

Figure 1: District heating and electricity load in Kalmar 1990-03-19 14:00 - 1990-03-26 13:00

It is obvious that the district heating load has a closer correlation to the outdoor temperature 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 Figure 1 is considered. This 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 Figure 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 the district heating load. The standard deviations for the two loads calculated on the weekly average values in Figure 2 are 10.685 for the district heating and 7.091 for electricity. These calculations thus shows the opposite result compared to the values found in Table 1, the district heating load varies less than the electricity load.

It is obvious that it is important to consider closely how the data is analysed

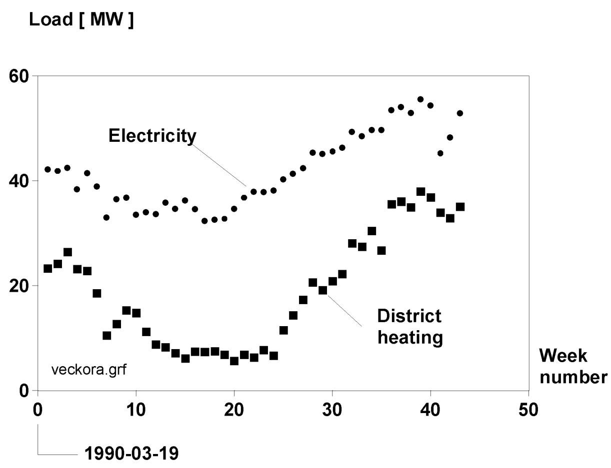

Figure 2: Average electricity and district heating loads for 43 weeks starting 1990-03-19

if any conclusions are to be made about the loads. The reason for the discouraging result is that the loads varies due to the time of day. In Figure 3 the loads and outdoor temperature have been presented as functions of the hours in one week, 1990-03-19 -1990-03-26 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. It could also be assumed that there must be a time lag between the outdoor temperature and the two loads, see for example [4]. When the temperature falls or raises it would take some time before the this could be observed in the load values. No such lag could be observed in the data set, or at least it is not obvious.

From the discussion above 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 run the values through a filter, taking away the influence of the fact that the load will increase just because of the time of day when people start to cook their meal in the morning and further start to work, the climatic load could be left for further analysis. Unfortunately, it proved very difficult to find such an equation even if the amplitude and the frequence are known, about 30 MW and 24 hours. This is to a part depending on the fact that the increase of the electricity load in the morning has a steeper slope then the decrease in the evening. Ordinary trigonometric functions, and further some combinations of such functions, have been tested but with a very poor result. One more problem is that the amplitude changes very much in the end of the week and therefore some other expression must be used there. Certainly, it would be possible to design a computer program which could simulate the load but the effort for this will probably be too much compared to the yield. Another way to decrease the

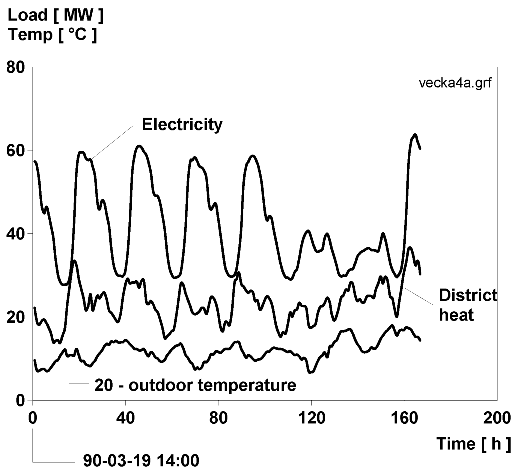

Figure 3: District heating, electricity load and outdoor temperature for one week starting at 90-03-19 14:00

influence of e.g. the industrial load could be to use only the values each day when the the load is as low as possible, and use the correlation coefficient to see if it has increased compared to the one for the total data base. In Figure 4 this is presented.

As can be found in the figure the correlation between the electricity load and the outdoor temperature has increased substantially if compared to Figure 1. The correlation coefficient, calculated by use of Expression (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 Figure 4 than on the values in Figure 1. The same procedure applied on the district heating load shows that the correlation will change from 0.895 to 0.892 which means that no further improvment was made. In Figure 5 the minimum points for the district heating load each day and the corresponding outdoor temperature are shown.

Important to notice is that even if the outdoor temperature varies very much, the same variation could not be found in the load. During the summer the load is almost constant, see the values from about day no 100 to 180. These values show the situation when the outdoor temperature is close to or higher than 20 °C and thus the temperature points in Figure 5 will be located around 0 or lower. This effect is not obvious to the same extent in Figure 4 even if it could be noticed once you know what looking for. Note that the minimum electricity points do not emerge the exact same hours as the minimum district heating points. No temperature values below 0 can be observed in Figure 4.

During the summer no climatic load is supposed to emerge. For the district heating load this will mean that about 7 MW is used for hot water heating which will probably be the only use for the heat. The electricity load in Figure 4 has a lowest value of about 21 MW but in that case it is not possible to say how

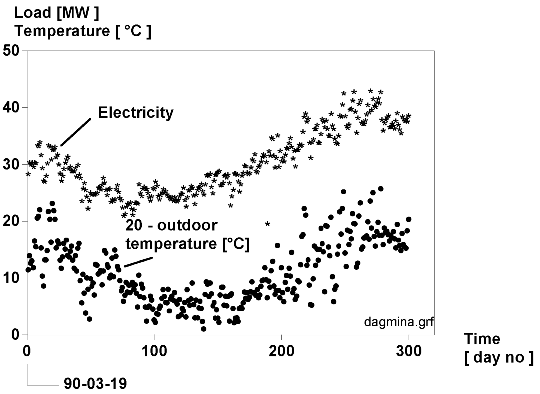

Figure 4: Electricity load and outdoor temperature for minimum point each day

the electricity is used. Hot water heating will be a part of the base load but lighting and other use for electricity is also covered here. However, it could be assumed that from day no 100 to 180 no electricity is used for space heating as was found for the district heating load. In Figure 6 these values have been excluded from the electricity data set.

The corresponding correlation coefficient has been calculated to 0.707, i.e. slightly lower than for the total number of minimum load days. Therefore, the procedure made the situation worse, instead of better which would be expected. The situation is alike for the district heating load, see Figure 7.

The correlation in Figure 7 was found to be 0.851, which also is a decrease compared to the situation for the total amount of the minimum load days. The standard deviations for the loads, however, decreased substantially and they are now 5.72 MW for the electricity and 7.86 MW for the district heating load. In Figures 6 and 7 the "best fit" equations, calculated by use of Expression (1) are shown. When the outdoor temperature is close to 20 °C, i.e. 0 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 $0.809 \times t$ for the electricity load and $1.18 \times t$ for the district heating load. The total transmission factor, with ventilation included, could thus be estimated to 809 kW/°C and 1 180 kW/°C respectively.

CONCLUSIONS

By use of simple statistical measures the electricity and district heating loads of Kalmar, Sweden, have been examined and their correlation with the outdoor temperature. From the survey it is obvious that the district heating load has a higher correlation with the temperature, 0.89, compared to the electricity load, 0.326, if values for each hour are used. The low correlation for the electricity load could be explained as a result of major variations during the day. By use of the minimum values on a diurnal base the correlation between the electricity load

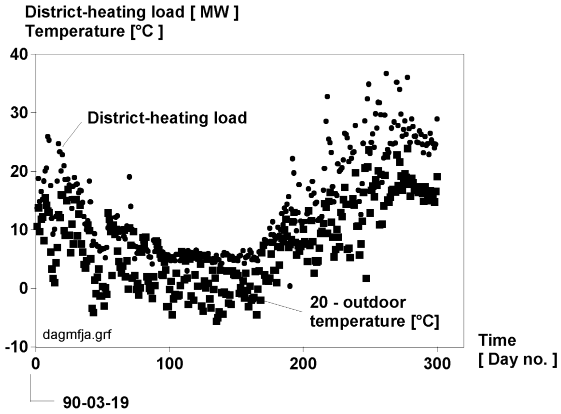

Figure 5: District heating and outdoor temperature for minimum daily load

and the outdoor temperature is improved substantially, from 0.326 to 0.748. The same procedure implemented on 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 showed also a lower correlation than the values where all minimum days were taken into consideration.

ACKNOWLEDGEMENT

The work with this paper has been financed by the foundation of Bengt Ingeström, Sweden

References

[1] Gustafsson Stig-Inge and Karlsson Björn G. Linear Programming Optimization in CHP Networks. *Heat Recovery Systems & CHP*, 11(4):231–238, 1991.

[2] Gustafsson Stig-Inge. Optimization of Building Retrofits in a Combined Heat and Power Network. *Energy - The International Journal*, 17(2):161–171, 1992.

[3] Anonymous. *Standard Mathematical Tables.* CRC press, 1972. 20 th edition.

[4] Werner S. E. *The heat load in district heating systems.* PhD thesis, Chalmers university of technology, Gothenburg, 1984.

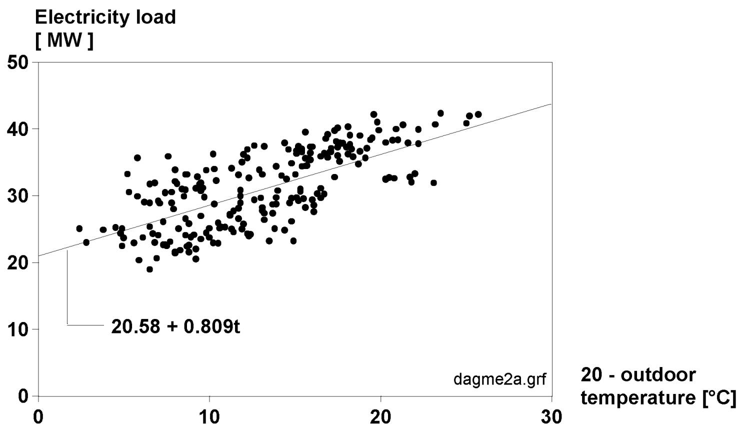

Figure 6: Electricity load as a function of outdoor temperature, summer excluded

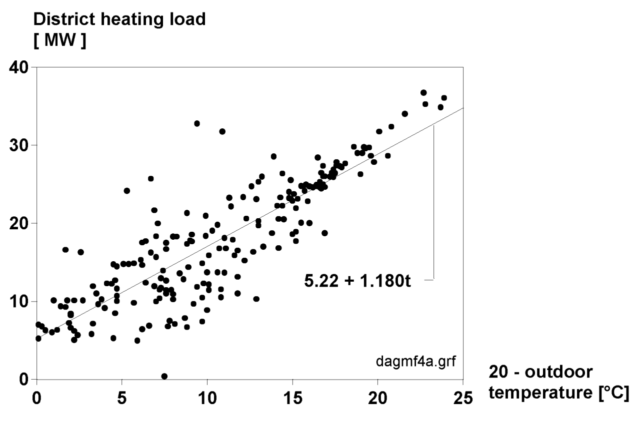

Figure 7: District heating load as a function of temperature, summer excluded