Using Multiple Regression Analysis to Develop Electricity Consumption Indicators for Public Schools

Corfitz Norén, Lund Institute of Technology, Sweden
Jurek Pyrko, Lund Institute of Technology, Sweden

ABSTRACT

This paper deals with problems of using Multiple Linear Regression (MLR) to develop Electricity Consumption Indicators (ECIs) for Swedish school buildings. Annual, monthly, daily, hourly, and peak ECIs are developed from whole building hourly load data measured during one year. 26 schools with a total annual electricity consumption of 17.5 GWh and a total floor area of 252 000 m^2 are analysed in this study. All schools are mainly heated by district heating although some of them use electrical heating to a minor extent. By using the MLR approach, it is possible to introduce variables accounting for factors that can explain the electricity consumption in school buildings. Such factors are "sports centre" and "kitchen activities". This procedure eliminates the need of several subgroups, like schools with or without kitchens. The methodology is easy to use for similar studies and provides important information about factors affecting the electricity consumption in schools.

Introduction

Knowledge of various consumers' electricity consumption patterns and electricity consumption indicators is required for (a) developing tools for energy auditors, (b) identifying operational and maintenance problems (Lyberg 1987). The number of Swedish studies on electricity consumption in commercial and public buildings is very limited.

The Swedish electric utility Vattenfall carried out in 1991 the most extensive study of Swedish commercial and public buildings hitherto, where schools were included in a category called "Education" (Vattenfall 1992). Only the annual electricity consumption (both for entire building and for end-uses) was studied; the load aspect was not considered. The average annual ECI for the "Education" category was estimated to 53 $kWh/m^2 \cdot yr$.

The first Swedish load shape study on commercial and public buildings was carried out in 1987-1990. This study presents typical load shapes for approximately 40 different types of buildings, ranging from one-family houses to commercial and industrial buildings (SEF 1991). The load shapes are presented in non-dimensional terms (related to annual electricity consumption). Partially, this study also deals with ECIs and the average annual ECI is determined to 42.8 $kWh/m^2 \cdot yr$. Another load shape study on commercial and public buildings presents non-dimensional load shapes (related to annual electricity consumption) for six categories of Swedish commercial buildings and was carried out at the Lund Institute of Technology in 1996 (Norén 1997).

Several load shape studies have been performed in Norway by EFI, however these studies focus on buildings using electric resistance heating. The results are also presented as relative load shapes in some cases (Livik & Rismark 1990; Feilberg & Livik 1993; Livik 1987). Many studies have been carried out in the USA by the Lawrence Berkeley National Laboratory and several other research groups (Akbari et al. 1989, 1991).

Background

Traditionally, ECIs are calculated as mean values and standard deviations. The deviations are often high, making it very difficult to determine what is a "normal" consumption. Many different kinds of features are mixed within the same category. The school category covers all kinds of schools, from small schools with no mechanical ventilation up to large schools with all mechanical ventilation and large kitchens. In a pre-study during 1996, 44 schools were audited and the annual ECIs were analysed. High variations were observed (22-112 kWh/m²·yr) but different installations and activities can explain some of them. The mean ECI was 61 kWh/m²·yr with an associated standard deviation of 22 kWh/m²·yr, and it is difficult to draw any conclusions based on these figures with such high deviations. A coarse classification can be done according to Table 1.

Table 1. Results from Pre-study on Electricity Consumption in School Buildings

Small schools (<1000 m²) with no mechanical ventilation	20-40 kWh/m²·yr
Schools with only mechanical exhaust air ventilation	40-50 kWh/m²·yr
Schools with mechanical supply and exhaust air ventilation. With or without sports centre, no kitchen	50-70 kWh/m²·yr
Schools with mechanical supply and exhaust air ventilation. With or without sports centre, with kitchen	70-80 kWh/m²·yr
Schools with suspected operational problems	>100 kWh/m²·yr

Another problem with "traditional" ECIs is that they in most cases are based on annual figures which are insufficient for identification of operational and maintenance problems. A rough estimation can be made but there is no possibility to identify time periods with suspicious consumption profiles. Another disadvantage with annual ECIs is that they do not provide any information about the factors affecting the electricity consumption.

Methodology

The methodology can be described in the following three steps: Determination of features possible to include in the study, audits and inquiries and analysis of measured load data. The number of features included in the study was limited by the number of objects where one-hour measurements of the electricity consumption are performed. 26 schools with a total floor area of 252 000 m² and a total annual electricity consumption of 17.5 GWh were included.

Analysis of Measured Data

At first, the measured data were checked for measurement errors by dividing the measured data into three subgroups depending on day-type. Three day-types were identified:

- Standard schooldays (172 days)
- Weekends and major holidays (113 days)
- Weekdays during off-school periods, like summer and Christmas (80 days)

Hypothesis. The specific electricity consumption (W/m², kWh/m²) is presumed to be a function of the parameters listed below. Several other parameters can be important but these are discussed later.

- Compared to other schools, schools with a large kitchen show a higher specific electrical demand during at least parts of the day. The demand level depends on the ratio between the number of meals cooked daily and the floor area of the school.
- Compared to other schools, schools with a large sports centre show a higher specific electrical demand at least during parts of the day, especially during the evening. The demand level depends on the ratio between the sports centre area and the floor area of the school.
- Compared to other schools, secondary schools show a higher specific electrical demand at least during parts of the day.
- Compared to other schools, schools with a high population density (high ratio persons/m²) show a higher specific electrical demand during at least parts of the day.

Initial analysis work. The first step was to make an initial analysis in order to remove the parameters that showed no correlation with the electricity consumption. Although some parameters seemed to have a significant influence on the electricity consumption in this initial analysis, some of them were found to be non-significant during certain time periods. Another reason for excluding a parameter was high or unreasonable variations from hour to hour, as occurred with the 'Sports centre' parameter during daytime (6 a.m. - 3 p.m. on standard schooldays) and the 'Population density' parameter (all hours during all days). The regression coefficient varied greatly and quite often the sign changed from hour to hour indicating that the parameter did not provide any information about actual operating conditions during these hours. It was considered correct not to include the parameters in the analysis during these time periods.

Hourly electricity consumption. The hourly electricity consumption was analysed by introducing factors that according to the hypothesis are affecting the electricity consumption. The Hourly Electricity Consumption Indicator, HECI, was defined as:

$$HECI = A_0 + K_1 \cdot A_1 + K_2 \cdot A_2 + D_3 \cdot A_3 + T \cdot A_4 \qquad \text{(Eq. 1)}$$

Where:
- K_1 = Number of meals cooked daily in the kitchen (-/m²)
- K_2 = Relationship between sports centre area and floor area
- D_3 = Dummy variable (DV), 1 for secondary schools, otherwise 0
- T = Daily mean outdoor temperature (°C)
- A_0 - A_4 = Regression coefficients

The regression was carried out for each of the hours 1-24 during the three different day-types, totally 72 regressions. Data from all the 26 schools were used in every regression. This means that the number of data points in each regression equalled the number of days for the specific day-type multiplied by 26, e.g. $26 \cdot 172 = 4472$ data points for the standard weekday case, $26 \cdot 113 = 2938$ data points for the weekend/holiday case and $26 \cdot 80 = 2080$ data points for the off-school period. The relationship can be written with matrices: **Y=XA** where the vector **Y** contains the measured load data normalised by the building floor area. The vector **Y** is then of the dimension 4472×1 in the standard weekday case. The **X** matrix contains the parameters listed above (1, K_1, K_2, D_3 and T), e.g. **X** is of the dimension 4472×5 for the standard weekday case. The vector **A** contains the unknown regression coefficients (A_0-A_4) which will be estimated and is of the dimension 5×1.

Daily, monthly and annual specific electricity consumption. Daily, monthly and annual ECIs were computed as sums of the hourly ECIs, using the number of different day-types for monthly and annual electricity consumption.

Analysis of the annual specific peak electrical demand. The three highest demands for each school were used as response variables. The reason for not choosing only the annual peak demand for each object was that only one year of load data was available, there was a possibility that the peak demand was caused by special circumstances and is not representative of a school building. The Peak Electricity Consumption Indicator, PECI, was defined as:

$$\mathrm{PECI} = A_0 + K_1 \cdot A_1 + D_3 \cdot A_3 \qquad \text{(Eq. 2)}$$

Where: K_1 = Number of meals cooked daily in the kitchen (-/m²)
D_3 = DV, 1 for secondary schools, otherwise 0
A_0-A_1, A_3 = Regression coefficients

If this relationship is written as **Y=XA**, then the vector **Y** contains the measured peak demands and is of dimension 78×1. The **X** matrix contains the parameters listed above (1, K_1 and D_3) and is of dimension 78×3. The vector **A** is of dimension 3×1 and contains the unknown regression coefficients (A_0-A_1 and A_3) which will be estimated.

Load factor. The load factor, LF, was defined as:

$$\mathrm{LF} = \frac{\text{Annual electricity consumption (kWh)}}{\text{Annual peak electrical demand (kW)} \cdot 8760\ \text{(h)}}$$

Statistical analysis. The analysis was performed on computer, using the software MINITAB. When using the ordinary least squares approach, a potential problem is multicollinearity, e.g. when the correlation among the independent variables is high. A rule of thumb is that multicollinearity becomes a potential problem when the partial correlation between any two independent variables is higher than the partial correlation between any of the independent variables and the response variable (Draper & Smith 1981). The highest correlation exists between the 'Sports centre' and the 'Type of school' variable and if the rule of thumb should be followed, multicollinearity could be a problem during hour 16, since it was the only period that both variables were used in the analysis. It was considered to have a minor effect on the results and was not investigated any further but the potential effects of multicollinearity must always be taken into consideration.

Results

The results are shown in Table 2 to Table 6. NS denotes non-significance or that the results from the regression do not follow the hypothesis, i.e., that variable is not included in the regression analysis during these time periods. The results are also shown in Figure 1 and Figure 2. The following assumptions were used when presenting the load shapes graphically:

- The ratio between number of meals cooked daily and gross floor area is 0.2 for the "Primary school with kitchen" load shape.
- The ratio between sports centre area and gross floor area is 0.10 for the "Primary school with sports centre" load shape.

Table 2. Results for Standard Weekday Hourly Electricity Consumption

Hour	A_0 W/m²	A_1 W/(-/m²)	A_2 W/(m²/m²)	A_3 W/m²	A_4 W/m²·°C	R^2 %
1	4.8	NS	NS	NS	-0.03	1.8
2	4.8	NS	NS	NS	-0.03	1.8
3	4.8	NS	NS	NS	-0.03	1.8
4	4.8	NS	NS	NS	-0.03	1.8
5	5.4	NS	NS	NS	-0.05	3.1
6	6.2	NS	NS	NS	-0.08	6.6
7	8.7	NS	NS	NS	-0.09	7.7
8	11.7	21.5	NS	0.8	-0.13	47.8
9	15.8	21.3	NS	2.4	-0.17	46.1
10	17.5	15.3	NS	2.4	-0.17	31.5
11	18.2	11.1	NS	2.8	-0.17	27.3
12	18.6	13.5	NS	2.1	-0.16	25.0
13	18.3	8.71	NS	2.1	-0.16	19.2
14	17.0	9.01	NS	3.0	-0.15	24.6
15	15.6	5.31	NS	3.0	-0.14	23.0
16	12.5	NS	10.0	3.0	-0.12	23.1
17	10.2	NS	9.3	2.2	-0.12	17.1
18	8.2	NS	17.4	0.4	-0.13	20.2
19	7.3	NS	20.0	NS	-0.13	26.1
20	7.1	NS	20.3	NS	-0.13	27.0
21	6.5	NS	20.0	NS	-0.10	27.1
22	5.8	NS	11.7	NS	-0.05	11.2
23	5.6	NS	NS	NS	-0.03	1.2
24	4.8	NS	NS	NS	-0.03	1.8

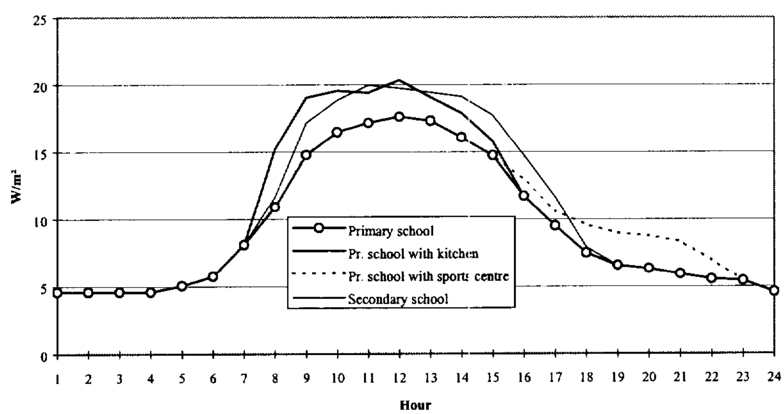

Figure 1. Load Shapes for Different Types of School Buildings, Weekdays

Table 3. Results for Weekend and Holiday Hourly Electricity Consumption

	Weekends			Holidays		
Hour	A_0 W/m²	A_4 W/m²·°C	R^2 %	K W/m²	A_4 W/m²·°C	R^2 %
1	4.6	-0.03	1.4	5.0	-0.05	3.9
2	4.6	-0.03	1.4	5.0	-0.05	3.9
3	4.5	-0.03	1.4	4.9	-0.05	3.9
4	4.5	-0.03	1.4	5.1	-0.05	3.9
5	4.6	-0.03	1.4	5.2	-0.07	6.5
6	4.8	-0.04	2.7	5.7	-0.09	6.7
7	4.7	-0.04	2.7	7.2	-0.09	7.0
8	4.8	-0.06	4.0	9.0	-0.10	5.4
9	4.9	-0.04	2.1	10.0	-0.11	4.4
10	5.1	-0.06	3.1	10.2	-0.11	3.4
11	5.2	-0.06	3.2	10.3	-0.11	3.2
12	5.2	-0.06	3.1	10.4	-0.11	3.2
13	5.3	-0.06	3.6	10.4	-0.11	3.3
14	5.3	-0.06	4.1	10.0	-0.10	3.4
15	5.2	-0.06	3.9	9.7	-0.09	3.2
16	5.1	-0.05	2.9	9.0	-0.09	3.2
17	5.1	-0.05	3.6	8.2	-0.10	2.8
18	5.1	-0.06	5.7	7.3	-0.12	8.2
19	5.0	-0.06	6.4	6.8	-0.12	9.7
20	5.1	-0.07	8.2	6.7	-0.13	10
21	4.8	-0.05	4.8	6.5	-0.12	11
22	4.8	-0.04	3.3	5.9	-0.09	8.7
23	4.6	0.03	1.5	5.4	-0.06	5.0
24	4.6	-0.03	1.4	5.0	-0.05	3.9

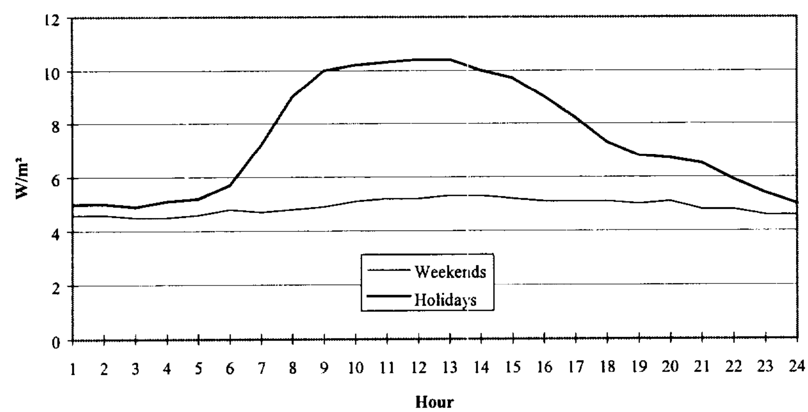

Figure 2. Load Shapes for School Building, Weekends and Holidays

Table 4. Results for the Annual Peak Demand

A_0 W/m²	A_1 W/(-/m²)	A_3 W/m²	R^2 %
21.1	33.7	3.9	74.0

If the values in Table 2 are compared to the results in Table 4, it can be noticed that the major difference is the kitchen parameter where the highest hourly ECI is 21.5 W/(-/m²) but 33.7 W/(-/m²) for the peak demand ECI, an increase of 50%. This is an actual condition in the schools with kitchens: the peak demand is substantially higher compared to other demands during the year and high day-to-day demand variations exist in the schools with kitchens, compared to the schools without kitchens. The annual peak demand in secondary schools was found to be higher than in primary schools and this depends on the vocational activities in many of the secondary schools.

Table 5. Results for Daily Electricity Consumption

Day	A_0 Wh/m²	A_1 Wh/(-/m²)	A_2 Wh/(m²/m²)	A_3 Wh/m²	A_4 Wh/m² ·°C
SWd	240	106	109	24	-2.4
We	117	NS	NS	NS	-1.1
Hd	179	NS	NS	NS	-2.2

SWd = Standard Weekdays; We = Weekends; Hd = Holidays

In order to calculate an annual electricity consumption, one must know the number of different day-types and the temperature profile for the year. If the figures from 1996 are used, this leads to the results in Table 6.

Table 6. 1996 Monthly and Annual Electricity Consumption

Month	A_0 kWh/m²·	A_1 kWh/(-/m²)	A_2 kWh/(m²/m²)	A_3 kWh/m²
January	6.1	1.8	1.9	0.4
February	5.8	1.7	1.7	0.4
March	6.1	2.0	2.1	0.5
April	5.3	1.7	1.7	0.4
May	5.4	2.0	2.1	0.5
June	4.4	0.3	0.3	0.1
July	4.0	0	0	0
August	4.8	1.1	1.1	0.2
September	5.4	2.2	2.3	0.5
October	5.6	2.0	2.1	0.5
November	5.8	2.1	2.2	0.5
December	5.6	1.5	1.5	0.3
Total	64	18.4	18.9	4.2

Annual electricity consumption is only slightly affected by the different factors but for the case with schools with kitchens it must be noticed that the kitchen parameter only accounts for the kitchen equipment. The kitchen also includes several other electrical demanding equipment, such as lighting and ventilation. This part of the kitchen electricity consumption is included in the A_0-term.

The analysis of the load factor showed a noticeable difference between schools with and without kitchens; the results are shown for all 26 schools in Figure 3. Six of the nine schools with kitchens have a LF lower than 0.3 and among these there are four schools with large kitchens and two small schools (<6000 m²) also equipped with a kitchen. One school has a slightly higher LF (0.3). The remaining two, which are quite large schools (>10 000 m²) and only cook food for the individual school, have LF 0.34 and 0.36 respectively.

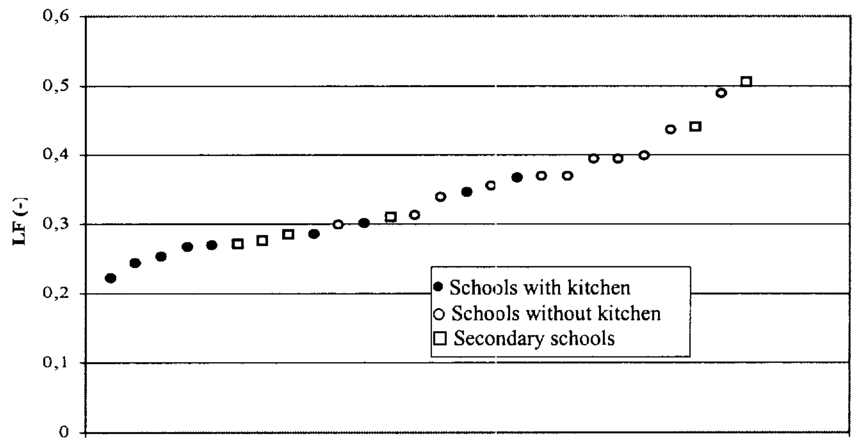

Figure 3. Results for the Load Factor (LF) for all 26 schools

This is an expected observation since the schools with large kitchens were found to have substantial higher peak electrical demands compared to other schools. Among the schools with LF lower than 0.35, four of the six secondary schools were found and these observations were also expected since the annual peak demand was found to be higher in secondary schools when compared to primary schools. It is also noticeable that all but four schools have LF lower than 0.4, while these four show LF between 0.44 - 0.51. This was further examined for one of the schools and it was found that the ventilation system operated 24 hours a day, causing a high annual electricity consumption.

Discussion on Reasons for Deviations

The poorest results were found at night (hrs 23-06) and some important reasons were identified. In some schools, as much as 50% (100% in one case) of the ventilation system is in operation at night for different reasons, while other schools shut off the ventilation system at night. In some schools the hallway lighting is left on at night to prevent burglary. Schools with large kitchens were at first presumed to show a higher consumption at night due to the refrigeration equipment running day and night, but this could not be identified with the proposed method.

During weekends and holidays no correlation between the described parameters (except for outdoor temperature) and the electricity consumption was found and the results were very poor during these day-types; many activities take place, not only sports centre activities.

During early morning hours (hrs 06-08), staff and pupils arrive at different times in different schools, causing early morning deviations.

During hours 09-14, the highest deviations were found in schools with kitchens, since cooking power varies with the food prepared. Substantial day-to-day variations were also observed in some of the secondary schools. The major factor may be varying electricity demand.

Afternoon and evening deviations were highest for schools equipped with sports centres, which may or may not be open at night.

Another important source of deviations is the fact that all schools are not efficiently operated and this also affects the result to some extent; in this study three schools with suspicious consumption patterns were found. This does not mean that the remaining 23 schools are efficiently operated.

Verification

Measurements from a school building located in the south of Sweden were used to verify the results. This 10,630 m^2 primary school holds approximately 800 pupils and 100 members of staff and is equipped with 1164 m^2 sports centre. District heating is used for heating and hot water, and approximately 1100 meals are cooked every day. This gives the following parameters in Eq. 1 and 2: K_1=0.10, K_2=0.11 and D_3=0, the daily outdoor temperature varies between 0.3°C and 2.8°C during the four days. The school was built in 1967 and was retrofitted in the end of 1996 (finished 1/11-96) when the old ventilation system was replaced. Hourly measurements were carried out after the retrofitting in December 1996 and these data were used for verification. Figure 4 shows the measured demand compared to the demand that was calculated using the ECIs from this study.

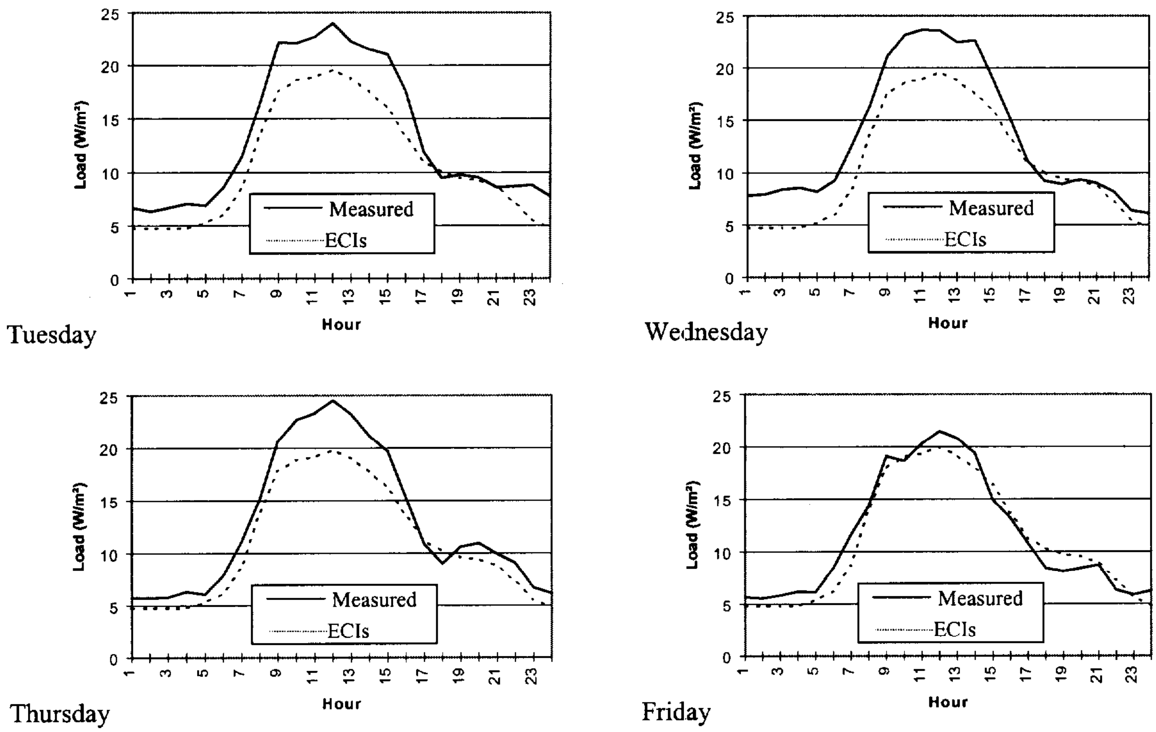

Figure 4. Measured Load Shapes and ECIs for Tuesday 961210 - Friday 961213

The night-time demand is approximately 1.5-2 W/m^2 higher than predicted by the ECIs but monthly electricity consumption data show a substantially lower consumption during off-peak hours[1] after 1/1-1997. Before 1/1 1997, the monthly off-peak consumption was 25-30 MWh/month but is now reduced to 18-20 MWh/month and this indicates an inefficient night-time and weekend consumption before the retrofitting. The total monthly consumption during hours 06-22 is also reduced after 1/1-1997, but not as much as the consumption during off-peak hours, indicating that the day-time consumption also was somewhat inefficient before the retrofitting. Why this reduction did not occur immediately after the retrofitting is not completely known; but the most probable cause is that the final adjustments of the ventilation system was done during Christmas 1996, and therefore, the electricity consumption just after the retrofitting was almost unaffected.

[1] Off-peak hours are defined as 10 p.m. - 6 a.m. during weekdays and all hours during the weekend

The peak demand did not change after the retrofitting. Measured peak demand is 25.8 W/m² and the peak ECI gives 25.0 W/m². Measured annual electricity consumption before the retrofitting was 70.6 kWh/m² and the ECIs gave 68 kWh/m². This was surprising since the hourly ECIs indicated high consumption, but this school is almost entirely closed during summer holidays and this is the most important single reason for the similarities between the annual ECIs and the differences between the hourly ECIs.

It was more difficult to verify the other parameters but for the case with the "kitchen" parameter there are load data from a building which contains a school kitchen. The mean annual load shape is shown together with the kitchen parameter in Figure 5. Although the measurements not only include cooking equipment, some observations regarding the characteristics of the load shapes can be made:

- Highest daily demands occurs around 8 a.m. and 9 a.m.
- Between 9 a.m. and 11 a.m. the demand decreases rapidly.
- At 11 a.m. there is a temporarily dip followed by a slight increase at 12 a.m.
- After 12 a.m. the demand decreases rapidly.

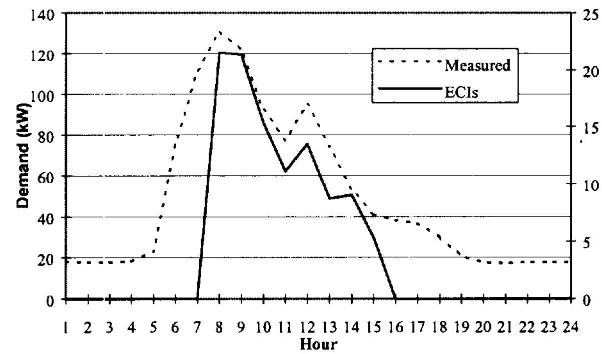

Figure 5. Measured Load Shape from a School Building with Kitchen, Compared to Results from this Study

No major conclusions should be drawn except that the kitchen parameter has the same characteristics as a measured load shape from a school kitchen. There are major differences between 4 p.m. and 7 a.m. but it is important to remember that the measured load shape also includes indoor lighting, ventilation, pumps and other equipment. The reason for not using the measured data in the analysis is that the measured data are not representative for the whole school, the building is a part of this school but cooking is the main activity.

Comparisons to Other Studies

The results from this study are compared to the results from three other studies, two Swedish studies (Norén 1997; SEF 1991) and one American study (Akbari et al. 1991). There are some differences between the three studies: two of them present non-dimensional load shapes and in order to compare these shapes with the results from this study and the LBL report, one must use an annual consumption figure. To compare the results with this study, some other parameters must also be chosen. The following parameters were used:

- Primary school without kitchen, annual electricity consumption 64 kWh/m²
- Annual mean temperature +8°C.

The four load shapes are highly correlated and the differences are small, see Figure 6. No sports centre was considered when using the results from this study but LBL reports that some evening activities take place and these were reported to be evening classes or maintenance; this is the major reason for the evening differences. No major conclusion should be drawn although the load shapes are very similar.

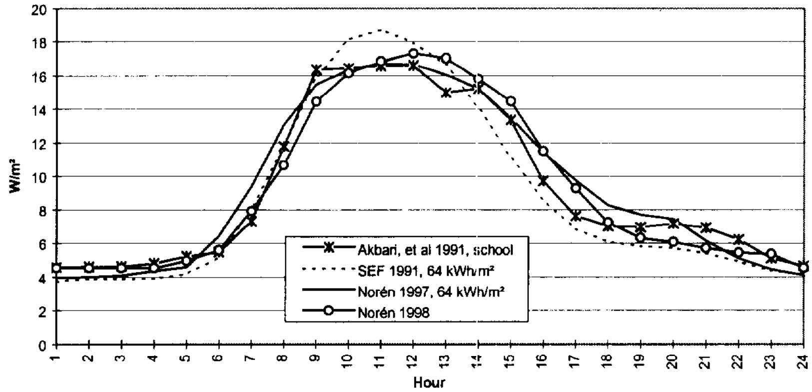

Figure 6. Results from this Study Compared to Results from Three Other Studies

Discussion and Conclusions

It is important to remember that the chosen regression parameters are indicators for common activities in school buildings, and were not chosen to provide the best data fit. The conclusion is that these parameters are important factors when analysing the electricity consumption in school buildings and the different indicator variables are definitely useful for the analysis.

Although the R^2-value is low during many hours, the proposed analysis method is applicable for similar studies, at least for school buildings. The method is untested in other building types. One reason for low R^2-values is that many parameters are not easily quantifiable, like human behaviour and different day-to-day schedules. The methodology is a step away from the previous Swedish load shape studies that presented relative load shapes and the data material in this study is much greater than in the two previous Swedish studies.

Some conclusions regarding school building electricity consumption can be drawn:

- Annual electricity consumption is only slightly affected by the studied factors but still these have high influence on the daily load shape.
- Night-time demand is very different from school to school depending on the choice of operating strategy.
- The school kitchen has a dominant influence on the annual peak demand.

Weekend and holiday ECIs are very difficult to estimate, but again, this is mainly due to different operating strategies.

Data for verification were only available from one school and the measured load shapes were correlated to the presented ECIs. The ECIs indicated that the consumption was high, which was proved to be correct when studying the consumption data for 1997. The "kitchen" parameter was compared to measured data from a school building with kitchen activity as a main activity and the characteristics of the two load shapes were similar. Comparisons with the results from other studies showed similarities and the load shapes from the four different studies were highly correlated.

The load demand was found to be temperature dependent although load data from district heated schools are analysed and it should be remembered that the schools use district heating as the *main* heating system. Electricity is used for some minor heating applications, such as: resistive heating in parts of the buildings, electrical heaters in the ventilating system and electrical coils to keep the drain pipes free from ice. This is the major reason for the temperature dependence.

Several applications for the developed ECIs exist. Examples include:

- Comparisons with measured data in order to evaluate the electricity consumption in a specific building.
- Estimation of load shapes if measurements are not available.
- Estimation of annual peak demands.

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