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Typical Load Shapes for Swedish Schools ans Hotels

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Typical load shapes for Swedish schools and hotels

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Abstract

In this study, typical load shapes for two categories of Swedish commercial and public buildings—schools and hotels—are presented and discussed. The measurements from 13 schools and nine hotels in the southern part of Sweden were analysed. Load shapes were developed for different mean daily outdoor temperatures and different day-types—standard weekdays and standard weekends. The load shapes are presented as non-dimensional normalised 1-h load. The typical load shapes give a reasonable approximation of the measured load shapes, although the relative errors exceed 20% of the mean values during some hours. Daytime (9 a.m.–5 p.m.) results are generally good with errors of about 10%. Absolute errors remain relatively constant during the year, but as mean values decrease, the relative errors increase, causing relative errors up to 30% during some time periods.   © 1998 Elsevier Science S.A. All rights reserved.

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1. Introduction

Electricity consumption in commercial and public buildings is the fastest growing end-use sector in many of the IEA countries with an annual growth rate of 4–5% [1]. Several factors influence the high growth rate, such as:
–increased use of office equipment,
–a growing need of air conditioning and other comfort equipment.
The fast technical development has made it possible to reduce electricity consumption by using more efficient equipment, but in many buildings, there is a potential of reducing the electricity consumption and the electricity costs.

The last Swedish extensive study on commercial buildings is the study made by the Swedish Association of the Electric Utilities in 1987–1990 [2]. Normalised load shapes are presented for approximately 40 different categories of buildings and for different outdoor temperature levels. Schools are one of the categories that has been investigated in this study, but the results are not generalisable and applicable in practice because different types of school buildings cannot represent a homogeneous category. Load pattern studies of Swedish public and commercial buildings are very limited. For example, the Swedish Vattenfall's study on commercial and public

buildings in Sweden [3] only presents annual electricity consumption for different end-uses. On the other hand, the contacts with users, distributors and producers of electricity has indicated a great interest and need for load studies of commercial buildings.

Norwegian EFI has carried out several studies on load patterns in commercial buildings, but these studies focus almost entirely on buildings with electrical space heating and the results are not comparable to the results from this study [4–6].

In the USA, many studies have been performed by various companies and organisations. Lawrence Berkeley Laboratory (LBL) has published several load related documents and reports. The load shapes presented in the LBL reports are often separated into end-uses like cooling, ventilation, lighting, etc., and usually presented as W/m^2 [7–13].

The object of this study is to develop typical load shapes for two categories of Swedish buildings, schools and hotels. Deviations from the 'normal values' and the reasons for these variations are discussed. The outdoor dry-bulb temperature is assumed to be representative for the entire area where the different objects are located. No weather variables, except for the outdoor temperature, are considered to affect the electricity consumption.

In the beginning of the study, the school category consisted of 23 objects, all located in the south of Sweden. But only 13 of these could be chosen to a homogeneous group of district

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heated buildings. This group was finally divided into two sub-groups since substantial differences were observed between the sub-groups:

    –six schools with district heating and kitchens,
    –seven schools with district heating and without kitchens.

The hotel category consists of nine hotels located in the south of Sweden. The heating systems of the different hotels are listed below:

    –six hotels with district heating,
    –one hotel with electrical space heating,
    –one hotel with district heating and electricity,
    –one hotel with oil furnace and electricity.

A question was raised whether the three hotels with electrical heating should be included in the study. As the large part of the electrical space heating is not connected to the same metering unit as the rest of the hotel, this caused no problems.

2. Methodology

The methodology is briefly described by Norén [14]. Some of the most important steps are discussed below.

To compare the load data for different objects, it is necessary to normalise the data by dividing every measured value with the object's mean load.

When using the basic statistical equations, an important question is whether load data are normally distributed. This is not always the case, but the data material is approximately normally distributed when the number of observations is large [15]. This is discussed in a Norwegian study, where the load data was considered to be approximately normally distributed [16]. However, some skewness of the load distribution was observed during most hours in this study, but this is very common due to a few outlying values, to which the skewness is highly sensitive [15]. Some few outlying values can make the standard deviations high and the two-sided confidence interval gives an incorrect picture of the deviations. Because of that, it is important to be careful in the cases where it is one or two deviating objects that caused high standard deviations. Although the standard deviations are high, the spreading might not be as large as indicated by the standard deviations.

2.1. Load shapes—calculation of mean normalised load $c_{cat}(t)$

The normalised load $C_i(t)$ at time t for object i can be calculated as:

$$C_i(t) = \frac{P_i(t)}{\overline{P_i}};$$

(1)

where $C_i(t)$ = normalised load at time t for object i (−); $P_i(t)$ = measured load at time t for object i (kW); $\overline{P_i}$ = mean annual load for object i (kW h/h).

The data are split into different groups, depending on day-type. The data in every group are sorted by hour, and every hour is sorted into different temperature intervals. Six intervals for mean daily outdoor dry-bulb temperature are used to sort the data: <0°C, 0–5°C, 5–10°C, 10–15°C, 15–20°C, >20°C.

Now, the mean value, $C_{cat}(t)$, can be calculated for every hour and each temperature interval [5]:

$$C_{cat}(t) = \frac{\sum\limits_{i=1}^{N} C_i(t)}{N}$$

(2)

where $C_{cat}(t)$ = mean normalised load at time t for a category at specified temperature interval (−); $C_i(t)$ = normalised load at time t for object i in the category at specified temp. interval (−); N = number of observations for time t for a category at specified temperature interval (−).

Standard deviations are calculated as [5]:

$$\sigma_{cat}(t) = \sqrt{\frac{\sum\limits_{i=1}^{N} (C_{cat}(t) - C_i(t))^2}{(N-1)}}$$

(3)

where $\sigma_{cat}(t)$ = standard deviation at time t for a category at specified temperature interval (−).

Eqs. (2) and (3) are repeated for:

● all temperature intervals
● all 24 h of the day
● weekdays and weekends
● all categories.

2.2. Disadvantages

This method is very sensitive to outlying values and objects that deviates from the other objects in the category. If one or two objects out of 10–15 do not fit the category, these objects will cause high standard deviations. The same problems occur if there is a high number of erroneous data and for this reason, it is necessary to exclude the erroneous data, otherwise, the final results will be affected in a very high degree.

2.3. Removal of erroneous data

The load data material was plotted for each hour and 'bad-quality' data were only removed when it was absolutely certain that the measurement errors were the cause, for example, if a building with a typical daytime load of 100–125 kW h/h, during a few hours only used 0–3 kW h/h, there was no doubt that the measurement errors were the reason. The data material quality was very good overall, and less than 5‰ of the data material was removed for certain objects. Such high rates of 'bad-quality' data were fortunately very rare.

3. Results for schools without kitchens

This category consists of seven objects with floor area ranging from 6700 m² up to 10,400 m², and all of the objects are located in the city area.

3.1. Year profiles

Fig. 1 shows the year profile for schools without kitchens. Summer holidays are easily distinguished by the drop in the consumption profile, which is also noticed during Christmas and the February holidays around day 50. During April and May, there are a number of drops. First at Easter, and then during all the holidays in May. During autumn, there are only two noticeable drops in the consumption profile, both corresponding to school holidays. Peak days are found during the colder part of the year, usually between November and beginning of February, but no specific day-type could be identified.

Standard deviations are quite high compared to some of the other categories, indicating a high degree of variation in consumption between different schools. This is a distinctive mark for the entire school category.

The activity level is very different, not only at different schools, but the same school can have large variations from day to day. Even during the same period of the year, and for the same temperature, which is further discussed later. Absolute standard deviations are relatively constant during the year but due to the lower demand during holiday and weekend periods, the relative standard deviations increase during these time periods. Some schools are open with several holiday and weekend activities, while others are closed, and the highest differences are found during the summer. As shown in Fig. 2, the weekend consumption varies quite a lot during the year, with the lowest consumption during the summer.
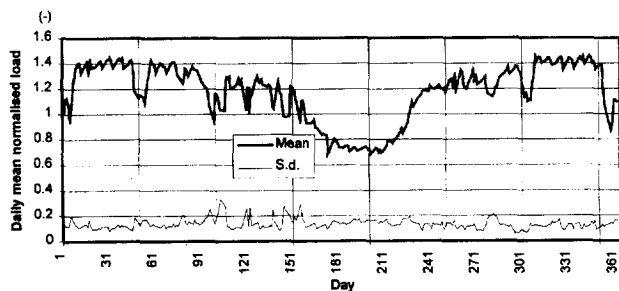

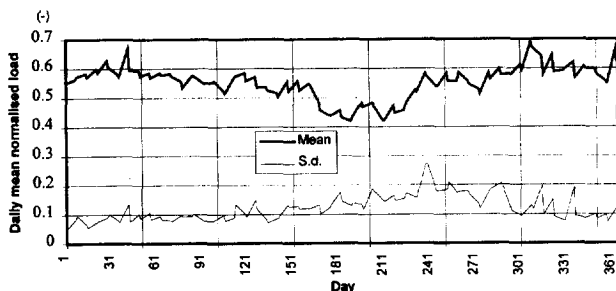Fig. 1. Year profile for district heated schools without kitchen, weekdays.

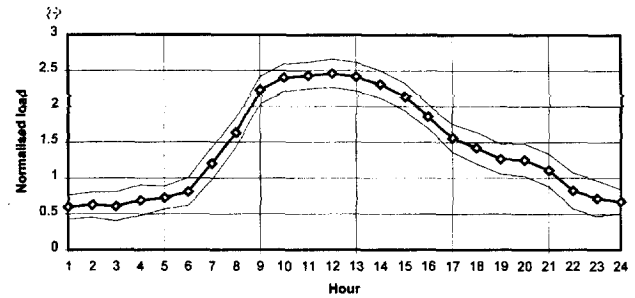Fig. 2. Year profile for district heated schools without kitchen, weekends.

Fig. 3. Standard weekday load shape for district heated schools without kitchen, temperatures below 0°C, mean temperature −2.3°C.

3.2. Daily load shapes

Fig. 3 shows a daily load shape with associated standard deviations for schools with district heating and no kitchens. Between 1 a.m. and 5 a.m., the demand is almost constant, but after 5 a.m., it begins to increase. At 9 a.m., the demand has stabilised, and relative standard deviations are now below 10%. Typical daytime (9 a.m.–5 p.m.) standard deviations in this temperature interval are less than 10% of mean values.

After 6 p.m., the demand is decreasing, while absolute standard deviations increase, causing 20–30% relative deviations of the mean values during the evening. This may be explained by the fact that some schools in the study are using the sports centre until very late in the evening, while others close earlier. It is not until 12 p.m. that the demand is at night-time levels.

As Fig. 4 shows, the daytime demand is 15% lower in the highest temperature interval. But absolute standard deviations are at the same level as during low temperature periods, and the relative standard deviations are 10–15% in the middle of the day. One factor may strongly influence the standard deviations: two schools with partial electrical heating have a lower normalised load at high temperatures, compared to the other five schools.

Unfortunately, this affects the load shape in an adverse manner: causing high standard deviations and large individual deviations from the typical load shape. A single school can, however, have standard deviations of the same magnitude (20% of the mean value) for the same hour and temperature interval. During the night and early morning hours, there is no difference between low and high temperatures. Differences occur after 8 a.m., which is shown in Fig. 5.
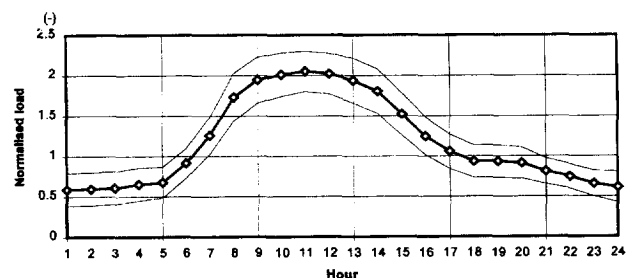

Fig. 4. Standard weekday load shape for district heated schools without kitchen, temperatures above 15°C, mean temperature 18.6°C.
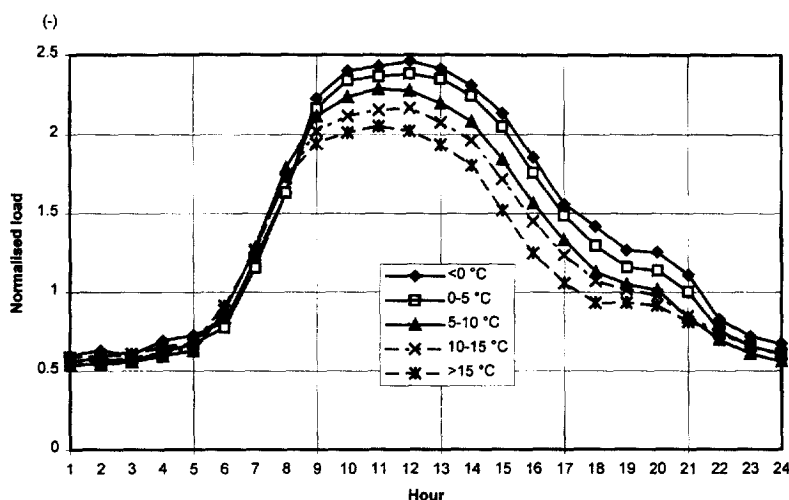
Fig. 5. Standard weekday load shapes for district heated schools without kitchen for five temperature intervals.

There might exist a season dependency also, during spring and parts of autumn, when less indoor lighting is required, and the consumption is therefore reduced.

No weekend load shapes are presented for this category. Standard deviations are very high, and no conclusions can be drawn, except that the activity levels vary greatly during weekends.

3.3. Relationship between outdoor temperature and electricity consumption

Fig. 5 shows mean daily load shapes for five temperature intervals. Before 8 a.m., the demand does not depend on temperature, but after 8 a.m. until late at night, the demand is lower at high temperatures, and some possible reasons for this have already been discussed.

To determine the relationship between electricity consumption and outdoor temperature, simple linear regression with daily mean load as response variable, and outdoor dry-bulb temperature as independent variable, was applied. Other studies suggest that regression analysis with daily data gives much better results than with hourly data, since natural variations tend to be more narrow when using daily data [2,7]. The regression results are shown in Tables 1 and 2.

During weekdays, the correlation is significant in five of the seven schools. The difference between the intercepts, P_0, is very obvious, ranging from 1.28 to 1.54—a difference of about 20%. The differences in temperature dependence are also quite large, approximately four times (school 4 and 7). Schools number 4 and 6 use some resistive electrical space heating.

During weekends, five of the schools show significant correlation between outdoor temperature and electricity consumption. Again, there are large differences of the intercept. Notice that school 6 has very poor regression statistics, and how school 2 now shows a significant correlation between electricity consumption and outdoor temperature.

3.4. Concluding remarks

There are several parameters influencing the load shape for school buildings. The following parameters have been considered especially important: (a) type of school: secondary schools tend to end later in the afternoon and start earlier in the morning than primary schools. (b) Operational strategy: parts of the ventilation system is in operation during night-time for different reasons in some schools, while other schools shut-off most of the ventilation system during night-time. This is an important reason why the night-time loads are different in schools. The night-time ventilation operation is more common in schools with new ventilation systems.

Table 1
Standard weekday regression results for district heated schools without kitchen

School	P_0 (−)	P_{sp} (−/°C)	Adj. R^2	Significance
1	1.28	−0.002	0.00	0.013
2	1.38	0.000	0.00	0.832
3	1.48	−0.018	0.71	0.000
4	1.54	−0.033	0.79	0.000
5	1.29	−0.011	0.29	0.000
6	1.32	−0.014	0.64	0.000
7	1.35	−0.008	0.32	0.000

Table 2
Standard weekend regression results for district heated schools without kitchen

School	P_0 (−)	P_{sp} (−/°C)	Adj. R^2	Significance
1	0.56	0.010	0.31	0.000
2	0.57	0.015	0.24	0.000
3	0.62	−0.015	0.65	0.000
4	0.69	−0.008	0.37	0.000
5	0.66	−0.004	0.08	0.001
6	0.48	−0.002	0.01	0.463
7	0.48	0.001	0.02	0.080

(c) There are major differences during the evening hours depending on whether the school has some evening activities. If it is equipped with a sports centre, it is not certain that it is used in the evening all days. (d) A few schools (typically secondary schools) have some vocational training activities, which causes high electrical demand when the machinery are used. Although the total effects are small, it is a reason for day-to-day variations. (e) Schools with some electrical heating (resistive space heating, electrical pre-heaters in the ventilation system, etc.) have a lower normalised load during the warmer periods of the year when compared to schools without electrical heating. (f) All schools are not efficiently operated. It has not been investigated whether the presented study only has included schools without any operational problems. Probably, it is an important reason for school-to-school variations.

The school category is unfortunately characterised by rather high standard deviations, especially at outdoor temperatures above 10°C. At temperatures below 10°C, the relative standard deviations are less than 10% between 10 a.m. and 4 p.m., but at higher temperatures and during the evening, standard deviations can be as high as 30% which mainly depends on a lower demand. Absolute standard deviations are less affected. The best way to solve this problem is to have more load data to be able to divide the school category into sub-categories like:

● objects without or with sports centres,
● objects with only one type of heating system.

It is important to remember that one single school can deviate from these typical load shapes, especially if it differs from the factors joining the seven objects included in this category:

● no food cooking,
● sports centre used in the evening as well,
● district heating as the main heating system.

4. Results for schools with kitchens

This category consists of six objects, and all are located in the city area. It is complicated to find representative objects for this category, since it is quite common today that schools which cook food have a separate metering unit that does not collect hourly load data for the kitchen. The floor area ranges from 9000 m² to 22,200 m², and all six objects are district heated.

The kitchen size varies, from the smaller ones that only cook a couple of hundred portions per day, to the biggest one that cooks around 5000 portions per day. The load shapes for this category are only valid for schools with rather large kitchens.

4.1. Year profiles

Figs. 6 and 7 show the year profiles for this category. The difference between this weekday year profile, and the year profile in Fig. 1, is the slightly higher normalised consump-
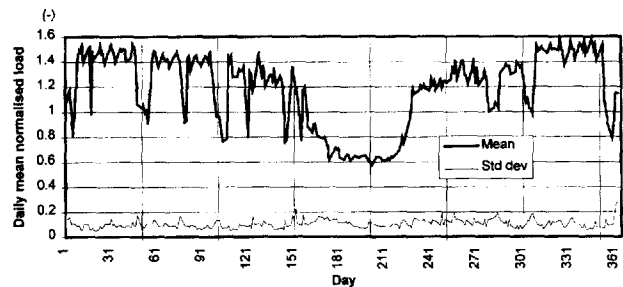

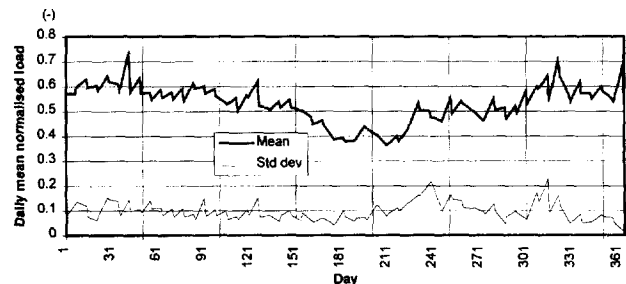Fig. 6. Year profile for district heated schools with kitchen, weekdays.

Fig. 7. Year profile for district heated schools with kitchen, weekends.

tion. This is an expected observation since schools that cook food use more equipment during standard weekdays compared to schools without kitchens. The lower consumption during holidays, is also a bit more noticeable for this category. Absolute standard deviations are of the same size as for schools without kitchens, even slightly lower from time to time.

If Figs. 7 and 2 are compared, the difference is very small. This is an expected observation since none of the kitchens normally are in operation during weekends. Again, the relative standard deviations are higher than during weekdays, depending on the more varying activity levels during the weekends.

4.2. Daily load shapes

As Fig. 8 shows, the demand in the middle of the day is approximately 20% higher than in schools with no kitchens. A distinctive mark for these schools is the very high standard deviations between 8 a.m. and 9 a.m. because some of schools in the study begin cooking very early and the different schools cook different number of portions/day. It is the one that cooks
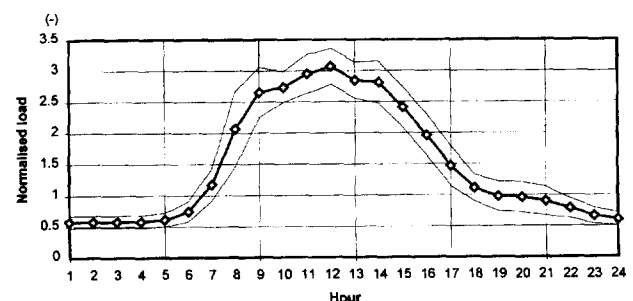

Fig. 8. Standard weekday load shape for district heated schools with kitchen, outdoor temperature below 0°C. Mean temperature −2.1°C.
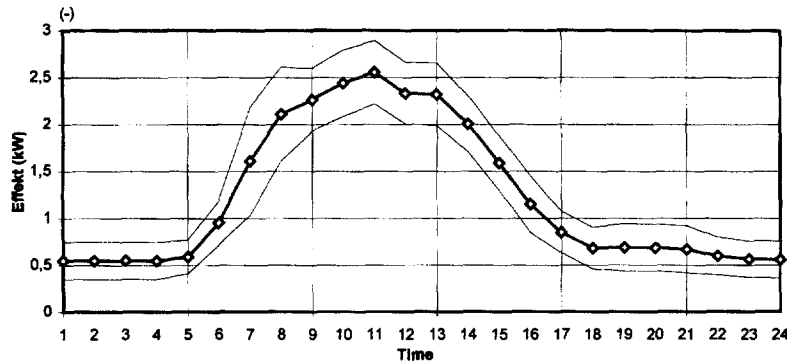
Fig. 9. Standard weekday load shape for district heated schools with kitchen, outdoor temperature above 15°C. Mean temperature − 18.3°C.
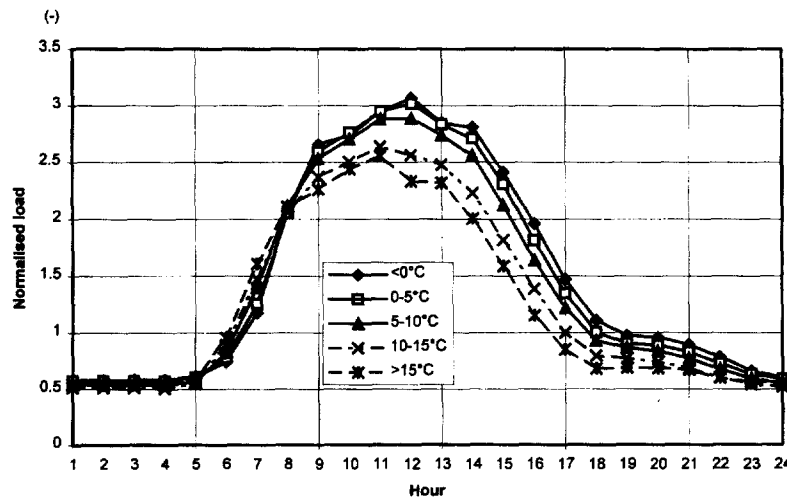

Fig. 10. Standard weekday load shapes for district heated schools with kitchen for five temperature intervals.

5000 portions/day that affects the load shape mostly during these 2 h, since cooking begins already at 7 a.m. in that school.

Absolute errors are higher compared to schools without kitchens during daytime and the demand variations from day-to-day are higher for these schools. The major difference, compared to schools without kitchens, is the higher normalised load between 8 a.m. and 4 p.m., and the lower normalised load between 5 p.m. and 10 p.m. On single days, the deviations from the typical load shape can be very large since the schools in the study showed a very varying demand, even during the same hour and temperature interval. Measurements in one of the school kitchens during 2 weeks in spring 1996 [17], showed that the kitchen demand varied very much depending on the kind of food that was served. On days when simple courses like soup was served, the demand was much lower compared to when more advanced courses were served, like fried fish with boiled potatoes.

Fig. 9 shows the daily load shape for the highest temperature interval. The maximum demand has decreased by 15%, but standard deviations are of the same size as at the low temperature interval.

No weekend load shapes for this category are presented here. All the shapes can be found in Ref. [14]. The differences between schools with and without kitchens are negligible on weekends.

4.3. Relationship between outdoor temperature and electricity consumption

Fig. 10 shows daily load shapes at different temperature intervals. Except for the higher demand in the middle of the day, the load shapes are quite similar to the ones in Fig. 5: hourly loads after 8 a.m. are most affected by temperature. The regression results are presented in Tables 3 and 4. All holidays and days with a mean outdoor temperature above 17°C were excluded.

As shown in Table 3, the R^2-values are low for four of the schools, but the correlation is significant in five schools. The temperature dependence varies very much in the different schools, almost six times between school 5 and 6.

Table 3
Standard weekday regression results for district heated schools with kitchens

School	P_0 (−)	P_{sp} (− /°C)	Adj. R^2	Significance
1	1.41	−0.011	0.28	0.000
2	1.45	−0.012	0.36	0.000
3	1.52	−0.016	0.31	0.000
4	1.54	−0.022	0.61	0.000
5	1.58	−0.028	0.58	0.000
6	1.41	−0.005	0.05	0.002

Table 4
Standard weekend regression results for district heated schools with kitchens

School	P_0 (−)	P_{sp} (− /°C)	Adj. R^2	Significance
1	0.68	− 0.008	0.23	0.000
2	0.58	− 0.007	0.17	0.000
3	0.54	− 0.002	0.02	0.089
4	0.71	− 0.012	0.34	0.000
5	0.61	− 0.014	0.45	0.000
6	0.49	0.008	0.15	0.000

Table 4 shows that temperature dependency generally is lower at weekends, and R^2-values are now low for all the objects, although the correlation is significant for five of these. Notice how school 6 now has a significant positive correlation between electricity consumption and temperature. Because of the great variations in temperature dependence, no general rule predicting how school buildings respond to temperature changes can be determined.

4.4. Concluding remarks

Just like the other school categories, this category is characterised by high standard deviations. The maximum demand is approximately 20% higher in schools with kitchens during daytime, but after 4 p.m., the demand is lower when compared to schools without kitchens. Very large variations can be observed from day to day, even in the same school. There are several reasons for the deviations and some have already been discussed, but the most important reason for the day-to-day demand variations in schools with kitchens is the fact that different kind of food requires a different amount of the kitchen capacity and different schools cook different number of portions per day.

5. Verification

To verify the typical load shapes, measured data from 1995 was used. Data from 14 schools that was not used to develop the load shapes were used to verify the load shapes for schools without kitchens. The measured total demand for the 14 schools was compared to the total model demand. Four weekdays were randomly chosen at different outdoor temperature levels.

Fig. 11 shows the typical load shape compared to the measured one. Although none of the objects really belongs to that category, the typical load shape matches the measured load shape very well. During some hours, errors exceed 10% but are below 10% most of the hours. The high errors in the evening is due to the sports centre; only some of the 14 schools are open in the evening. Several of the previously discussed factors can influence the errors.

Fig. 12 shows the typical load shape and measured load shape. Errors are quite high during most of the day and, when trying to apply the typical load shape in this temperature
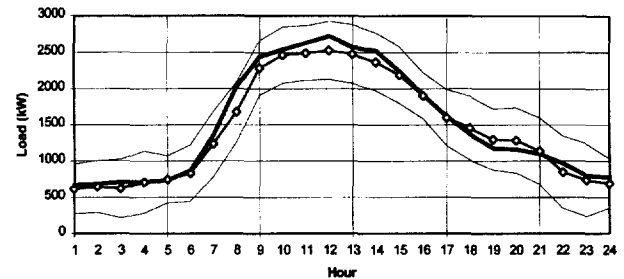

Fig. 11. Total demand from 14 schools (thick line) not included in the 'schools without kitchen' category, compared to the typical load shape (thin line with boxes) of that category. Thursday 951214, mean daily outdoor temperature − 3.0°C.
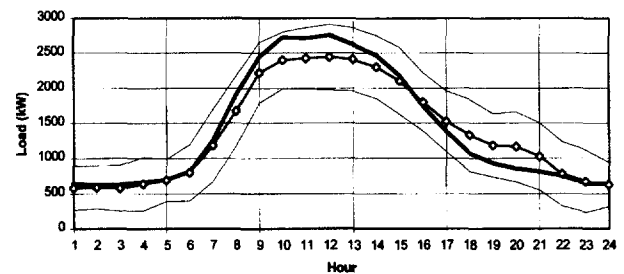

Fig. 12. Total demand from 14 schools (thick line) not included in the 'schools without kitchen' category, compared to the typical load shape (thin line with boxes) of that category. Friday 951110, mean daily outdoor temperature 7.3°C.

interval for other days, the results were identical: quite high errors during most of the day.

Fig. 13 shows a comparison between the typical load shape and a measured load shape from one of the hottest days during autumn 1995. Errors are well below 10%, except between 4 p.m. and 10 p.m., when the operating hours of the sports centre have great influence on the load shape.

Fig. 14 shows a measured load shape compared to the typical load shape during a day when, for some reason, some of the schools with kitchens had a quite low electricity consumption. This caused the high errors between 6 a.m. and 9 a.m. The errors in the evening are smaller compared to the other typical load shapes presented in Figs. 11–13.
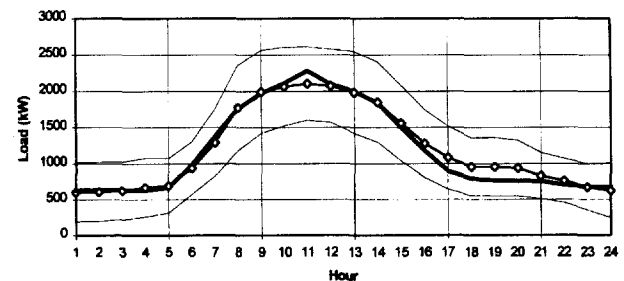

Fig. 13. Total demand from 14 schools (thick line) not included in the 'schools without kitchen' category, compared to the typical load shape (thin line with boxes) of that category. Monday 950821, mean daily outdoor temperature 20.6°C.
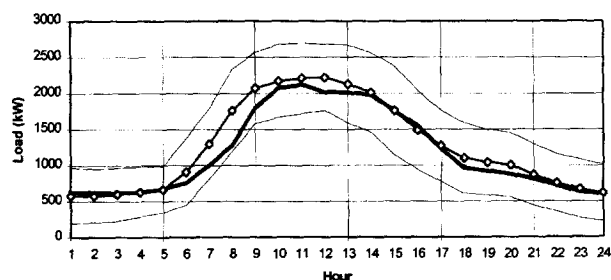
Fig. 14. Total demand from 14 schools (thick line) not included in the 'schools without kitchen' category, compared to the typical load shape (thin line with boxes) of that category. Wednesday 951011, mean daily outdoor temperature 12.8°C.

6. Results for hotels

The hotel category consists of nine objects with floor area ranging from 5000 to 37,500 m², eight of them are located within city area and one in the countryside.

6.1. Year profiles

Fig. 15 shows the year profile for Mondays to Fridays. Christmas and New Year are easily recognised, when electricity consumption is much lower than for the rest of the days during the same time period. Standard deviations are much higher during Christmas and New Year when the activity levels vary greatly between different hotels.

During Easter, there is another obvious drop in the consumption profile, and the third drop of the year takes place in the beginning of May, around May day. During summer, standard deviations increase and the electricity consumption is lower than during the rest of the year. The major reason for the higher standard deviations during summertime is that one of the hotels has a positive correlation between electricity consumption and outdoor temperature. This hotel is the most recently built of the nine included in this study. Seven of the nine hotels showed a negative correlation between temperature electricity consumption. Temperature may not be the only reason of lower consumption, as hotels with much lighting equipment will be affected by more hours of daylight, and consumption decreases. Akbari et al. [9] report that indoor lighting and miscellaneous equipment shows a lower consumption during summer months, compared to the rest of the year. These results are valid only for the USA, but it is a possible reason for the variations in observed Swedish results.
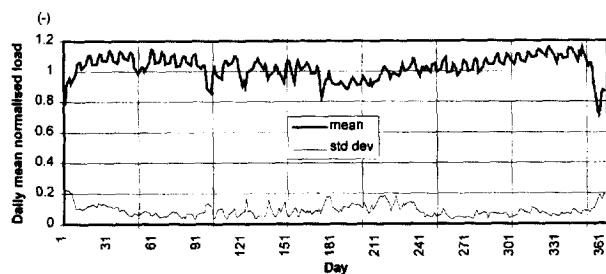
The highest daily consumption occurs during the winter. No special day-type or time period can be identified. Generally, the highest daily consumption can be found in December to February.

During standard Mondays–Fridays, the standard deviations are generally low and during spring and autumn comprise to 6–10% of the mean values. The absolute standard deviations increase slightly on non-standard weekdays, depending on the activity level at the different hotels. Some are open as usual, but others only serve food for guests staying at the hotel while the public restaurant closes early.

There is also a noticeable difference between different weekdays. The consumption on Mondays and Fridays is clearly lower compared to Tuesday–Thursday. The difference is approximately 5%, and this is another possible source of errors when analysing the daily load shapes, where all standard weekdays are included.

Fig. 16 shows the year profile for Saturdays and Sundays. Again, consumption decreases during Christmas and New Year. The reasons are the same as previously discussed.

The electricity consumption is almost constant between April and October, with a tendency to increase during the winter months. Standard deviations are almost constant, except during Christmas and New Year and in the beginning of August. The reason for this sudden increase of standard deviations and electricity consumption during the beginning of August, cannot be explained. The relative standard deviations are higher during most of the year than for Monday to Friday, mainly due to a slightly lower consumption during weekends. This depends on the activity levels. On weekdays, most hotels are open until late in the evening, but during weekends, some are still open until late in the evening, while others close earlier. The most probable cause of the lower electricity consumption during weekends is the kitchen, since it is generally open for fewer hours during weekends than during the weekdays.

Differences in electricity consumption on any day might depend on several factors, and some of the most probable are listed below:

● Different numbers of occupied beds
● Different operating hours for the kitchen, some of the hotel kitchens are open until 1 a.m., while some close earlier in the evening

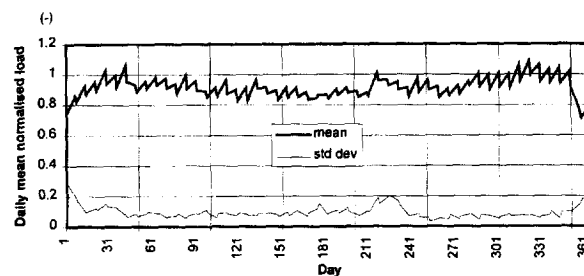Fig. 15. Year profile for hotels, weekdays.

Fig. 16. Year profile for hotels, Saturdays and Sundays.

● Some hotels have installed electricity saving equipment, four of the hotels report having installed electricity saving equipment.

6.2. Daily load shapes

As shown in Fig. 17, the demand does not fluctuate very much for hotels. The difference between minimum and maximum demand is less than 100% which should be compared to the school category where the difference was 4–6 times. Between 9 a.m. to 9 p.m., the demand is almost constant. Night-time demand is quite high, depending heavily on lighting equipment and ventilation. The hotel kitchen equipment and indoor lighting are assumed to be the reason for the major part of the daytime demand variations.

Absolute standard deviations are constant during early morning hours. It is not until 7 a.m. that they begin to increase from 0.1 during night-time, to 0.14 during the later part of the morning (7 a.m.–9 a.m.), and then stabilises after 10 a.m., at around 0.12. The higher standard deviations during morning hours depend to a great extent on breakfast time. Survey answers indicated that breakfast time starts between 6 a.m. and 7:30 a.m. at the different hotels.

After 9 a.m., the demand is constant until lunch is over at 2 p.m., which is followed by a slight demand decrease. At 5 p.m., another increase occurs, and standard deviations also become larger at this time, depending on whether the hotel serves dinner or not. One hotel in the study did not serve any food in the evening, which affected the errors.

After 9 p.m., the demand decreases rapidly, some of the kitchens are beginning to close, while others are open until 1 a.m. This is assumed to be the major reason of the higher (0.16–0.20) standard deviations during the evening.

Fig. 18 shows another hotel load shape for standard weekdays, but this time, for higher outdoor temperatures. The load shape is displaced about 0.1 compared to the load shape in Fig. 17, which may depend on temperature, but also on other factors like different operating hours for lighting equipment because of more hours with daylight. Absolute standard deviations are slightly higher during daytime than for lower temperature, but again, it is one single hotel that affects the standard deviations. If this hotel is excluded, the standard deviations are of the same size as for lower temperatures.

Fig. 19 shows a daily load shape for standard weekend days. The weekend shapes are characterised by lower daytime
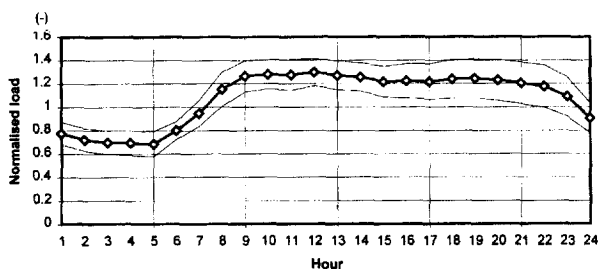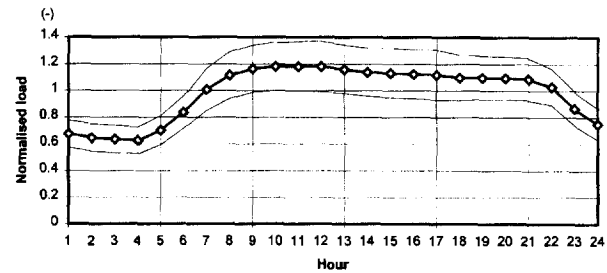

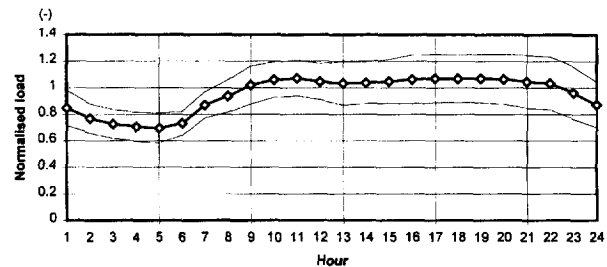Fig. 18. Standard weekday load shape for hotels, temperature interval 15–20°C. Mean temperature 17.3°C.

Fig. 19. Standard weekend load shape for hotels, temperature below 0°C. Mean temperature −2.3°C.

demand than on weekdays and slightly higher standard deviations. Night-time demand is almost equal to the weekday shape, but 15–20% lower during the rest of the day. This indicates that night-time loads are constant over the year and little affected by the occupancy rate.

A possible reason for the higher errors is the opening hours of the kitchen. During the morning, breakfast is served as usual, but after 12 a.m., the standard deviations increase, indicating that some hotels do not use as much electricity as others during weekends. This is the case for hotels located outside the centre of the city. Generally, it was found that hotels with public restaurants located in the centre of the city have higher consumption during weekend days, compared to the ones located outside the city centre.

6.3. Relationship between outdoor temperature and electricity consumption

Fig. 20 shows weekday load shapes for six temperature intervals. No standard deviations are shown in the figure. As the figure shows, the demand is lower at higher temperatures, except between 5 a.m. and 7 a.m. Between 1 a.m. and 5 a.m., it is the demand at lower temperatures that is most affected, but in daytime and in the evening, only the demand at temperatures above 5°C is affected by temperature.

During daytime, the lowest demands corresponds to high temperatures, but hotels with a high amount of cooling equipment will not be affected to such a high degree. The results are presented in Tables 5 and 6. Days with mean outdoor temperatures above 17°C and holidays are excluded.

Five of the hotels show a significant negative correlation between temperature and electricity consumption, three hotels shows a non-significant correlation, and the last one, a
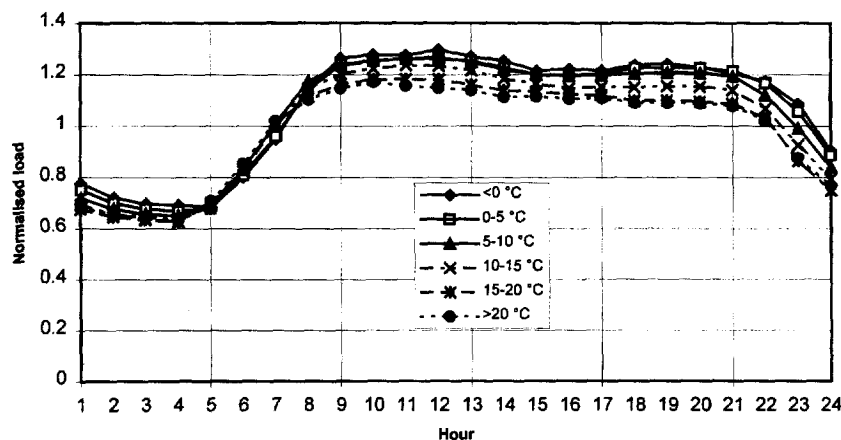

Fig. 17. Standard weekday load shape for hotels, temperature below 0°C. Mean temperature −2.1°C.

Fig. 20. Standard weekday load shapes for hotels, for six different temperature intervals.

Table 5
Standard weekday regression results for hotels

Hotel	P_0 (–)	P_{sp} (– /°C)	Adj. R^2	Significance
1	1.18	–0.018	0.73	0.000
2	1.06	–0.002	0.04	0.006
3	1.05	0.003	0.07	0.005
4	0.98	0.009	0.23	0.000
5	1.05	0.000	0.00	0.678
6	1.08	–0.003	0.06	0.000
7	1.05	–0.003	0.13	0.000
8	1.19	–0.016	0.70	0.000
9	1.05	–0.003	0.08	0.000

Table 6
Standard weekend regression results for hotels

Hotel	P_0 (–)	P_{sp} (– /°C)	Adj. R^2	Significance
1	1.1	–0.016	0.77	0.000
2	0.92	0.000	0.00	0.802
3	0.89	0.004	0.05	0.039
4	0.88	0.007	0.10	0.000
5	0.91	–0.002	0.02	0.043
6	0.9	0.000	0.00	0.767
7	0.99	–0.003	0.18	0.000
8	0.99	–0.013	0.60	0.000
9	0.97	–0.002	0.04	0.018

significant positive correlation (hotel 4). Hotel 4 is the one most recently built and the most luxurious of the hotels in the study. The intercept load at 0°C varies by more than 20%, and it is the two hotels with partial electrical heating, that have the highest consumption at 0°C and the highest temperature dependence.

R^2-values are generally poor, except for the two hotels with partial electrical heating. Although the regression line cannot explain more than 23% of the variations in electricity consumption for the other seven hotels, the correlation between electricity consumption and outdoor temperature is significant in four of these seven. The conclusion of this is that no

general rule, predicting how electricity consumption depends on outdoor temperature, can be determined for hotels.

The regression results for weekends are presented in Table 6. The intercept, P_0, is slightly lower compared to weekdays, and only four objects show significant correlation. Still, it is only the two hotels with some electrical space heating, that have high R^2-values.

7. Verification

To verify the typical load shapes, measured data from 1993 was used. One hotel with gas furnace was used to verify the hotel load shapes. Three different weekdays were randomly chosen.

Fig. 21 shows the typical hotel load shape compared to a measured load shape. The typical load shape matches the measured load shape quite well during most of the day. During late night and morning hours, errors are approximately 10%.

Fig. 22 shows another hotel load shape, this time at colder weather conditions. Errors are of the same size as in Fig. 21, except during late night and early morning hours. Altogether, the typical load shape gives a fair approximation of a load shape for a hotel. Errors are below ± 10% during most of the day, except during late night and early morning hours.

The last hotel load shape is shown in Fig. 23. Errors during the chosen Saturday are less than 10%, except during late
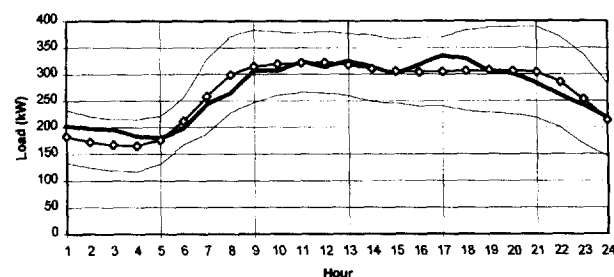

Fig. 21. Typical load shape for a hotel (thin line with boxes) and measured data from October weekday in 1993 (thick line). Temperature interval 5–10°C. A 95% probability for the associated standard deviations.
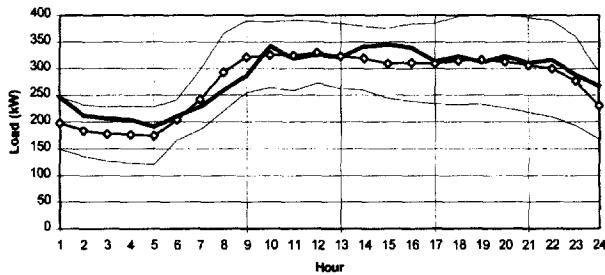
Fig. 22. Typical load shape for hotels (thin line with boxes) and measured data from December weekday 1993 (thick line). Temperature below 0°C. A 95% probability for the associated standard deviations.
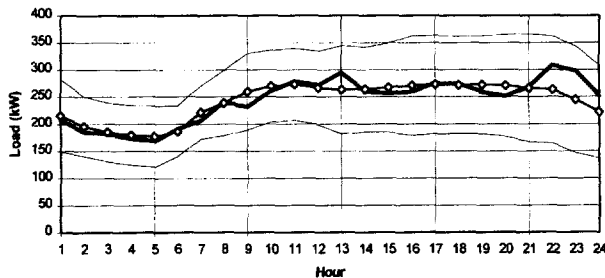

Fig. 23. Typical load shape for hotels (thin line with boxes) and measured data from December Saturday 1993 (thick line). Temperature below 0°C. A 95% probability for the associated standard deviations.

evening hours, and twice in the middle of the day. The unexplainable high demand that occurred between 10 p.m. and 11 p.m., caused very high errors during these hours.

7.1. Concluding remarks

A typical daily load shape can be developed for hotels with reasonable accuracy, and typical daytime standard deviations are approximately 8–10% of the mean values. Errors begin to increase when temperatures rise above 15°C which depends very much on the air conditioning system in the hotels. During weekends, errors are higher than during weekdays. This is quite natural since weekend activity levels are very different for different hotels. The electricity consump-

tion varies only slightly during the year, except during Christmas and New Year, when consumption is much lower than during the rest of the year.

8. Comparison to other studies

In order to compare the load shapes from this study to load shapes developed within other studies, usually presented in W/m^2 terms, it is necessary to use an annual electricity consumption to obtain a W/m^2-load shape. Lawrence Berkeley Laboratory (LBL) has developed load shapes for schools and lodging buildings, where the lodging category includes hotels and motels, and measured load data for these two categories are compared to the results from this study. The temperature interval 5–10°C was chosen for the representation of the Swedish load shapes to provide the best representation of the annual mean outdoor temperature. LBL load shapes for coastal buildings were assumed to be most similar to Swedish conditions and all objects in this study are located in the coastal area too. The comparisons are shown in Figs. 24 and 25.

The school building load shape from this study is correlated to the LBL school load shape, although there is a vertical displacement during hours 6 a.m. to 8 p.m. The highest differences occur in the morning and an important reason is the fact that this study also includes secondary schools which were observed to begin earlier in the morning compared to the primary schools. The reasons are the same for the differences that occur in the late afternoon. An interesting observation is the effect of the cooling equipment. If cooling equipment is included, there is a 2 W/m^2 displacement during daytime, but if cooling is excluded, the load shape is very similar to the LBL load shape. Swedish schools are very seldom equipped with cooling systems.

If the hotel load shape is compared to the LBL results for the lodging category, there are some noticeable differences. Night-time demand match the LBL load shape well but major differences occur during daytime when there is a 3–4 W/m^2
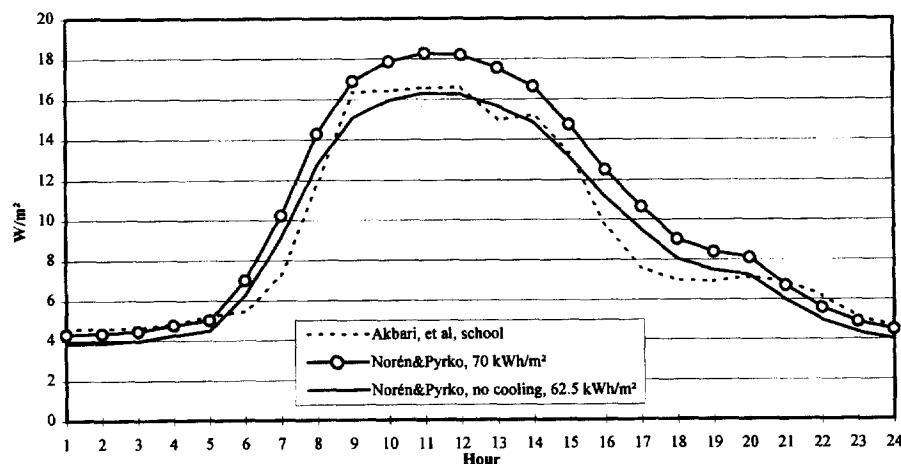

Fig. 24. Load shape for schools without kitchen from this study compared to results from Akbari et al. [9].
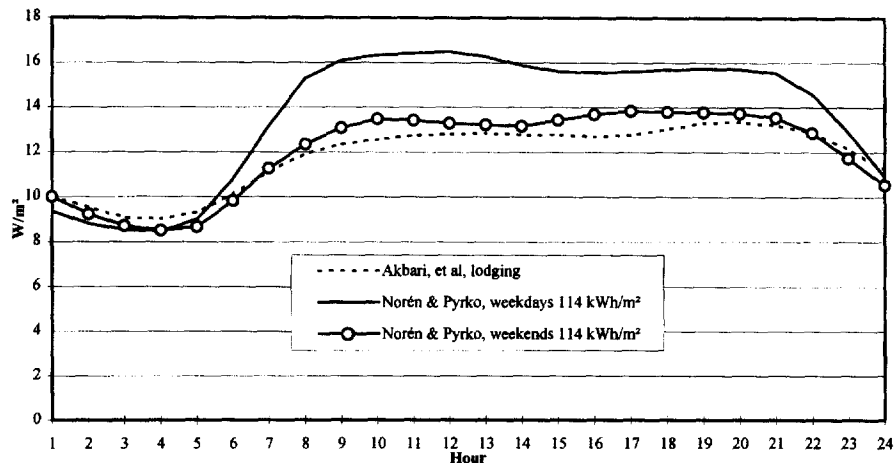
Fig. 25. Load shape for hotels from this study compared to results from Akbari et al. [9].

difference between the two load shapes. The LBL lodging load shape is more flat and the daytime demand is lower compared to the load shape developed within this study. The most probable single reason for the differences is less usage of electrical cooking equipment in the lodging buildings. Cooking equipment is reported to only account for approximately 1% of the annual electricity consumption in lodging buildings [9]. The Swedish Vattenfall study reports 30% for kitchen equipment in Swedish hotels [3]. All of the hotels in this study are equipped with kitchens and most of them have quite large kitchens, providing the hotels' public restaurants with food.

Two load shapes are very well-correlated: the LBL lodging load shape compared to the weekend load shape developed within this study. An interesting observation from the LBL study is that no differences could be observed between standard days and non-standard days. In this study, major differences between standard weekdays and weekends were observed and previously, it was stated that less cooking equipment is used during weekends in Swedish hotels compared to weekdays. The major reason for the differences between the LBL results and the weekday load shapes from this study seems to be less usage of electrical cooking equipment for the lodging category.

LBL load shapes and the load shapes developed in this study are quite similar although there are substantial differences. The similarities between the load shapes are better than initially expected by the research group, though different conditions in Sweden and the USA.

9. Applications of the results

Knowledge of electricity consumption patterns and electricity consumption indicators is necessary for developing new tools for energy auditors and for identifying operational and maintenance (O&M) problems. Several types of indicators are available, such as: annual electricity consumption figures, hourly load shapes and other efficiency indicators,

but if O&M problems should be detected, hourly load shapes probably are among the best tools. There are several applications for the load shapes presented in this study, such as: (a) conversion from annual electricity consumption to hourly load shapes. The set of typical load shapes can be used to estimate the building load profile without load measurements. For example, the school load shapes have been used to evaluate the possibilities to install a gas engine for small scale co-generation in a school building. (b) Identification of O&M problems. If O&M problems are suspected, it is possible to compare the load profiles obtained by the normalised load shapes with measured data. In case of differences, the time of day and magnitude of the deviations can be identified. (c) Evaluation of energy efficiency projects. If an energy efficiency retrofitting is carried out and no hourly measurements before the retrofitting were carried out, the electricity consumption from the previous year can be used to estimate the hourly load shape before the retrofitting which then can be compared to the hourly load shape after the retrofitting.

10. Conclusions

The typical load shapes give a reasonable approximation of the measured load shapes, although the relative standard deviations are quite high during certain hours, but this is mainly due to decreasing demand. Daytime (9 a.m.–5 p.m.) results are generally good with standard deviations below 10% of mean values but there are quite high day-to-day variations, where some possible reasons have been discussed. Only a limited amount of data was available for verification, although the typical load shapes provided quite good approximations of the measured load shapes. Comparisons with results from Lawrence Berkeley Laboratory showed both similarities and differences, especially for the hotel category, but it is important to consider that Swedish and American conditions are different. The developed load shapes can be applied if a fair approximation of a school/hotel load shape is required. The presented methodology is simple to use for similar studies.

Acknowledgements

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