An analysis of electricity consumption and load demand in Swedish grocery stores

Corfitz NORÉN and Jurek PYRKO
Lund Institute of Technology, Dept. of Heat and Power Engineering, Sweden

1 - SYNOPSIS

Load shapes and electricity consumption indicators are developed for grocery stores using a multiple regression approach with parameters accounting for factors that affect the electricity consumption.

2 - ABSTRACT

This paper deals with electricity consumption and electrical load demand in Swedish grocery stores. Several interesting results were observed, such as: non-linear correlation between floor area and electricity consumption, and non-linear correlation between outdoor temperature and electricity consumption. Electricity Consumption Indicators (ECIs) were developed based on 11 months of load research data from 21 grocery stores. Load shapes, and daily, monthly and annual consumption indicators were developed. The usage of two different area figures was studied: the gross floor area and the sales floor area. The analysis showed that the sales area provides the most information about the actual store conditions and is of greater importance when analysing the electricity consumption in grocery stores. There was a high level of agreement in comparisons to measured data.

3 - INTRODUCTION

Grocery stores are among the highest electricity consumers if the specific electricity consumption (kWh/m²·yr) is compared. In many cases, the specific electricity consumption in grocery stores is more than 5 times as high as for other commercial and public buildings such as schools and office buildings. A Swedish study (Vattenfall 1991) estimated that grocery stores account for only 4.4% of the total area of Swedish commercial and public buildings but 10.5% of the total electricity consumption.

There are substantial differences between grocery stores and other commercial buildings and there are some reasons for these differences:

- Very high capacities of refrigeration equipment are installed in grocery stores and these are operated 24 hours a day and 365 days a year.
- Other commercial buildings are typically operated between 7 a.m. and 5 p.m. whereas grocery stores are open until late at night, 9 p.m.-11 p.m., in many cases.
- Many other commercial buildings are operated only during standard weekdays whereas grocery stores are usually open 7 days a week.

The amount of literature on grocery store electricity consumption is limited, but some sources have been identified. The most interesting are two studies that have reported non-linear correlation between floor area and electricity consumption (FFE 1990, Cox et al 1993).

The perhaps most interesting report is a Danish report (FFE 1990) on building electricity consumption which also includes grocery stores and makes an attempt to take the non-linear relationship into consideration by making a separate analysis for "small stores" (<400 m²) and "large stores" (>400 m²) and to base their results on
sales floor area. It was found that the specific annual electricity consumption in the small stores was considerably higher than in the large stores, however, no further attempts were made to quantify or analyse this phenomenon. The major reason for the differences was reported to be behavioural aspects but none of them are mentioned or taken into consideration in the analysis. The load situation was not studied either.

An American study on energy consumption in grocery stores also makes these observations although a linear correlation was used in the analysis (Cox et al 1993). Here, some noticeable differences were observed between stores larger than 40 000 ft² and stores smaller than 40 000 ft² respectively, where the specific electricity consumption was reported higher in the small stores.

A previous Swedish study on load shapes for commercial buildings reports results on non-dimensional load shapes but concentrating on department stores rather than grocery stores. The Association of Swedish Electric Utilities performed a large electricity consumption study on residential, commercial and small industrial buildings between the years 1987-1991, where grocery stores were included among the studied objects (SEF 1991). This study only reports non-dimensional load shapes and annual ECIs.

The Energy Analysis Group at Lawrence Berkeley National Laboratory has published several reports on energy consumption and load shapes for commercial buildings and these studies also report results on grocery stores (Akbari et al 1991, 1993).

### 3.1. Grocery store electricity consumption characteristics

Grocery stores are characterised by a very high annual specific electricity consumption and high specific load demands, compared to other types of commercial buildings. The high electricity consumption is mainly due to the high base load, caused by the refrigeration equipment which is operated all day. Swedish electric utility Vattenfall’s study estimated the annual electricity consumption for grocery stores to 296 kWh/m², where the consumption of different end-uses is shown in Table 1 (Vattenfall 1991). Refrigeration and indoor lighting are the two dominant end-uses, where refrigeration is reported to account for 39% of the annual electricity consumption and indoor lighting for 23%. Together, these two end-uses account for almost two thirds of the annual electricity consumption.

The correlation between electricity consumption and outdoor temperature is an important factor in grocery stores and several other studies have identified a positive correlation between electricity consumption and outdoor temperature during summer.

<table>
<thead>
<tr>
<th>End-use</th>
<th>Electricity consumption (kWh/m²·yr)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical space heating</td>
<td>34</td>
<td>11</td>
</tr>
<tr>
<td>Fans</td>
<td>24</td>
<td>8</td>
</tr>
<tr>
<td>Hot water</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Cooling equipment</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Refrigeration equipment</td>
<td>114</td>
<td>39</td>
</tr>
<tr>
<td>Miscellaneous cooling</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Pumps</td>
<td>2</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Indoor lighting</td>
<td>68</td>
<td>23</td>
</tr>
<tr>
<td>Office equipment</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Kitchen equipment</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Outdoor equipment</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>Miscellaneous equipment</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>296</td>
<td>100</td>
</tr>
</tbody>
</table>

### 3.2. Building characteristics

All 21 stores are smaller grocery stores located in the south of Sweden, gross floor area varies between 300-2565 m² and sales floor area between 190-1817 m². These stores are rather small, with food sales as the major activity.
All the 21 objects belong to the same grocery chain but each store has a local manager. Some of the stores are located within cities while others are located in smaller suburban areas.

3.3. Initial analysis

The following parameters were considered important for the analysis:

- Floor area
- Schedules - primarily shop opening and closing hours but also different schedules for the different day-types
- Connected refrigeration capacity
- Outdoor temperature

Unfortunately, only information about floor area and outdoor temperature could be collected, day-to-day schedules were considered as important for the analysis but only information about opening and closing hours could be determined. Schedules are difficult to determine as several other activities take place, such as cleaning of the store before opening or after closing hours. The only means of obtaining information about the connected refrigeration capacity would be to perform visual inspections in each store, but due to different geographic locations, this was considered an impossibility.

An important question to consider is whether the relationship between floor area and electricity consumption is linear. Traditionally, a linear relationship is assumed most frequently, but in the case of grocery stores there are some factors indicating that a non-linear relationship provides a better fit of data. Initial analysis shows an obvious and statistically significant trend that smaller stores have a higher specific electricity consumption than larger ones.

3.4. Which area figure to use?

Many different definitions of floor area exist, such as, gross floor area, net floor area and rental area as three examples. In this study, the use of two different area figures was studied: gross floor area (GFA) and sales floor area (SFA). The sales floor area is defined as the area of the actual store and does not include other areas such as storage rooms, offices, etc. Figure 1 shows the sales area plotted versus the gross floor area and there are noticeable differences, varying from a factor of 1.2 up to a factor of 2.68. A linear regression analysis was performed, which estimated the ratio between GFA and SFA to 1.62.

![Figure 1: Plot of gross floor area versus sales floor area.](image)

An initial analysis, using both area definitions, was carried out and the result obtained showed that the difference between the results using total floor area and results using sales area, was substantial in some cases. The conclusion was that the sales floor area provides the most accurate figure of actual conditions in the stores, and that the floor areas of other spaces in the store (storage rooms, offices, etc.) seem to be of lesser interest when analysing the electricity consumption. For this reason, the sales area is used throughout the analysis. A second reason for using the sales area in the analysis is that most grocery store owners seem to use this particular area definition when computing energy consumption indicators, which makes the results more useable.
4 - DATA ANALYSIS

21 stores with a total sales floor area of 11 200 m² (total GFA 19 100 m²) and a total annual electricity consumption of 9.1 GWh were included in the study. The geographic location for all the stores is the south of Sweden but the climatic differences are small and only one set of temperature data was used in the analysis. Two different day-types were identified: standard weekdays (229 days) and weekends/holidays (95 days). The reason for using 11 months of load data instead of 12 months, is that hourly measurements had only been carried out for 11 months when the study was initiated.

4.1. Suspicious data

All data were sorted by day-type and hour and were plotted in order to easily identify suspicious data points. Approximately 30-50 zero-readings were discovered and removed before the analysis. Some other suspicious data was discovered but this was not removed and is considered to have only a minor effect on the final results.

4.2. Relationship between floor area and electricity consumption

Since non-linear relationships between floor area and electricity consumption have previously been reported, the first choice was to investigate whether a non-linear relationship exists in this case. Figure 2 shows the annual specific electricity consumption versus floor area and a regression analysis of the data showed a significant relationship between floor area and the annual specific electricity consumption. The data point which is marked with a circle is of course a very influential observation but even if it is excluded, the correlation between sales floor area and the annual specific electricity consumption is still highly significant.

![Figure 2: Plot of specific annual electricity consumption versus sales floor area.](image)

Two different approaches for the analysis of the non-linear relationship between floor area and electricity consumption are studied:

\[ E = C_0 \cdot SFA^X \]  
\[ E_{sp} = C_0 + C_1 \cdot SFA \]  

Where:  
E = Electricity consumption (kWh)  
\( E_{sp} \) = Specific electricity consumption (kWh/m²)  
SFA = Sales floor area (m²)  
C₀, C₁, X = Parameters to be estimated

The difference between the two analysis approaches is that the first approach analyses the electricity consumption and the second approach the specific electricity consumption. The first analysis method provides a slightly better fit of data but is highly sensitive to the size of the estimated exponent X and this method of data analysis must be considered to give very unstable results. For this particular reason, equation 2 was chosen for the further analysis.
4.3. Relationship between electricity consumption and outdoor temperature

Outdoor temperature is a very important factor when analysing electricity consumption in grocery stores, other studies report a strong correlation between outdoor temperature \( T \) and electricity consumption \( E \) (Norén 1997, Cox 1993). Norén suggests the following relationship for analysis of the temperature dependence:

\[
E = C_0 + C_1 T + C_2 T^3 \tag{3}
\]

This relationship provides a good fit of data but the following relationship, requiring less parameters, was found to be equally good and was used in the further analysis:

\[
E = C_0 + C_1 T^2 \tag{4}
\]

Daily mean outdoor temperature was used for the analysis; hourly temperature data was available but to eliminate the effects of heat accumulation in the stores daily mean temperature was used. Another possible way would be to analyse the relationship between hourly electricity consumption and the delayed hourly outdoor temperature, i.e. study the correlation between \( T(t-n) \) and \( E(t) \) where \( n = 1,2,\ldots, n \) hours delay.

4.4. Hypotheses

The following hypotheses were set up:

- A positive correlation between outdoor temperature and electricity consumption is expected during all hours and day-types.
- The refrigeration equipment is assumed to be the major reason for the positive correlation between outdoor temperature and electricity consumption. Since the refrigeration equipment is operated at all hours, this correlation is expected to be found during all hours.
- The magnitude of the temperature dependence should remain approximately constant during all hours and day-types.
- Smaller stores are expected to have a higher specific electricity consumption and the magnitude of the area dependent specific demand is assumed to remain approximately constant during all hours and day-types.

4.5. Hourly electricity consumption

The **Hourly Electricity Consumption Indicator**, HECI, was defined as:

\[
\text{HECI} = C_0 + C_1 \cdot \text{SFA} + C_2 \cdot T^2 \text{ (W/m²)} \tag{5}
\]

Where:
- \( C_0, C_1, C_2 \) = Regression coefficients
- SFA = Sales floor area (m²)
- T = Daily mean outdoor temperature (°C)

Multiple linear regression using the Ordinary Least Squares (OLS) approach was used for estimation of the unknown parameters \( C_0, C_1, \) and \( C_2 \) (Draper & Smith 1981). MINITAB® and MATLAB® was used for the data analysis.

The regression was carried out for each of the hours 1-24 during the two different day-types, a total of 48 regressions. Data from all the 21 stores were used in every regression. This implies that the number of data points in each regression equalled the number of days for the specific day-type multiplied by 21, i.e. 21·229=4809 data points for standard weekdays, 21·95=1995 data points for the weekends. The relationship can be written with matrices: \( Y = XA \). 

**PANEL 3**
Where: 
\[ Y = \begin{bmatrix} D_1 \\ D_2 \\ \vdots \\ D_{4809} \end{bmatrix}, \quad X = \begin{bmatrix} 1 & SFA_1 & T^2_k \\ 1 & SFA_1 & T^2_k \\ \vdots & \vdots & \vdots \\ 1 & SFA_{21} & T^2_{21} \end{bmatrix}, \quad A = \begin{bmatrix} C_0 \\ C_1 \\ C_2 \end{bmatrix} \]

\[ D_i = \text{Measured data } i (\text{kW}) \]
\[ SFA_j = \text{Sales floor area for store } j (\text{m}^2) \]
\[ T^2_k = \text{Squared mean daily outdoor temperature at day } k \left( ^\circ \text{C}^2 \right) \]

The vector \( Y \) contains the measured load data normalised for the sales floor area. Furthermore, the vector \( Y \) is of the dimension 4809×1 in the standard weekday case. The \( X \) matrix contains the parameters listed above (1, SFA and \( T^2 \)), i.e. \( X \) is of the dimension 4809×3 in the standard weekday case. The vector \( A \) contains the unknown regression coefficients \( (C_0, C_1, C_2) \) which will be estimated and is of the dimension 3×1.

4.6. Daily, monthly and annual electricity consumption

Two different ways of computing the daily electricity consumption is studied:

- Computation of the integrals (or sums) of the HECI
- Direct analysis of the daily electricity consumption. The **Daily Electricity Consumption Indicator**, DECI, was defined as:

\[
\text{DECI} = C_0 + C_1 \cdot \text{SFA} + C_2 \cdot T^2 (\text{kWh/m}^2) \tag{6}
\]

Where: \( C_0, C_1, C_2 = \text{Regression coefficients} \)
\( \text{SFA} = \text{Sales floor area (m}^2) \)
\( T = \text{Daily mean outdoor temperature (} ^\circ \text{C}) \)

The variation between these two methods should be small since the same data is analysed, the only difference is that the sums are computed after the analysis when sums of the HECIs are computed and before the analysis when analysing daily data. Monthly and annual electricity consumption are computed as integrals (or sums) of the daily electricity consumption, using the number of different day-types and a temperature profile. The temperature profile for 1997 was used when computing the results for monthly and annual electricity consumption.

4.7. Annual peak demand

The annual peak demand is analysed using the same methodology as for the hourly electricity consumption, but here the temperature dependence term is excluded. Instead of studying only the annual peak demand, the three highest demands for each store over the year were used in the analysis. Only 11 months of load data was available and there is a potential risk that the annual peak demand was caused by special circumstances and in order to minimise this risk, the three highest demands were used in the analysis. The **Peak Electricity Consumption Indicator**, PECI, was defined as:

\[
\text{PECI} = C_0 + C_1 \cdot \text{SFA} (\text{W/m}^2) \tag{7}
\]

Where: \( C_0, C_1 = \text{Regression coefficients} \)
\( \text{SFA} = \text{Sales floor area (m}^2) \)

If this relationship is written in matrix form, \( Y = XA \), the vector \( Y \) contains the three measured highest demands for each store normalised for the sales floor area. The vector \( Y \) is of the dimension 63×1 in the standard weekday case. The \( X \) matrix contains the parameters listed above (1 and SFA), i.e. \( X \) is of the dimension 63×2 for the standard weekday case. The vector \( A \) contains the unknown regression coefficients \( C_0 \) and \( C_1 \) which will be estimated and is of the dimension 2×1.
4.8. Load factor

The load factor LF is defined as:

\[ LF = \frac{\text{Annual electricity consumption (kWh)}}{\text{Annual peak demand (kW) \cdot 8760 (h)}} \]  

This implies that building categories with high annual consumption and relatively low peak demands will have a high load factor, whereas buildings with high peak demands will have a lower load factor.

5 - RESULTS

5.1. Hourly electricity consumption

The regression results for the HECI are shown in Table 2 and these results are also presented graphically for a prototype store, further into the paper.

Table 2: Analysis results for the hourly electricity consumption.

<table>
<thead>
<tr>
<th>Hour</th>
<th>Hour C (W/m²)</th>
<th>Hour C (W/m²)</th>
<th>Hour R² (%)</th>
<th>Weekends and holidays</th>
<th>Weekends and holidays</th>
<th>Weekends and holidays</th>
<th>Weekends and holidays</th>
<th>Weekends and holidays</th>
<th>R² (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>84.3</td>
<td>-0.033</td>
<td>0.014</td>
<td>39</td>
<td>83.8</td>
<td>-0.033</td>
<td>0.015</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>84.2</td>
<td>-0.034</td>
<td>0.018</td>
<td>41</td>
<td>83.9</td>
<td>-0.033</td>
<td>0.016</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>83.8</td>
<td>-0.032</td>
<td>0.013</td>
<td>37</td>
<td>83.5</td>
<td>-0.033</td>
<td>0.014</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>84.0</td>
<td>-0.033</td>
<td>0.014</td>
<td>40</td>
<td>83.9</td>
<td>-0.033</td>
<td>0.013</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>82.9</td>
<td>-0.031</td>
<td>0.012</td>
<td>38</td>
<td>82.0</td>
<td>-0.029</td>
<td>0.011</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>82.5</td>
<td>-0.023</td>
<td>0.007</td>
<td>17</td>
<td>81.0</td>
<td>-0.022</td>
<td>0.003</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>97.7</td>
<td>-0.009</td>
<td>0.005</td>
<td>2</td>
<td>96.4</td>
<td>-0.027</td>
<td>0.024</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>122.2</td>
<td>-0.022</td>
<td>0.029</td>
<td>19</td>
<td>105.5</td>
<td>-0.029</td>
<td>0.032</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>139.3</td>
<td>-0.034</td>
<td>0.023</td>
<td>44</td>
<td>132.5</td>
<td>-0.035</td>
<td>0.036</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>138.4</td>
<td>-0.035</td>
<td>0.026</td>
<td>46</td>
<td>136.1</td>
<td>-0.036</td>
<td>0.027</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>137.7</td>
<td>-0.036</td>
<td>0.028</td>
<td>48</td>
<td>135.3</td>
<td>-0.036</td>
<td>0.029</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>137.2</td>
<td>-0.035</td>
<td>0.028</td>
<td>49</td>
<td>135.1</td>
<td>-0.036</td>
<td>0.030</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>135.4</td>
<td>-0.034</td>
<td>0.026</td>
<td>48</td>
<td>133.5</td>
<td>-0.036</td>
<td>0.029</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>135.7</td>
<td>-0.035</td>
<td>0.028</td>
<td>46</td>
<td>134.5</td>
<td>-0.036</td>
<td>0.028</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>136.2</td>
<td>-0.035</td>
<td>0.030</td>
<td>45</td>
<td>134.6</td>
<td>-0.037</td>
<td>0.031</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>138.5</td>
<td>-0.037</td>
<td>0.027</td>
<td>48</td>
<td>136.8</td>
<td>-0.039</td>
<td>0.028</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>138.2</td>
<td>-0.036</td>
<td>0.024</td>
<td>45</td>
<td>137.3</td>
<td>-0.045</td>
<td>0.026</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>139.1</td>
<td>-0.037</td>
<td>0.019</td>
<td>46</td>
<td>138.6</td>
<td>-0.053</td>
<td>0.030</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>138.8</td>
<td>-0.038</td>
<td>0.015</td>
<td>39</td>
<td>138.9</td>
<td>-0.057</td>
<td>0.028</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>134.4</td>
<td>-0.036</td>
<td>0.015</td>
<td>30</td>
<td>134.5</td>
<td>-0.053</td>
<td>0.020</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>130.3</td>
<td>-0.042</td>
<td>0.012</td>
<td>27</td>
<td>109.6</td>
<td>-0.044</td>
<td>0.008</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>110.6</td>
<td>-0.044</td>
<td>0.013</td>
<td>30</td>
<td>108.8</td>
<td>-0.045</td>
<td>0.005</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>91.8</td>
<td>-0.037</td>
<td>0.014</td>
<td>39</td>
<td>102.6</td>
<td>-0.046</td>
<td>0.013</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>90.3</td>
<td>-0.037</td>
<td>0.013</td>
<td>41</td>
<td>91.0</td>
<td>-0.037</td>
<td>0.013</td>
<td>43</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3 shows the estimated area dependence for weekends and weekdays. As can be seen, the area dependence is almost constant during the day for both day-types except for early morning hours when it suddenly decreases slightly, however, this depends on analytic problems due to different opening hours. There is a tendency that the larger stores open earlier in the morning, which causes the area dependence to drop during early morning hours. The high area dependence on weekdays during the evening hours is caused by the fact that the larger stores are generally open for longer hours during weekends.

Figure 4 shows the estimated temperature dependence for the two day-types and the main difference is the somewhat higher temperature dependence on weekend and holidays. The temperature dependence is decreasing over night which is believed to be due to the fact that there are no internal heat gains in the stores during the night, causing the refrigeration load to decrease during this period. During daytime, the temperature dependence
is considerably higher compared to the night period and the two most probable reasons are higher refrigeration loads during day-time, due to internal heat gains, and the need for air conditioning which is not operated during the night.

![Graph](image)

**Figure 3**: Estimated area dependence on standard weekdays and weekends.

**Figure 4**: Estimated temperature dependence on standard weekdays and weekends.

In order to present the results graphically, the other two parameters (area and outdoor temperature) must also be known. A prototype store with a sales floor area of 535 m² (mean value of all stores in the study) is used. The hourly load shapes are shown at different outdoor temperatures in Figure 5 and 6. The difference between weekdays and weekends is very small but there are some differences, especially during opening and closing hours and this was the major reason for separating weekdays and weekend days in the analysis.

![Graph](image)

**Figure 5**: Load shapes for standard weekdays at different outdoor temperatures.

**Figure 6**: Load shapes for weekends and holidays at different outdoor temperatures.

### 5.2. Daily, monthly and annual electricity consumption

The results for the daily electricity consumption using the two different approaches is studied, and are shown in Table 3.

<table>
<thead>
<tr>
<th></th>
<th>Standard weekdays</th>
<th></th>
<th>Weekends and holidays</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C_0$ (W/m²)</td>
<td>$C_1$ (W/m²·m²)</td>
<td>$C_2$ (W/m²·°C²)</td>
</tr>
<tr>
<td>Hourly</td>
<td>2800</td>
<td>-0.80</td>
<td>0.45</td>
</tr>
<tr>
<td>Daily</td>
<td>2790</td>
<td>-0.81</td>
<td>0.50</td>
</tr>
</tbody>
</table>

**Table 3**: Analysis results for daily electricity consumption.
The results from the two different approaches are similar, which had to be expected. The only difference is that the \( C_2 \) coefficient was found to be slightly higher when analysing the daily data, which is caused by the fact that the estimated temperature dependence was low during some hours (6-7 a.m.). Figure 7 shows the annual consumption pattern when using the temperature profile and the number of day-types for 1997 for the prototype store.

![Figure 7: Annual consumption pattern for the prototype grocery store.](image)

Table 4 shows the results for the monthly and annual electricity consumption when using the number of day-types and the temperature profile for 1997 and it can be noticed that the electricity consumption is mostly affected by outdoor temperature during the two warmest months (July and August) and less affected during the rest of the year.

<table>
<thead>
<tr>
<th>Month</th>
<th>( C_0 ) (kWh/m²-month)</th>
<th>( C_1 ) (kWh/m²-m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>87</td>
<td>-0.026</td>
</tr>
<tr>
<td>February</td>
<td>78</td>
<td>-0.024</td>
</tr>
<tr>
<td>March</td>
<td>87</td>
<td>-0.026</td>
</tr>
<tr>
<td>April</td>
<td>84</td>
<td>-0.025</td>
</tr>
<tr>
<td>May</td>
<td>88</td>
<td>-0.026</td>
</tr>
<tr>
<td>June</td>
<td>88</td>
<td>-0.025</td>
</tr>
<tr>
<td>July</td>
<td>92</td>
<td>-0.026</td>
</tr>
<tr>
<td>August</td>
<td>93</td>
<td>-0.026</td>
</tr>
<tr>
<td>September</td>
<td>87</td>
<td>-0.025</td>
</tr>
<tr>
<td>October</td>
<td>88</td>
<td>-0.026</td>
</tr>
<tr>
<td>November</td>
<td>84</td>
<td>-0.025</td>
</tr>
<tr>
<td>December</td>
<td>87</td>
<td>-0.026</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1041</strong></td>
<td><strong>-0.31</strong></td>
</tr>
</tbody>
</table>

### 5.3. Annual peak demand

<table>
<thead>
<tr>
<th></th>
<th>( C_0 ) (W/m²)</th>
<th>( C_1 ) (W/m²-m²)</th>
<th>( R^2 ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PECI</strong></td>
<td>173.4</td>
<td>-0.033</td>
<td>18</td>
</tr>
</tbody>
</table>
The results for the analysis of the annual peak demand are shown in Table 5 and as can be noticed, the magnitude of the \( C_1 \) parameter does not differ from the findings concerning the analysis of the hourly electricity consumption. The major difference is the \( C_0 \) parameter, which is approximately 35 W/m² higher compared to the standard weekday case. Outdoor temperature is a major reason for the higher \( C_0 \) coefficient and all peak demands are observed during day-time in the summer. Typically, the peak demand occurs during the opening hours (8-10 a.m.).

### 5.4. Load factor

The load factor was expected to be high in grocery stores due to the high annual electricity consumption and as can be seen in Figure 8, this was the case. The load factor varies between 0.5-0.75, whereas two stores (marked with circles) differ from the other 19 stores, which have load factors between 0.58-0.75. No reasons for why the two stores differ from the others could be determined except that one of the stores, with a load factor about 0.5, showed a very high measured peak demand when compared to the other stores, even if the area dependence is taken into consideration.

![Figure 8: Analysis results for the load factor.](image)

### 5.5. Error analysis

Of course, not only the load shape itself is of interest, the errors associated with the load shape are of equal interest too. The errors can provide important information whether the measured values are greater/smaller than certain limits. For evaluation of energy performance, it is of interest to study how the building performs, compared to the energy use intensities for other buildings. The true errors (or residuals) were chosen for error analysis. For every estimated value there is an associated error \( \varepsilon_i \) and the relative error was computed as:

\[
\text{Relative error} = \frac{\varepsilon_i}{y_i} = \frac{y_i - y_i^*}{y_i^*}
\]  \hspace{1cm} (8)

Where:
- \( \varepsilon_i \) = Residual \( i \)
- \( y_i \) = Estimated value of observation \( i \)
- \( y_i^* \) = True value of observation \( i \)

The standard deviation (or Root Mean Square Error, RMSE) of the relative error for each hour was computed as follows:

\[
\text{RMSE (t)} = \sqrt{\frac{\sum_{i=1}^{N} \left( \frac{y_i - y_i^*}{y_i^*} \right)^2}{N}}
\]  \hspace{1cm} (9)

Where: \( \text{RMSE (t)} \) = RMSE of the relative errors during hour \( t \)
Figure 9 shows the error plot. Typical for the error plots are the peaks during morning and late night hours. The high errors during these hours correspond to different opening and closing hours for the stores. Day-time results are generally good, with RMSE around 10-20%, except the weekend load shape, and the higher errors are partially caused by the fact that all stores are not open the same hours on Sundays. The major reason is different opening and closing hours - some are only open during parts of the day and some are open the whole day.

Figure 9: RMSE of the relative errors for grocery stores on weekdays and weekends.

5.6. Verification

Two months of load research data was available from four grocery stores and the data was used for verification of the developed ECIs. One day was chosen randomly for each grocery store and some information about the stores is shown in Table 6 and the results are shown in Figure 10. These four stores belong to the same grocery chain as the other 21 stores.

Table 6: Information about the verification.

<table>
<thead>
<tr>
<th>Store</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales floor area</td>
<td>936 m²</td>
<td>1199 m²</td>
<td>568 m²</td>
<td>392 m²</td>
</tr>
<tr>
<td>Day chosen for verification</td>
<td>971029</td>
<td>971008</td>
<td>971128</td>
<td>971218</td>
</tr>
<tr>
<td>Mean daily outdoor temperature</td>
<td>8°C</td>
<td>13°C</td>
<td>2°C</td>
<td>-3°C</td>
</tr>
</tbody>
</table>

Figure 10: Load shapes for the four stores used for verification, results from the current study, measured data and the errors of the typical load shapes.
As can be seen in the figures, there are some differences between the developed load shapes and the measured load shapes. Some of the differences are due to different opening and closing hours but in general, there is a high concordance between the ECIs and the measured load shapes. Something happens during night-time in store 2, at 3 a.m. the load demand increases suddenly and the reason for this is not known, however, it might be caused by timers which are not correctly set.

6 - DISCUSSION AND CONCLUSIONS

Load shapes and electricity consumption indicators have been developed for grocery stores. Two important determinants for grocery store specific electricity consumption have been identified:

- Floor area: a relationship between the specific electricity consumption and floor area was found, two other studies also report this kind of non-linear relationship between floor area and electricity consumption. The usage of sales floor area improved the analysis results considerably and must be considered to be a better indicator of store size than gross floor area, when analysing electricity consumption in grocery stores.
- Outdoor temperature is a very important factor when analysing the electricity consumption in grocery stores. The refrigeration equipment is the major source for increasing electricity consumption in grocery stores at high outdoor temperatures. A positive correlation with outdoor temperature was observed during all hours. Typically, the electricity consumption starts increasing at outdoor temperatures above 10-15°C.

Together, these two factors increase the understanding of why the electricity consumption in grocery stores varies and the assumption that all grocery stores have a constant specific electricity consumption has to be questioned. However, it should be noticed that the results may not be valid for stores which are larger than the stores studied here (sales floor area 190-1817 m²). These results are definitely not applicable for larger stores like warehouses. The reason for the area dependency is not entirely clear but the most probable reason is the fact that the refrigeration equipment is affected by size and smaller stores have a higher specific connected refrigeration capacity compared to larger stores.

There are some other variables that likely would improve the results:

- The effect of location - are there any differences between stores located in the cities and stores located in suburban areas? Are the shopping habits different in the cities or vice versa?
- Seasonal changes - is all the variation due to outdoor temperature or are there seasonal variations? These seasonal variations could be different mix of groceries during summer/winter or different shopping habits during these periods.
- The effects of the manager's "energy awareness" - are there any differences for stores operated by an energy aware manager and can these differences be generalised?

The problem is that these explanatory factors are difficult to take into consideration and an important question is how much of the variations can really be explained by introducing these extra variables. With the two variables included in the analysis, approximately 50% of the variations can be explained. It should be estimated if collecting information and introducing extra variables can increase explanation substantially. Another reason for keeping the number of variables down is the applicability of the developed ECIs. If the ECIs include many, and in some cases complex variables, this will limit the possibilities to apply the ECIs in practical situations such as: evaluation of energy performance and estimation of load profiles.

The annual specific electricity consumption was found to be considerably higher than for other types of commercial and public buildings and is caused by the very high connected capacities of refrigeration equipment, operating all day. The annual peak demand was also found to be high, mainly due to the high base load, caused by the refrigeration equipment. The high annual electricity consumption causes a high load factor, load factors were observed to vary between 0.5-0.75, where two stores deviated from the other 19 stores, which were observed to have load factors between 0.58-0.75.
Since the sales floor area was used in the current study, it is difficult to compare these results with the results from other studies and the main conclusion to be drawn from the comparisons, is that results differ very much between various studies. Depending on what area figure that was used in the analysis and what type of objects that were included in the study (grocery stores, warehouses etc.) the results may vary. Comparisons to measured data from four grocery stores showed high concordance although some differences do exist.

Several applications for the developed consumption patterns and consumption indicators exist, such as:

- Estimation of load shapes for buildings where no measurements are available
- Estimation of peak loads
- Evaluation of energy performance for buildings where measurements are available

7 - ACKNOWLEDGEMENTS

This study was carried out with financial support from the Swedish Council for Building Research, grant No. 19970426 and the Swedish Electrical Utilities R & D Company - Elforsk, grant No. 4083, to the Lund Institute of Technology, Dept. of Heat and Power Engineering, Div. of Energy Economics and Planning, Sweden.

8 - REFERENCES


