Energy Consumption
in Tertiary Buildings in Sweden
Case-study: M-building at Lund University - LTH

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Thesis for the Degree of Master of Science

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Abstract: Energy consumption remains invisible for most of consumers. This problem is even worse in the tertiary sector where in most cases the direct consumer doesn’t even pay the bill. Therefore it’s important to know how energy is used to be able to decide where and how energy efficiency measures should be applied in order to improve the effectiveness of those actions. This report is focused on one specific university building in Lund, Sweden, M-building at the LTH campus area.

The main goal of this investigation was to study the field of energy behaviour in service sector. In order to achieve it, the research was divided into three main parts:

The first goal of the project was to create an energy profile of the consumer as well as study the final energy use in order to decide where and how energy saving measures should be implemented to be more effective.

Secondly, it was important to evaluate the potential of energy savings due to user habits at M-building at Lund University – LTH.

Finally, the last objective was to apply different measures to achieve energy savings by a change in behaviour and study the effectiveness of those measures. get a general picture of the employees’ use of energy, to create an energy profile of users’ behaviour, and to propose some energy savings measures.

The study was done by carrying out two surveys: one about electrical appliances in the offices and another one about the employees’ energy behaviour. 99 and 75 respondents answered the surveys respectively. One of the results was that the main loads at the offices were computers and screens with a 71.1% of the total. Even if the general energy related behaviour was correct, according to the standard used, there were still some potential savings through a change in daily habits such as computers use. However, to quantify exactly the potential savings a more accurate measurement system would be needed since the M-building only had one electric meter and the load demand is mainly affected by operational loads.
Acknowledgements

Thanks to Jurek Pyrko, my supervisor, for his guidance, kind help and for offering me the possibility to carry out this project. I have learned many things from him. Thanks to Hans Petersson, from Akademiska Hus, he was really helpful and without his patience this project couldn’t have been done.

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INTRODUCTION

Background

The energy supplied in Sweden was of 568 TWh in 2009. This corresponds with an average value of about 63.7 MWh per capita. The total final use was 376 TWh according to the Swedish Energy Agency (S.E.A.) and 367 TWh according to Eurostat (2011). That means losses of 192 TWh and 201 TWh respectively for non-energy purposes such as conversion losses or international transport.

The distribution of energy consumption per sector in 2009 is shown in Figure 2. Compared with the EU-27 average, Sweden has a higher percentage of energy consumption in the industry and services sectors, while it has a lower ratio in transport and residential sector. It’s remarkable that, compared to the EU-27 average, the percentage of energy used in Industrial sector is 11 points higher only surpassed by Finland.

Figure 1: Total energy supplied in Sweden 2009 per energy carrier. Source S.E.A. 2010

Figure 2: Final energy use per sector. Source: Eurostat 2011
With more than 14,000 kWh per-capita of electricity consumption, Sweden is one of the countries with highest electricity consumption in the world. Only Iceland, Norway, Canada and Finland have a higher ratio. Comparing to EU-27 average, Sweden uses more than the double of electricity per capita. This is undoubtedly due to the cold climate. However, other factors such as historically low electricity prices and a high proportion of electricity-intensive industries contribute to this fact (S.E.A. 2010).

Service sector represents, with 43.23 TWh, the 13.4% of the Swedish energy consumption. This is almost as much as the total energy consumption of a country like Latvia. Therefore it’s important to study this sector to get a general overview on how energy is used in order to apply the most effective saving measures.

Objectives

The aim of this report was to study the field of energy behaviour in service sector. In order to achieve it, the research was divided into three main parts:

The first goal of the project was to create an energy profile of the consumer as well as study the final energy use in order to decide where and how energy saving measures should be implemented to be more effective.

Secondly, it was important to evaluate the potential of energy savings due to user habits at M-building at Lund University – LTH.

Finally, the last objective was to apply different measures to achieve energy savings by a change in behaviour and study the effectiveness of those measures.
Methodology

Energy profile and appliances use

The first part of the project was the creation of the user energy profile and the study of the use of energy. This part was carried out through two surveys.

The first survey (about energy user behaviour) was developed in a previous phase of this study (see Gargallo i Pallardó 2011). The survey consisted of different questions about daily habits on energy use such as dealing with lighting, heating or computer use. Each response was scored according to the criterion determined in the previous phase. This criterion consisted basically on scoring as zero the behaviour considered correct, meaning by correct the behaviour that uses less energy without affecting consumers’ comfort. Positive points were given to better habits than the standard and negative points were given for worse behaviour than the standard.

This survey was distributed through an on-line application. The intent to distribute it this way was to facilitate the processing of results. Since the answers were anonymous the risk of receiving few answers was assumed. The fact of receive more or less answers would be considered as a result itself of the willingness of the employees to participate on the program.

The aim to get the energy profile was to figure out where and how more energy was wasted in order to focus the measures in the points with most potential for savings. A version of the survey with the score for each response can be found in Appendix 1.

The second survey was about electrical appliances use. The aim of this survey was to get an approximate view of how energy is used in the offices and therefore where it should be convenient to focus the measures. This survey was on paper form (see Appendix 2) to make easier to get the answers from the respondents. Once the facts were collected the following step was to analyse the different loads and the weight of each appliance in the global load demand.

Evaluation of potential energy savings

The second part was to study the potential of energy savings. This part was done in collaboration with Akademiska Hus (AH – Academic Houses in English), the company that owns many university buildings in Sweden.
In order to determine the potential savings data of energy load for the last two years were analysed. These data were provided by AH. They have meters with possible hourly meters so the feedback could be almost instantaneous.

Another measure to determine the potential savings was to ask users to turn off all the non-essential appliances during one night. The aim was to see the differences between the load curves of a normal day and the day of the test using the data provided by AH.

For all the calculations concerning areas BRA area was used. This means all the usable area (or “bruksarea” in Swedish). This is the measured area inside the external walls were non-heated areas (<10ºC) are excluded.

The main problem with this methodology was that the measurements taken by AH were too rough. The measurements should be more accurate in order to get a deeper insight into the situation and the small changes in the load curve.

Limitations

The methodology based on has many limitations. The most important is to take the results of the survey as the basis for the study instead of studying the real behaviour. Geller (1981) found disparities between what people say when answering a questionnaire and what they really do. However it would take too much time and resources to study how people use their electrical appliances by using observations. This project had limited time and resources, therefore the results of the survey were accepted knowing that the reality may be a bit different.

The first survey was scored setting a standard behaviour. This standard is based on subjective criterion, considering the proper behaviour the one using less energy without affecting users’ comfort. Using other criteria the proper behaviour could be set differently than the one used.

The results of the second survey don’t show the exact energy load. The survey was carried out to get an approximate picture of the energy use, not an accurate measure. The electricity loads were calculated from the answers of the respondents who gave the approximate number time of use and an approximate load per appliance.
LITERATURE SURVEY

Tertiary buildings in Sweden

The total final energy use in services sector in Sweden in 2009 was 49.23 TWh according to Eurostat. Figure 3 shows the total final energy use per energy carrier for the residential and services sector. There it can be observed that electricity and district heating represent the main part of the final energy use in the residential and services sector. This is a characteristic distribution in a northern country were heating is mainly done by district heating instead of individual heating systems like in southern European countries.

![Figure 3: Final energy use per energy carrier in residential and services sector 2009. Source Swedish Energy Agency (S.E.A.)](image)

The use of heating and hot water in non-residential premises was of 17.7 TWh in 2009. The most commonly energy source used was district heating, followed by electricity. Electricity was mainly used in smaller buildings, while district heating was used in the 54% of the buildings representing the 72% of the total area.

Table 1: Heating and hot water use per energy source 2009. Source: S.E.A 2011

<table>
<thead>
<tr>
<th>Heating source</th>
<th>TWh</th>
<th>Percentage</th>
<th>Consumption kWh/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>District heating</td>
<td>14.06</td>
<td>79.3%</td>
<td>134</td>
</tr>
<tr>
<td>Oil</td>
<td>0.75</td>
<td>4.2%</td>
<td>134</td>
</tr>
<tr>
<td>Electricity</td>
<td>1.84</td>
<td>10.3%</td>
<td>139</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.37</td>
<td>2.1%</td>
<td>112</td>
</tr>
<tr>
<td>Biofuels</td>
<td>0.65</td>
<td>3.7%</td>
<td>98</td>
</tr>
<tr>
<td>Others</td>
<td>0.07</td>
<td>0.4%</td>
<td>----</td>
</tr>
<tr>
<td>Total</td>
<td>17.73</td>
<td>----</td>
<td>135</td>
</tr>
</tbody>
</table>
According to SCB (Statistiska Centralbyrån; Swedish Statistics in English) the specific annual energy use for heating in services buildings per m² was in 2004 119 ± 2 kWh/m² per year. This annual average varies considerably depending on the year of construction of the building. For buildings built after 1980 the heating use was of about 97-98 kWh/m² per year, while those built before 1980 used from 120 to 133 kWh/m² per year. According to another study carried out in 2011 the average of 123 surveyed buildings in 2009 was 106 kWh/m². The trend over the last years is to substitute oil products and electricity as sources of energy for heating systems (See Swedish Energy Agency 2011).

Regarding the use of electricity in non-residential premises a study was carried out by Swedish Energy Agency in 2007. This study involved the analysis of 123 buildings. The average of these surveyed buildings was 108 kWh/m² per year. However one of the buildings is extremely outside the range with 1318 kWh/m² per year without this extreme value the average was almost 99 kWh/m² per year. These averages should be used carefully since checking the results of this study some slight miscalculation and contradictions can be found. Table 2 shows the distribution of electricity use in various applications.

Table 2: Specific electricity consumption per use, averages and percentages: S.E.A. 2007

<table>
<thead>
<tr>
<th>Distribution of Electricity</th>
<th>[kWh/m²]</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>23</td>
<td>21.20%</td>
</tr>
<tr>
<td>Computer rooms/server</td>
<td>10.7</td>
<td>9.90%</td>
</tr>
<tr>
<td>Computer devices</td>
<td>15.4</td>
<td>14.20%</td>
</tr>
<tr>
<td>(Without extrem value)</td>
<td>(8.7)</td>
<td></td>
</tr>
<tr>
<td>Other appliances</td>
<td>8</td>
<td>7.40%</td>
</tr>
<tr>
<td>Printer</td>
<td>1.1</td>
<td>1.10%</td>
</tr>
<tr>
<td>Copy Machines</td>
<td>1.6</td>
<td>1.50%</td>
</tr>
<tr>
<td>Air compressor</td>
<td>0.4</td>
<td>0.40%</td>
</tr>
<tr>
<td>Kitchen</td>
<td>3.1</td>
<td>2.80%</td>
</tr>
<tr>
<td>Washing Equipment</td>
<td>0.2</td>
<td>0.20%</td>
</tr>
<tr>
<td>Heaters</td>
<td>1.5</td>
<td>1.40%</td>
</tr>
<tr>
<td>Total operational electricity</td>
<td>57</td>
<td>52.70%</td>
</tr>
<tr>
<td>Fans</td>
<td>17.9</td>
<td>16.50%</td>
</tr>
<tr>
<td>Electrical heating</td>
<td>6.5</td>
<td>6.00%</td>
</tr>
<tr>
<td>Other building electricity</td>
<td>9.5</td>
<td>8.80%</td>
</tr>
<tr>
<td>Pumps</td>
<td>5.5</td>
<td>5.10%</td>
</tr>
<tr>
<td>Cooling condensators</td>
<td>0.8</td>
<td>0.70%</td>
</tr>
<tr>
<td>Elevators</td>
<td>0.7</td>
<td>0.60%</td>
</tr>
<tr>
<td>Air circulation</td>
<td>2.6</td>
<td>2.40%</td>
</tr>
<tr>
<td>Refrigeration machines</td>
<td>10.6</td>
<td>9.80%</td>
</tr>
<tr>
<td>Total Building electricity</td>
<td>44.5</td>
<td>41.10%</td>
</tr>
<tr>
<td>Others</td>
<td>6.8</td>
<td>6.20%</td>
</tr>
<tr>
<td>Total</td>
<td>108.2</td>
<td>100%</td>
</tr>
</tbody>
</table>
Lighting and fans represent, with the 37.7 %, the most significant part of the total load. Computer labs and servers and computer devices are the third main part of the load. Together represent the 24.1% of the total, value that is significantly reduced if we don’t consider the extreme value. The operation electricity represents the 52.7% while the building electricity is the 47.3% of the total.

Electricity consumption in lighting varies between 7 and 53 kWh/m$^2$ per year. The mean value is 23 kWh/m$^2$ per year. The distribution of the load demand by type of device is shown in Figure 4. Fluorescent lamps represent the 73% of the total load. The most common one is the fluorescent lamps with conventional ballast which have a load demand three times bigger than T5 or T8 tubes.

![Figure 4 Distribution of the installed power per m2 for lighting on different types of light sources. Source Swedish Energy Agency, 2007.](image)

Most of this lighting is used in common areas such as corridors, halls, etc. The lighting consumption of private offices is the 34% of the total, while in open areas and large rooms is 7%. The rest is consumed in common areas.

The Swedish Energy Agency has calculated the potential savings for electricity in offices, schools and care centers. According to their calculations, the potential savings are approximately of 2 TWh per year around the 30% of the total use of this
kind of buildings (Swedish Energy Agency 2011). The distribution of these potential savings can be seen in Table 3.

Table 3: Estimated potentials for electricity efficiencies for lighting and ventilation. Source Anders Göransson through Swedish Energy Agency 2011

<table>
<thead>
<tr>
<th>Offices</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting/operating time adapted</td>
<td>0.05 TWh</td>
<td></td>
</tr>
<tr>
<td>Bulbs Changed to low-energy lamps</td>
<td>0.05 TWh</td>
<td></td>
</tr>
<tr>
<td>Fluorescent lamps conventional operation changed to T5 tubes</td>
<td>0.2 TWh</td>
<td></td>
</tr>
<tr>
<td>Adaption of ventilation system's operating times</td>
<td>0.19 TWh</td>
<td></td>
</tr>
<tr>
<td>Ventilation flow adapted</td>
<td>0.11 TWh</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.6 TWh</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Schools</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulbs Changed to low-energy lamps</td>
<td>0.06 TWh</td>
<td></td>
</tr>
<tr>
<td>Fluorescent lamps conventional operation changed to T5 tubes</td>
<td>0.36 TWh</td>
<td></td>
</tr>
<tr>
<td>Adaption of ventilation system's operating times</td>
<td>0.27 TWh</td>
<td></td>
</tr>
<tr>
<td>Ventilation flow adapted</td>
<td>0.12-0.33 TWh</td>
<td></td>
</tr>
<tr>
<td>Better ventilation units (SFP=2)</td>
<td>0.1 TWh</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.9-1.1 TWh</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Care centers</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulbs Changed to low-energy lamps</td>
<td>0.05 TWh</td>
<td></td>
</tr>
<tr>
<td>Fluorescent lamps conventional operation changed to T5 tubes</td>
<td>0.19 TWh</td>
<td></td>
</tr>
<tr>
<td>Adaption of ventilation system's operating times</td>
<td>0.22 TWh</td>
<td></td>
</tr>
<tr>
<td>Better ventilation units (SFP=2)</td>
<td>0.14 TWh</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.5 TWh</strong></td>
<td></td>
</tr>
</tbody>
</table>

Changing fluorescent lamps with conventional ballast to T5 tubes could save a total of 750 GWh per year in this kind of buildings. While improvements in ventilation systems could achieve up to 700 GWh per year. These figures show the great potential of energy saving in tertiary just by improving the equipment.
Energy behaviour

Energy consumption level is influenced mostly by equipment’s energy efficiency, consumers’ behaviour, their comfort and income levels (Apolinario, I. et al, 2009). Energy savings are usually achieved by consumers’ investments in more efficient equipment or by changes in habits. To change patterns of behaviours might reduce household use of energy up to 22% in US (Laitner et al 2009). Reported savings reached by intervention programmes on energy behaviour were between 3-22% for electricity (Uitdenbogerd et al 2007).

Unlike most consumer goods, electrical and heating energy consumption remains invisible to the consumer’s eye, and also in a direct way to the consumer’s pocket since the electricity bill is usually paid through a bank account monthly or bimonthly. The common way to know the consumption is through a monthly/bimonthly bill. This issue has been highlighted by many researchers (Ehrhardt-Martinez 2011, Faruqui et al. 2009). The problem is even worse in tertiary sector where the real consumers get no feedback about their consumption. Usually employees don’t have a limit for their energy use. They don’t have to justify their energy consumption and the expense is borne by the employer without considering if there has been a waste.

Feedback is been proved to be the best tool to get energy savings although there is little evidence on which kind of feedback is most effective. A variety of feedback initiatives have reduced electricity consumption between 4-12% (Edrhardt-Martinez et al 2010). Darby (2006) concluded after a literature review that it’s possible to get savings between 5-15% with direct feedback such as smart meters, and between 0-10% with indirect feedback such as more frequent and detailed bills. Giving feedback the problem of energy invisibility can be partially solved.

Other methods to get energy savings by changing behaviour have been prove to be less effective. However those methods are still interesting. Tiedemann et al (2011) modelled the effectiveness of different measures. The conclusion showed that even if feedback was the most effective measure, it could be complemented by other measures such as rewards and information campaigns to improve the effectiveness. This study also concluded that to set goals was not really effective but there was still a chance to get energy savings by establishing goals.
CASE-STUDY: M-building at Lund University - LTH

Akademiska Hus

Akademiska Hus is the company that owns M-building and therefore is responsible for building’s energy management. This company is owned by the Swedish government and is one of the largest property companies in Sweden with more than 3.2 million square meters. The main business of AH is leasing their properties to educational and research institutions. With a 64% of the market share is the main provider of premises to colleges and universities. Teaching and laboratory premises are the largest proportion of floor space with and 82% of the total surface (Akademiska Hus 2010a).

The assessed market value of their properties was 49497 MSEK in 2010, more than 535 M€. The rental revenue was 4983 MSEK, around 540 M€, and the net operating profit was 3134 MSEK 340 M€ approximately (Akademiska Hus 2010a).

In terms of energy the total consumption of buildings owned by AH was more than 900 GWh per year in 2010. This is around the 1.89% of the total energy consumption in the services sector in Sweden. Of this 900 GWh per year more than 400 GWh where used as electricity, around 400 GWh as heating and approximately 70 GWh in cooling systems. Per square meter, the total energy use was 241 kWh/m², 112 kWh/m² in electricity, 110 kWh/m² in heating and around 19 kWh/m² in cooling systems (Akademiska Hus 2010b).

Energy and water supply expenditure were 650 MSEK in 2010, this was 69% of the total operating cost of the company. This is an average of 203 SEK/m² per year. Figure 5 shows the distribution per final use. The main part of the energy cost is due to electricity consumption, about 390 MSEK. Heating costs were 217 MSEK while cooling costs were 20 M SEK (Akademiska Hus 2010a).

![Figure 5: Energetic and water supply costs distribution. Source AH, 2010b](image-url)
AH is divided in six delegations according to geographical distribution, North, South, East, West, Stockholm and Uppsala. The energy consumption per region in kWh/m² over the last 3 years is shown in Table 4.

**Table 4**: Energy consumption per region in buildings owned by AH. Source AH, 2010b

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>South</td>
<td>133</td>
<td>129</td>
<td>130</td>
<td>112</td>
<td>113</td>
<td>110</td>
<td>31</td>
<td>33</td>
<td>31</td>
</tr>
<tr>
<td>West</td>
<td>103</td>
<td>101</td>
<td>99</td>
<td>87</td>
<td>77</td>
<td>76</td>
<td>14</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Est</td>
<td>107</td>
<td>103</td>
<td>104</td>
<td>94</td>
<td>91</td>
<td>86</td>
<td>33</td>
<td>32</td>
<td>36</td>
</tr>
<tr>
<td>Uppsala</td>
<td>134</td>
<td>134</td>
<td>134</td>
<td>149</td>
<td>148</td>
<td>140</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Stockholm</td>
<td>107</td>
<td>108</td>
<td>107</td>
<td>127</td>
<td>128</td>
<td>122</td>
<td>26</td>
<td>29</td>
<td>28</td>
</tr>
<tr>
<td>North</td>
<td>109</td>
<td>110</td>
<td>107</td>
<td>91</td>
<td>87</td>
<td>82</td>
<td>6</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Average</td>
<td>115.5</td>
<td>114.2</td>
<td>113.5</td>
<td>110.0</td>
<td>107.3</td>
<td>102.7</td>
<td>18.3</td>
<td>19.0</td>
<td>19.0</td>
</tr>
</tbody>
</table>

**M-building**

M-building is situated in LTH campus, in the city of Lund in southern Sweden. It’s one of the main buildings of Lund University’s Faculty of Engineering. Four entire departments and two divisions of other departments have their headquarters and their main activities in this building. Those departments are the Department of Automatic Control, the Department of Energy Sciences, the Department of Industrial Management and Logistics, the Department of Mechanical Engineering, the Division of Industrial Electrical Engineering and Automation and the Division of Solid Mechanics.

Around 300 people are working in M-building. The main activities carried out in this building are teaching, research and office work. Therefore, the energy use varies widely depending on the activity which it is intended. The building was refurbished between 2005 and 2010. After that the total BRA surface is 26024 m² unevenly distributed over 6 floors.

This building is heated mainly by district heating although electrical heating is occasionally used by some people. The district heating load has increased over the last five years from 2.55 GWh in 2006 to 3.16 GWh in 2010. This means average energy demand of 121.42 kWh/m² in 2010. The main reason for this increase was the temperature difference between those years. 2010 was an average of approximately 2ºC colder than 2006 (Source: Swedish Meteorological and Hydrological Institute SMHI).
Compared with the district heating average of AH buildings in the region, M-building’s demand is 11 kWh/m² higher. Compared with the average of all AH buildings in Sweden, this figure is almost 20 kWh/m² higher although the building is situated in the warmest region of Sweden. The main reason for this may be the materials used in the construction of the building. If the heating load in 2009, 105.6 kWh/m² is compared with the results of a study carried out by the S.E.A. in 2011, where the average of the 123 buildings surveyed was 106 kWh/m² in 2009, it can be seen that it’s almost the same.

Electricity consumption has decreased by 33.6% over the last 5 years. The electricity demands was 2780.8 MWh or 106.85 kWh/m² in 2006. This demand was significantly reduced to 1846.8 MWh or 70.96 kWh/m² in 2010. Compared with the average of AH buildings, it is significantly lower, more than 40 kWh/m² i.e. 37% lower than the national average. This figure is even better if we compare it with the average of all the buildings in the region, where the average in 2010 was 130 kWh/m², 45.4 % lower.
RESULTS

Electrical appliances use

The first survey carried out in this study was distributed among the employees of the different departments through the secretaries of each division. The data collection was more complicated and slower than it was expected. It took more than two weeks to collect 99 answers from 71 different offices. The estimated number of employees is 265; it’s not an exact number since there are some temporary guest professors and PhD-students and some others are in an exchange period in other universities. Therefore, if we consider a number of 265 employees, the response rate was 37.36%. This ratio varied considerably depending on the department.

Table 5: Number of responses per department

<table>
<thead>
<tr>
<th>Department</th>
<th>Number of Responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dep. Energy Sciences</td>
<td>47</td>
<td>59%</td>
</tr>
<tr>
<td>Dep. of Automatic Control</td>
<td>4</td>
<td>7.2%</td>
</tr>
<tr>
<td>Dep. of Industrial Management and Logistics</td>
<td>17</td>
<td>48.6%</td>
</tr>
<tr>
<td>Dep. of Mechanical Engineering</td>
<td>9</td>
<td>22.5%</td>
</tr>
<tr>
<td>Division of Industrial Electrical Engineering and Automation</td>
<td>8</td>
<td>24%</td>
</tr>
<tr>
<td>Division of Solid Mechanics</td>
<td>14</td>
<td>63.6%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>99</td>
<td>37.36%</td>
</tr>
</tbody>
</table>

The number of responses was accepted as sufficient due to the slow reception of responses. In some departments, such as the Department of Automatic Control, the rate of responses was very low. The survey was distributed through the secretaries of the different departments.

Figure 6 shows the results of this survey. The results are presented in percentage and not in KWh because is an estimation. Besides the aim of the survey was to get a general picture on how energy is used in offices and not to get exact numbers of energy load. These results only refer the percentage of the electricity load in offices. Other parts of the building, such as common areas, laboratories, lecture rooms or computer rooms, were not studied since the impact of human behaviour in the energy load in these areas is not so important. For example in computer rooms the energy settings of the computers are set and controlled by a centralized system. Lighting through all the building is controlled by movement sensors so users’ behaviour in the use of lights does not significantly affect the total energy demand.
As we can see in Figure 6, the main electricity demand is due to computer use. Desk computers, laptops, and screens represent the 71.1% of the total estimated load in the offices. Of the 99 respondents, 57 use only desk computers, 32 only laptops and 10 both. The 90% use at least one screen. Analyzing Figure 6, it can be observed that there are some potential savings. Some measures taken in new desk computers showed an electricity load of 65 kWh when running few programs and up to 130 kWh at full load. For older devices, the measures showed loads of 120 kWh while running few programs and almost 200 kWh at full load. Other measures taken in laptops for the same running conditions showed an average of 29 kWh. This means that in all the applications without a high requirement of calculations and heavy software, desk computers could be replaced by laptops with potential saving between 35 and 90 kWh per device replaced. The implementation of a protocol to control the power settings of both computers and screens could represent a significant savings as it will be explained later.

Regarding lighting, little can be done since movement detectors are installed in all the offices and only 8% of the lighting load is due to desk lamps while the 92% corresponds to ceiling light. On the other hand, if electrical heating appliances were removed it could be saved up to a 5.5% of the electricity load. Only a 5% of the respondents use electrical heating for a few days. However, the high demand of electricity of this kind of appliances makes them a significant part of the total load.

Other appliances only represent the 5% of the total load. Most of the appliances included in others are difficult to remove without affecting the comfort of the user. Some of these appliances are routers, clocks, speakers, external hard disks, etc.
However there is one of these appliances that could be easily removed, printers. Personal printers represent the 0.7% of the total load. All the offices are connected through local network to shared printers, so there is no need to have personal printers.

**Energy profile**

This survey was distributed through an on-line application. That made easier to evaluate the data and work with it. However the response rate was lower than the Electrical appliances use form. A paper version of the survey and the scores can be consulted in Appendix 1. The total number of responses was of 75 respondents, i.e. 28.3%.

**Table 6: Number of responses per department**

<table>
<thead>
<tr>
<th>Department</th>
<th>Number of Responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dep. Energy Sciences</td>
<td>32</td>
<td>40%</td>
</tr>
<tr>
<td>Dep. of Automatic Control</td>
<td>9</td>
<td>16%</td>
</tr>
<tr>
<td>Dep. of Industrial Management and Logistics</td>
<td>8</td>
<td>22.85%</td>
</tr>
<tr>
<td>Dep. of Mechanical Engineering</td>
<td>10</td>
<td>25%</td>
</tr>
<tr>
<td>Division of Industrial Electrical Engineering</td>
<td>10</td>
<td>29.41%</td>
</tr>
<tr>
<td>and Automation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Division of Solid Mechanics</td>
<td>6</td>
<td>27.3%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>75</strong></td>
<td><strong>28.3%</strong></td>
</tr>
</tbody>
</table>

Some factors may have influenced this lower rate of responses. The first one is the fact that this second survey was completely anonymous. The only question about identity was to ask to which department they belonged. Therefore it wasn’t possible to ask individually to answer the survey and it had to be done for the departments with lower responses rate. Another factor may have been the confusion of having two different surveys distributed in two different ways for the same study at the same time. When some departments were asked to improve their response rate, some people answered that they had already handed in the paper version.

As in the previous survey, the lower responses rate came from the Department of Automatic Control. Probably a better communication with this department would have improved the results. Other factors that may explain this low rate are the fact that this department is divided in different floors. The major part of employees of this department works on a different floor than administration employees. Since the survey was distributed through the secretaries this could be an explanation. Finally,
some of the secretaries of this department are half-time employees it was difficult to contact them.

On the other hand the Department of Energy Sciences was the one with a highest rate. This study was carried out with this department as a base which could have made it easier to encourage employees to answer both surveys.

Regarding the results of the survey itself, the average score of all the responses was -12 points. According to the classification made in a previous study (see Gargallo 2011), the general energy user profile of all the users at M-building is those who “try to save some energy but they could still do a little bit more”. Seven respondents were below -20 points and only one above 0 points. This means that there are some potential savings by changing small details of everyday’s’ users habits.

Looking the results thoroughly, the first aspect where some energy could be saved is in the use of computers. More than the 60% of respondents (48 respondents) never turn off the computer or leave it in suspend/hibernate mode when they live their offices for more than 20 minutes. Besides, computers of twenty-two of this forty-eight never pass to suspend mode automatically and for nine more it takes more than 30 minutes. This means that the 30% of computers are always on no matter if they are being used or not. On the other hand, only eight respondents answered that they turn off the computer while the other nineteen leave it in suspend or hibernate mode. According to our own measures, the difference between leaving the computer in suspend mode or turn it off may be significant for old desk computers, while for new computers and laptops there is no big difference if the device is not unplugged.

This survey offers different results than the Electrical Appliances use form regarding the use of desk computers against laptops. In this survey thirty-four respondents answered that they use desk computers while forty-one answered that they use laptops. That means 54.6% of laptops and 45.4% of desk computers, while in the other survey the ratios were 43.25% and 57.75% respectively. The differences are not so important, and even if an exact number can’t be concluded, it’s obvious that desk computers represent an important part of computers use. Since desk computers consume more than laptops, as it was explained in the previous point of this report, the replace of this kind of computers, as far as possible, could achieve some energy savings.

Considering the screens use, some energy savings could be achieved by improving the use of these devices. Thirty-five respondents answered that they use their screens with more than 80% of brightness and twenty-six with the screen brightness between 60 and 80%. Adjusting the settings of the screen can reduce the energy consumption by 10%-28% without affecting the usability (Kazandjieva et al, 2009). Measurements taken on a 22” LCD screen showed that consumption might vary between 47 watts at 100% brightness and 36 watts at 40% brightness, which means a
saving of more than 23%. In energy terms the difference is about 22KWh per year per screen. 61 respondents leave their screens in Standby instead of turning it off. Fifty-two of them use screensaver. When the screensaver is activated the screen is still consuming the same amount of electricity as if it was being used. However, the screens of Fifty-five respondents pass to Standby mode in less than 15 minutes so the screensaver consumption doesn’t seem to be really important, but it is still a little save of energy.

Regarding the use of heating, most of users keep their offices in a temperature range of 20-22ºC. However, fifty-eight respondents never turn off or bring the heaters down when they leave their offices. Heating control is challenging since the building has to be kept at a temperature of at least 16-18ºC to avoid fungi problems and the water temperature has to be above 50ºC to prevent from legionella.

Finally, the last aspect regarding the use of appliances is that the 78.7% of respondents never unplug their cables. Twenty respondents have an electrical power strip, but only four of them use it often, while the other sixteen rarely or never use it. This means that the use of electrical power strips without any other measure is probably not the solution to avoid Standby consumptions.

When employees were asked about their opinion about their own behaviour the 44% answered that it was correct and there were few things they could do to improve it. Almost the same amount of respondents, the 42.67% answered that they knew they could do more but it was hard to improve their behaviour. Finally only 5 respondents answered that they knew they could do more but they didn’t want to change their habits. Curiously the two respondents with the lower score answered that they knew they could do something and they had enough information and feedback, but it was just that they didn’t want to change their habits.

About the need of information or feedback, most of respondents answered that they didn’t need any kind of feedback and they had enough information. On the other hand twenty-seven surveyed would like to have more information or some kind of feedback about their progresses.
Evaluation of potential savings

The first measure to see the potential savings was to analyse the load curves for different periods of the year and during weekends and week days. Four periods were analysed, winter period with full activity, winter holidays, summer holidays and spring full activity days.

![Figure 7: Total electricity load in kWh every hour of the day for different periods.](image)

![Figure 8: Weekend electricity load in kWh every hour of the day for different loads](image)
Analyzing the three figures above it can be observed that there is a base load of about 150 kWh/h. This basic load represents more than the 70% of the yearly load. This means that less than the 30% of the building load is directly related to users’ activities. According to AH, the basic load corresponds to permanent loads such as ventilation, pumps, lifts, etc. Besides the approximately 125 computers and screens of the computer rooms are never switched off. According to the responsible of the computer rooms this is because the system has to be running all the time due to maintenance, updates and proper operation. Therefore, consumers’ behaviour does not affect significantly the total load of the building and small changes in consumers’ habits won’t represent significant energy saving in percent. However, in absolute terms the load related to users’ habits is more than 500 MWh a year and around 487 500 SEK (52 500 €).

The second measure to see the potential savings was to ask people to turn off the non-essential appliances for one day and see the difference in the load curves. The results of this test are shown in Figure 10. There are no big differences between both graphs. It was expected to see some differences between 19:00 and 7:00. However, during this period both curves are almost equal and if the total consumption of this period is compared the difference is of only 5 kWh less for the test day than the average of the rest of the month.

Figure 9: Week days electricity load in kWh every hour of the day for different periods.
Two main reasons could explain this result. The first one could be that not many people followed the instructions and they did as any other day, going home without turning off the non-essential appliances. The second, and probably the most important, is that the measures taken by AH are too rough. There is only one meter for the whole building, except for Max-lab, a big laboratory located in the building but completely independent. Therefore any action in users’ habits can be hardly appreciated in the meter measurements, since that only represent a small part of the total building load as it has been explained before.

**Measures taken and evaluation of effectiveness**

No measures to change consumers’ behaviour were possible to be taken. This goal could not be reached and the Thesis had to be focused on the study of how energy is used by employees. The main reason was the impossibility to analyse the changes in the load curve. As it has been explained, the measures taken by AH are too rough to see significant differences in the load curve when consumers’ change their habits. Any difference in a load curve before and after applying a measure in this field couldn’t have been considered as a result of the measure itself. Hence, with the current system of measures, with one meter for the whole building, it is not possible to perform a study on the effectiveness of behaviour change measures on the use of energy.
CONCLUSION AND DISCUSSION

In this report, the use of energy by employees at M-building has been analysed, proving that there are some potential saving by changing users’ behaviour. These potential savings couldn’t be quantified due to the rough measurement system used by AH. Any estimation would have to be done with caution and with a detailed development of the parameters used. To be able to analyse thoroughly to potential saving the meter system should be changed to a more accurate measurement system.

In order to propose a metering system would be necessary to study in detail the electrical circuits of the M-building. The metering should separate, at least, the operational loads from the fluctuating daily loads. Of course, the more detailed measurements the better. The perfect system would be the one where the electric load would be split per department, separated in common areas, offices, laboratories, lecture rooms, etc. However, that would complicate the meter system and the cable distribution through the building. A system good enough could consist on separating the load in three different meters. On one side, all the ventilation system, pumps, lifts and permanent loads. A second meter should be installed for laboratories. Finally, a third meter covering offices, lecture rooms and common areas.

With the current measurement system there are some products on the market that could help to have a more detailed control of electricity consumption. Some of these products offer the possibility to have an instantaneous control of all the appliances connected to different plugs through a wireless network. All the appliances connected to this system can be connected and disconnected remotely. There is also the possibility to get an instantaneous measure of the electrical load at any moment and record the data. Another characteristic of this product is that it incorporates a standby killer, so when an appliance connected to this device switches to standby it can be completely disconnected. This is just an example of the many possibilities that technology offers to us.

Without a more accurate measurement there is still the possibility to get some energy savings even if it won’t be possible to quantify those potential savings. One of the measures proposed is to create a protocol for the energy settings of the computers used in offices. This is already being done in the computer labs. However personal computers can’t be controlled remotely so the procedure should be to create a guide of the proper computer energy settings offering the possibility to make the changes by a specialist. This could save up to a 20% of the screen electricity consumption and would avoid having computers running when they are not being used with the corresponding savings.
Another measure that could be taken is to change, as far as possible, desk computers for laptops. That would save between 35 and 90 kWh per device changed considering that they would keep using an external screen. But in the cases that the external screens were removed it could be saved 35 kWh more per device. Besides the energy savings there are more benefits of changing in to laptops such as the improvement in mobility, facilitating the work and the economical savings. Of course in some applications where powerful software needs to be use desk computer offer better performance.

In conclusion if the consumers’ energy behaviour in tertiary wants to be studied properly an accurate measurement is needed to quantify the improvements in order to give feedback to users and see in detail the changes in the load curve. However, there are still some measures that could be applied getting significant energy savings.

Future research

There is a big gap in the research field of energy behaviour in tertiary sector. The effectiveness of the different measures to change consumers’ habits should be deeply studied. For that is essential to use an accurate measurement system, where it could be seen in detail the effect of each measure in real time if possible. Much research has been done in the residential sector. The results of these studies can be used as a starting point being aware of the differences between residential and tertiary sector.

In any case the companies of distribution and sales of energy should work into making energy more visible for consumers. The technology to take that step is available. It’s only a matter of willingness and to make a small financial effort that may be recompensed by the potential energy savings and the consequent reduction in the electricity bill.
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APPENDICES

APPENDIX 1

ENERGY BEHAVIOUR QUESTIONNAIRE

The aim of this questionnaire is to study the behaviour of people using energy in order to improve the efficiency of the building. This survey is completely anonymous. Try to choose the answer closest to your behaviour.

OFFICE

- **Computer**

1. What kind of computer do you use?
   - Desktop computer with conventional screen (-4p)
   - Desktop computer with LCD screen (-2p)
   - Laptop with additional LCD screen (0p)
   - Only laptop with (+1p)

2. If you use laptop, how do you use it?
   - Usually connected to the socket with the batteries inside (0p)
   - Usually unplugged until the batteries are almost empty (-1p)
   - Sometimes unplugged and with batteries and sometimes connected to the grid. (-2p)

3. What percentage of brightness do you use in your screen?

<table>
<thead>
<tr>
<th>&lt;40%  (+2p)</th>
<th>40-60% (0p)</th>
<th>60-80% (-1p)</th>
<th>&gt;80%  (-3p)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When you are not using your computer:

4. Do you use any screensaver?
   - No (0p)
   - Yes (-2p)
5. How long time does it take for the computer to turn off the screen when you
are not using it?

<table>
<thead>
<tr>
<th>0-5 min (+1p)</th>
<th>5-15 min (0p)</th>
<th>15-30 min (-1p)</th>
<th>more than 30 min (-2p)</th>
<th>Never (-3p)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. How long time does it take for your computer (grid connected) to pass to
suspend/sleep/hibernate mode (viloläge)?

<table>
<thead>
<tr>
<th>0-5 min (+1p)</th>
<th>5-15 min (0p)</th>
<th>15-30 min (1p)</th>
<th>more than 30 min (-3p)</th>
<th>Never (-4p)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When you leave the office during the day (for more than 30 min)

7. Do you usually turn off the screen?

☐ Yes (0p)       ☐ No, I leave it in Standby (-1p)

8. Do you usually turn off the computer?

☐ Yes (0p)       ☐ I leave it in suspend (-2p)

☐ I leave it in hibernate/sleep (-3p)       ☐ No, I leave it on (-4p)

- Lights

9. How many lights do you use?

☐ Only the light in the ceiling (+1p)

☐ I use only desktop light (+2p)

☐ I use both, ceiling and desktop light (0p)

☐ I have more than two lights (-2p)

10. If you use desktop light, which kind of light bulb do you use?

☐ Low energy light bulbs (fluorescent) or LED (0p)

☐ Halogen (-1p)

☐ Incandescent bulbs (-2p)
11. How much do you use artificial light?

☐ I always have the ceiling light on (−1p)
☐ If I have enough day light I turn the lights off (+1p)
☐ I always have the desktop light on (−1p)
☐ I always have all the lights on (−2p)
☐ Sometimes I use artificial light even if there is enough day light (0p)

12. What do you do when you leave the office?

☐ I usually turn the light off (+1p)
☐ Since we have light sensors I usually leave the light on (−2p)
☐ Sometimes I leave it on and sometimes off (−1p)

- Ventilation

13. How long time per day do you leave the window open when it’s cold (<15ºC)?

☐ I never open it (+2p)
☐ I open it very seldom (+1p)
☐ I open it less than 10 minutes/day (0p)
☐ I open it less than 30 minutes/day (−1p)
☐ I open it more than 30 minutes/day (−3p)

14. When you are in your office, how do you have the door?

☐ Usually open (−2p)
☐ Usually closed (+1p)
☐ Open if I have visiting hours, otherwise closed (0p)
☐ Sometimes open, sometimes closed (−1p)

- Heating

15. What temperature do you have at your office?

<table>
<thead>
<tr>
<th>&lt;18ºC (+1p)</th>
<th>18-20ºC (+2p)</th>
<th>20-22ºC (0p)</th>
<th>22-24ºC (−2p)</th>
<th>&gt;24ºC (−4p)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
16. What do you do with the heating (radiators and/or extra heater) when you leave the office? (You can select multiple options)?

- I never turn it off (-3p)
- Sometimes I turn it off (or bring down) when I go home (-1p)
- I turn it off when I open the window (0p)
- I turn it off (or bring down) when I go home (+1p)

**Other equipment**

17. How much do you use your own printer?

- I usually have it on (-2p)
- I only turn it on when I’m going to print something (0p)
- Sometimes I have it on when I’m not using it (-1p)
- I don’t have printer in my office (+1p)

18. Do you have more electrical appliances in your office?

- Yes (depend)  
- No (+1p)

19. How many?  

- 1= 0p  
- 2=-1p  
- 3=-2p  
(more than 4=-3p)

20. Which ones? (If some of them are high consuming we could subtract 1 point)

21. Do you use any electrical power strip with switch to connect all the wires?

- Yes, and I turn it off always when I go home (+1p)
- Yes, I turn it off almost every day when I go home (0p)
- Yes, but I rarely turn it off (-2p)
- No, but I unplug all the appliances when I go home (0p)
- No, I always leave the appliances plugged in stand-by (-2p)
COFFEE ROOM / KITCHEN

22. What do you use to boil water?

☐ A pot (-3p)
☐ Microwave (-1p)
☐ An electric kettle (0p)
☐ Hot water from the coffee machine (+1)
☐ Not applicable (0p)

INFORMATION (You can tick as many answers as you want)

23. Do you think you can do something else at work to get significant energy savings (you can select multiple options)?

☐ No, I think my behaviour is correct; there are very few things I can do
☐ Yes, I know I could do more and I try it, but it’s hard to change my habits
☐ Yes, I know that there are many things to do, but I don’t want to change my habits
☐ Other: __________________________________________

24. If you answered yes on the previous question, what do you think you need to save more energy at work? (you can select multiple options)

☐ More information about how to save energy
☐ Some feedback about my progress would encourage me to do more things
☐ I don’t need anything else; I have enough information and feedback
☐ Other: __________________________________________
APPENDIX 2

ELECTRICAL APPLIANCES IN MY OFFICE

Introduction:

The aim of this study is to investigate the use of electrical appliances in M-building and the potential for more efficient energy use at our department. This is a previous step for a future study in energy behaviour.

Please indicate all the electrical appliances you have in your office and such as lamps (bulbs and fluorescent tubes), laptops, screens, etc. and how long time you use them per day. If you know, also indicate the electrical demand in watts and approximately how many days a year you use them. Use the comments box to indicate further details such as the season you usually use them (i.e. “only during summer”) or any other comments you would like to make.

Thank you for your help!

Room number: ____________ Number of people in the office: _____

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Number</th>
<th>Load [W]</th>
<th>Time [h/day]</th>
<th>Days a year</th>
<th>Comments</th>
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Inledning:

Målet med den här typen undersökningen är att studera användningen av elapparater i M-huset och potentialen att effektivisera energianvändningen på vår institution.

Var god notera all elutrustning på Ditt kontor såsom lampor (glödlampor och lysrör) datorer, skärmar, etc. och ange hur lång tid de används under dagen. Om Du vet, notera gärna hur många watt och ungefärligt hur många dagar per år de används. Använd gärna kommentarsfältet för detaljer som vilken årstid användningen gäller (exempelvis ”endast under sommaren”), eller något annat Du vill kommentera.

Tack för hjälpen!

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<tr>
<th>Rumsnummer:</th>
<th>Antal personer med hjälp av kontor:</th>
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