ENERGY EFFICIENCY ANALYSIS OF RESIDENTIAL ELECTRIC END-USES: BASED ON STATISTICAL SURVEY AND HOURLY METERED DATA

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ABSTRACT

By the end of 2013 at the latest almost all electric consumption will be measured hourly in Finland. Beyond billing facilitation and troubleshooting, AMR provided great deal of opportunity for energy efficiency analysis.

This study evaluates efficiencies and saving potential factors of household electricity end-use consumption by analyzing data from AMR meters and questionnaire collected statistical data. The interdependency of household appliances in factoring the gross household CO_2 emission will be given much attention to achieve holistic approach. The study analyzes the extent of utilization of AMR in improving efficiencies of household consumptions.

INTRODUCTION

Energy saving potential of end-use sectors in EU-25 residential households account for an estimated 27% of the total 2020 target savings. [6] Implementing informed energy saving policies on residential households in parallel with creating customer awareness programs with involvement of utility companies plays major role. On the other hand, since 1995 Automatic Meter Readings (AMRs) technology has been installed in Finland creating third party access for most customers' electric power consumption.

The customary way of analysis for appliances' energy efficiency has been solely based on individual level appliance specific studies. Some of the most recent (2007) energy saving actions in Finland includes energy labelling scheme for windows and promoting renewal of old oil heating systems. The interdependency of household appliances in factoring the gross household CO_2 emission was not given much attention and therefore lacks a holistic approach. This study evaluates efficiencies and saving potential factors of household end-uses analyzing data from AMR meters and questionnaire collected statistical data. Two databases were established for statistical and hourly power consumption data from Kajaani, Savo and Vantaa area households. MYSQL 5.1 was used for data storing, Matlab for database interrogation and Excel for data post processing.

Section 2 introduces the data analysis framework used in this study. In section 3 and 4 major results of efficiencies and saving potentials of end-users are presented respectively and the subsequent section concludes the study.

A FRAMEWORK FOR ANALYSIS

The introduction of smart meters in recent years resulted in an opportunity to look in to detailed consumption profiles of households. Nevertheless, deciphering the hourly metered consumption without additional information from the specific household is quite difficult, at least from data analysis point of view. Incorporating survey data with the power consumption will enhance effective interpretation.

Establishing databases

In this study consumption and survey databases has been built and filled with data. Main purpose of survey data was to group households of similar profile later in the analysis of power consumption. In survey database we have had statistical information of 2063 households from Kajaani, 869 from Savo and 898 from Vantaa areas.

In consumption database we have got full year hourly power consumption of 1647 households from E.ON Kainuun Sähköverkko Oy and 704 households from Savon Voima Verkko Oy. Each household has 8760 consumption data in the case of Kajaani households for the time span from 01-07-2008 to 30-06-2009. In the case of Savo households, the consumption year is 2008 with 8784 data points

Database interrogation

The establishment of survey and consumption database lead to availability of grouping and analysis. The two databases has common primary key which is the meter id of the specific household. For every hypothesis to be tested, exclusive query was written to sort out the specific issue. In the process the minimum number of households in a group for comparison is set to be six in most cases. The query is rewritten rigorously until it is believed to represent the unique case. The general process of the analysis method and software involved are shown in Figure 1.

The main idea of the analysis is that for two groups of households, where the standard deviation of consumptions inside a group is minimum, the variation of consumption between the groups is then attributed to the initially targeted hypothesis.

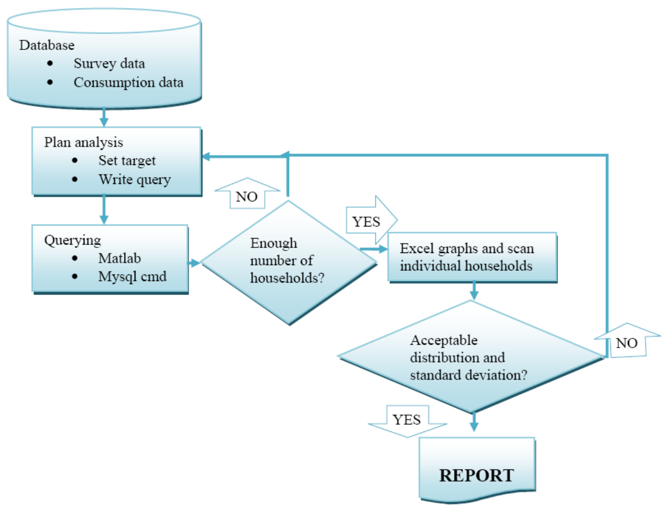

Figure 1 Overview of database interrogation process

RESULTS ON EFFICIENCIES OF MAINLY CONSUMING APPLIANCES

In Finland, heating is the giant predator accounting for above 40% of household electric power consumption. The actual energy savings and efficiencies of various heating systems as well as other appliances are evaluated from our database. The evaluated figures are fairly reliable but one should keep in mind that they are subjected to statistical errors.

Ground Source Heat Pumps (GSHPs)

GSHPs has 20.6% share from the EU target of 20% primary energy consumption reduction. Efficiency of heat pumps is expressed as Coefficient of Performance (COP) which is highly dependent on both the source and emitter temperatures. In the development of heat pumps for the last 20 years COP increased from an average of 2.5 to 4.5. In Finland installation of heat pumps is emerging highly from year to year. According to the 2009 EHPA report heat pump market raised by 30% in 2008 compared to 2007.

The general overview of our statistical database with respect to GSHPs as shown below:

- All households with GSHPs as primary heaters are one family detached houses.
- 72.5% of houses with GSHPs as primary heaters are constructed from wood.
- Almost all houses with GSHPS as their primary heaters use wood heating (e.g. storing fire place) for supportive heating.

In this analysis we evaluated the efficiency of GSHPs mainly by comparing it with the direct electric heaters. To separate heated and non-heated seasons clearly winter was considered from January to March and summer from June to August. The average consumption of each hour was evaluated for the two periods and we came up with 24 hour consumptions of average hours to give average day consumption.

After curve fitting on the 24 hours consumption the area under the curve was evaluated, this gives the daily average energy consumption. The assumption here is the difference between average daily energy consumption of winter and summer mainly imply the heating consumption.

The above calculation was done for three heated area groups with GSHPs and direct electric heaters as their primary heaters. At average GSHPs save 27.45% to 47.0% of direct electric heater consumption.

In another approach we selected two households of similar profile except one with GSHP primary heater and the other with direct electric primary heater. Then the scatter plot of their daily consumption was plotted with average daily temperature as shown in Figure 2. If we calculate the overall heating energy savings from the rate of change of consumption for each degree centigrade temperature drop, we will get the following value.

Saving% = (3.044-1.260)*100/3.04 = **58.6%**

Assuming 100% efficiency of direct electric heater, we may calculate the heating season performance factor which is equal to 2.42.

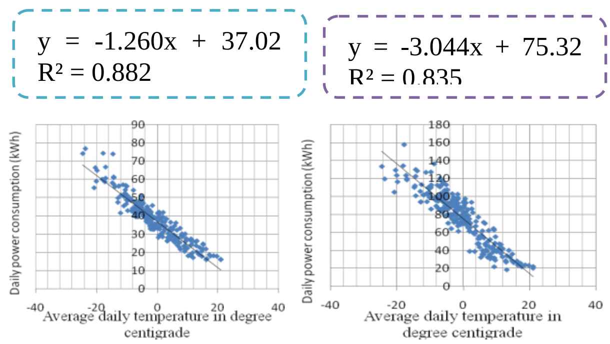

Figure 2 Household with GSHP for 18-Oct-08 to 30-Jun-09 (left) and Household with direct electric heating for18-Oct-08 to 30-Jun-09 (right).

The value we calculated is comparable with other northern countries experiencing less than 3 performance factor. In Canada, where air temperature can go below -30 °C, and where winter ground temperatures are generally in the range of -2 °C to 4 °C, earth-energy systems have a COP between 2.5 and 3.8.[2][3][4]

Possible reasons for lower COP values are listed below:

1. The overall COP will be high if the GSHP is used for both heating and cooling season but in environment like Finland cooling is not used as such.
2. The need for electric supplemental heating was significant on the coldest winter days as we observed in cyclic hourly consumption of GSHPs for temperature less than -15 ^{o}C.

Air Source Heat Pumps (ASHPs)

The heat source for ASHPs is the outside ambient temperature which is highly variable throughout the year. These heaters are considered to be supportive heaters. According to our statistical database, about 80% of supportive ASHPs were used with electric primarily heaters.

We did comparison to evaluate savings with introduction of ASHPs. Two groups were set up in such a way that one was collection of purely direct electric heated households and the other group was identical households with previous group except for having supportive ASHP heaters.

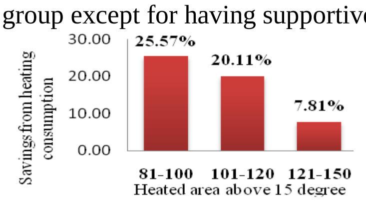

Figure 3 Percentage reduction of heat energy needed by using DE heaters with ASHPs than DE alone.

Based on our observations the following two conclusions were drawn.

1. In comparison with sole direct electric heater, incorporating air source heat pumps showed a reduction of heating consumption by 7.8%-25.6%.
2. Air source heat pumps suit best for smaller heated areas (Figure 3).

Energy Saving Lamps

According to our statistical database, in average Finnish household, 62.86% of the total lamps are incandescent bulbs, 35.4% are fluorescent lamps and 1.74% other lamp types. Excluding consumption for heating, lighting accounts for about 22% of per-household electric consumption. [1] For houses grouped to have similar electronic equipments number and with primary heating of district heating, replacing every ILB by energy saving lamps showed saving of 13.62% to 17.06% from the total household electric power consumption other than heating.

In Figure 4, average day hourly power consumption of ILB majority households and their respective CFL majority households is plotted. In both cases primary heating system is either district heating or oil heating. One observation in the graph is that the variation in consumption gets significantly higher for hours of the day where lighting is used much.

Another observation from the data analysis shows that the expected savings of CFLs in case of direct electric heated households was marginalized by possibly the heating effect of ILBS. There is significant possibility of down sized savings from energy saving lamps in the case of direct electric heated households.

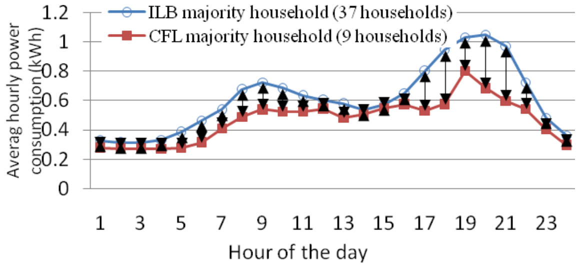

Figure 4 Average daily consumption for households with district heating or oil primary heating.

Ventilation Systems

In our database, of the households built after 2000 above 65% use mechanical supply and exhaust ventilation with heat recovery. This might be due to the Finnish national building code (D2 2003), which requires at least 30% heat recovery from the exhaust air.

The total power savings of households with mechanical supply and exhaust ventilation with heat recovery compared to those with mechanical supply and exhaust ventilation is plotted in Figure 5.

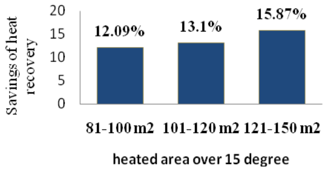

Figure 5 Savings from heat recovery incorporated ventilation systems.

EVALUATED SAVING POTENTIAL FACTORS

In this section results of calculations of theoretical factors and saving potentials using information from both databases are presented.

Standby energy consumption of households

According to the 2020 EU plan the standby electricity consumption is expected to decrease by 73%. This is possible if reduction rate of 50 TWh per annum is achieved. [5]In Finland, according to our database, the total standby power consumption per household is at average 33.7W (the penetration rates from statistical database are used in the calculation) and the yearly standby energy is about 295.21 kWh per households. The above result represents the 70%-80% of household total standby consumption.

In another case, household power consumption in the time between 2AM and 4AM is the lowest consumption of the day, which is used to estimate standby consumption after subtracting possible consumptions of 24 hour working devices.(Figure 6)

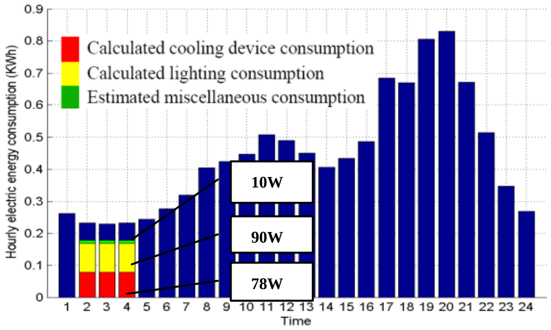

Figure 6 Average daily load curve of 17 households 101-120 heated area (46.2W average standby consumption)

Indoor temperature levels and programmable thermostats

Two things are considered in this section. One is saving potential of lowering room temperature by one degree and the other is effect of installing programmable thermostats and following Energy Star setting recommendation.

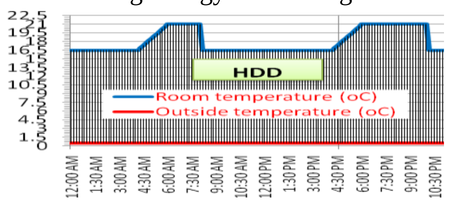

Figure 7 Thermostat Energy Star setting.

In evaluation of effect of lowering room temperature, household savings were calculated in each heated area group with decrement of room temperature. Then after normalizing with heated area and calculating the weighted averages, overall savings of 3.43% from household consumption is observed for each degree lowering from inside room temperature.

Also, considering a specific model house, two situations were compared to evaluate savings from following the Energy Star thermostat settings. (Figure 7) An average saving of 14.7% from heating energy was calculated for using programmable thermostat and following Energy Star setting. The saving is also highly dependent on the outside temperature and the actual saving is formulated as shown below.

$$\text{Saving (\%)} = \frac{3}{21 - Tout} * 100$$

CONCLUSION

This study analyzed efficiencies and evaluated saving potentials of various household end-uses. The analysis was done based on survey data and AMR metered hourly household power consumption. The following challenges have been experienced during the process.

- Power marketing trend with cheap night time pricing distorted the daily consumption structure. Even households other than with electric storage heaters use this cheap price power.
- Even distribution of electronic equipments among all households blocked the pinpointing of single influences.
- An increase of lighting consumption with the same trend as heating consumption throughout the year.

Nevertheless, the calculated factors were fairly reliable and practical compared to theoretical calculations. The factors evaluated in this study are used for online household balance sheet calculator which is capable of generating user specific energy saving actions.

The household basis load monitoring has stepped forward with installations of AMRs and further more reliable information and data is expected with incorporation of nonintrusive load monitoring systems with AMRs. Power companies can utilize the data from AMRs for more than billing purpose. They are able to engage in the process of load monitoring, creating energy saving awareness among customers and researches for efficiency actions.

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