More or Less about Data:
Analyzing Load Demand in Residential Houses

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ABSTRACT

Load demand in residential houses is a significant contributor to peak load problems experienced by utilities. The knowledge about demand variation in households is fairly limited as well as the use of various tools to analyze the demand. Many utilities have recently installed interval (hourly) metering at their residential customers. The availability of hourly data is a significant progress, however, the utilities use this data only to a limited extent, mostly for billing purposes only. This study aims to discuss the possibilities and the benefits of using this valuable data.

There are several established load analysis tools, such as load curve, typical load curve, load duration curve, load factor, superposition factor, etc., which utilities could apply and develop to provide feedback to small electricity users. Among other benefits, the hourly load data analysis can provide the detailed characteristics of load demand, define the consumption patterns and can help to identify which households contribute most to the utility peaks. This information is essential when developing new energy services, appropriate pricing, load management strategies and demand response programs.

Through the analysis of strengths and weaknesses of different load analysis tools, this paper defines the knowledge they could give, how applicable they are and what value they could have both for the utility and the residential customer. The study is exemplified with ten cases of households with electric space heating in Southern Sweden.

Load Demand and Load Data in Households

Traditionally, when approaching load demand problems, the focus is on bigger electricity users (industrial). But the fact is that the residential, commercial and services sector accounts for half of the total electricity consumption in Sweden (Swedish Energy Agency 2003). Electric space heating currently accounts for just over 30% of the total electricity consumption in the sector. High electric load demand variations occur in winter season together with temperature variation. Load demand in Sweden increases by 350 to 400 MW for each ºC of outdoor temperature drop (Pyrko, 2004). Furthermore, load demand in the residential sector varies significantly during the day and normally has its peaks during morning and evening hours.

The dominating energy source for heating and domestic hot water for detached residential houses in Sweden is electricity. An increased number and a variety of household equipment may also lead to load shortages if used simultaneously.

Most energy experts agree that the residential sector should be seriously considered when approaching peak demand problems and ensuring a well functioning electricity market.

The existing knowledge about demand variation in households is fairly limited. Many utilities have recently installed or consider installing interval (hourly) metering at their residential customers. This is partially enforced by the new law of billing on actual electricity use (Sernhed 2004). The availability of hourly electricity use data is a big step forward, however, the use of various tools to analyze the demand is limited. The utilities use collected data mostly for billing purposes.

The Swedish electricity market was de-regulated in 1996. However, if private customers wanted to change their supplier (retail company) they were forced to invest in a new electricity meter with hourly metering. The cost of such a device was typically around 900EUR. Very few customers changed their supplier at this stage (Matsson 2001). The requirement for hourly metering was abolished in 1999. It was replaced by a profile-settlement, meaning that different consumption patterns are applied when estimating the electricity consumption within a specific period of time. Each pattern is valid for all customers within a specific geographical area (Wallin 2005).

The major advantage of new profile-settlement was that the electricity consumers with smaller consumption (residential) were able to switch electricity supplier and directly benefit from the new electricity prices without having to invest in the metering system. One major disadvantage was that the connection between real physical electricity use and customer electricity cost in high-peak periods vanished (Wallin 2005).

There are a number of suppliers of new metering systems promoting their products. With the latest technical development of automated meter reading (AMR) systems the residential customer becomes more "visible". Hourly data is available now both to the customer and the utility. New meters allow even more detailed statistics as well as opens new possibilities for customer-supplier dialogue and the development of new energy services. This is a new possibility but at the same time a new challenge, requiring reconsideration of long term customer – utility relations. In the present market conditions keeping the customer becomes the major task for a utility. The use of modern metering and communication system could be seen as a competitive advantage influencing customer choice.

The objective of this paper is to discuss the ways and benefits of using this valuable end-use data. The electricity use of ten pilot households is shown as an example of using the analysis tools described in this paper.

Analyzing Load Demand

Several characteristics can be derived when analyzing load on the demand side to describe load demand conditions as:

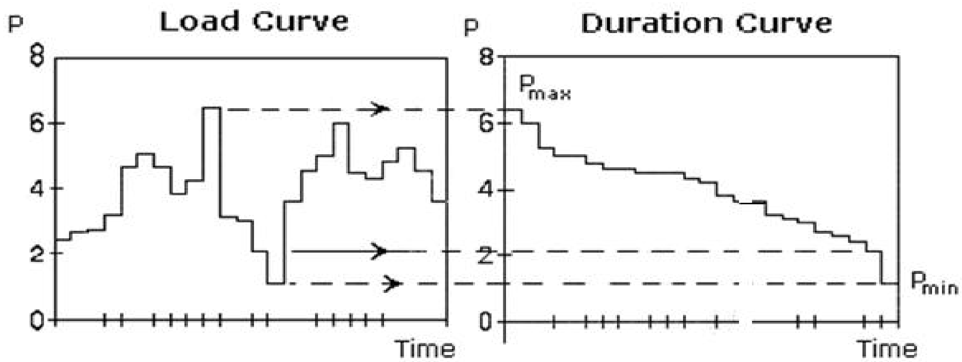
- Magnitude of energy use and load demand
- Variation of the demand in time
- Minimum and maximum demand values
- Duration of minimum and maximum load
- Contribution to total pattern/total utility load

There are several established load analysis tools, such as load curve, typical load curve, load duration curve, load factor, superposition factor, etc, which are used to describe these conditions. The definitions, interpretation and applicability of these tools are discussed in this section.

Load Curve and Load Duration Curve

Load curve illustrates variation of load demand during a specific period. A load curve can be converted into a *load duration curve* showing duration of a particular load demand. A graphical explanation of load curve and load duration curve is given in Figure 1.

Figure 1. Load Curve and Load Duration Curve



Source: Pyrko 2004

The load curve is a good visual representation of electricity use in a household and its variation over time. It shows minimum and maximum use values against time-of-day and, depending on the given resolution, their duration. It could be considered as a "user friendly" way to explain the customer peak load phenomenon and can be an incentive for the customer to look at what is beyond the needle peaks in the consumption. Therefore this method should be an attractive one for the customer (expected to have some sort of behavioral influence) and convenient for the utility. However, to be realistic, one should keep in mind the question when and why would customer care to look at their load demand. Three conditions could be emphasized:

- Customer is interested to see the existing pattern
- Customer is interested to see the changes when some measures (energy/load saving etc.) have been implemented in the household
- Customer has a direct incentive to care about load pattern when, for example, having a tariff with load demand component. However, an important prerequisite here is that customer would have to have instantly available information on a device or screen, otherwise the feedback would come too late to expect changes in use.

It should also be mentioned that load curve could be a useful way to identify the operational problems when running the building.

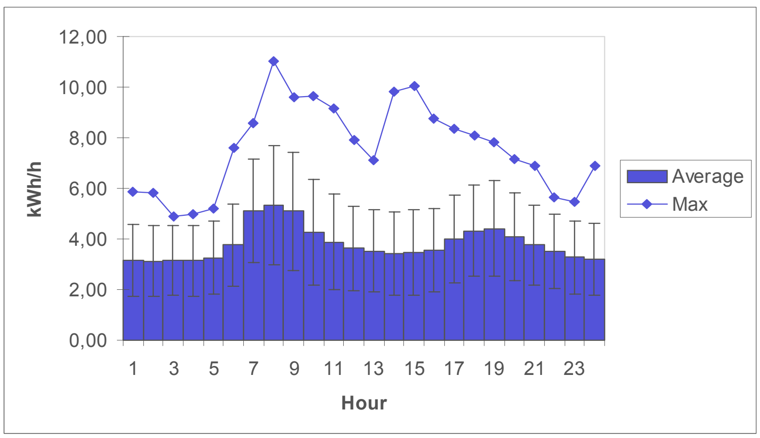
The load duration curve for the utility is essential information about customer's load demand, especially looking at the longer perspective (full year or season). A significant benefit given by the duration curve for the utility is that it directly shows the number of hours when the demand exceeds a certain load demand level, where there's the greatest need for load control actions.

Typical Load Curves

The typical load curve is different from the simple load curve as it is more than just a momentary visualization of electricity use. It normally shows the mean load demand value for each hour during the specified period (week, month, year, etc.). The typical load curves are often developed to compare the demand on weekdays and weekends. Figure 2 shows the daily load curve of one household for the winter period. The average and maximum hourly load as well as standard deviation is shown.

The typical load curve can be used for comparison of "typical" patterns and for a selected time the actual energy performance. This method therefore is useful both for customer and utility. It is a good graphical representation and clear picture of household-specific energy use and daily consumption pattern. The method provides valuable information for a utility for designing demand response strategies and new value-added energy services.

Figure 2. Daily Load Curve Example



Load Coincidence

Different customers naturally differ in the load curves/patterns. What principally matters for the utility is the total load pattern of all the customers – the coincidence load. The coincidence load curve should be as even as possible. This would be a favorable situation for the utility. The coincidence factor is the ratio of coincident load maximum value to maximum value of partial load demand (equation (1)).

$$CF = P_{max} / \Sigma P_{imax} \tag{1}$$

where:
P_{max} = coincidence load maximum value,
P_{imax} = maximum value of partial load i.

This ranges between 0 and 1 as coincident demand should always be less than or equal to the maximum demand.

Load Factor

Load factor is simply the ratio of the average load during a specific period of time to the maximum load occurring during that period, as given in equation (2):

$$\text{Load Factor} = \frac{Load_{average}}{Load_{\max}} \qquad (2)$$

The load factor is used to demonstrate variations of the household's load demand. This factor can range between 0 and 1, where a value of 1 would indicate that the household load curve was completely flat and no peaks were present. From the supplier's point of view, it is preferable to remove peaks and flatten out the load curve, corresponding to an increase in load factor.

The load factor is a good tool both for utility and customer. However, the major shortcoming of the load factor is that it does not represent the magnitude of the consumption, i.e. the value of the highest load and average loads. For the utility, looking at just the load factor, makes it difficult to judge the load reduction potential for the specific customer and the influence on the total utility load.

The load factor can be used as a parameter when designing or analyzing new electricity tariffs. For example, it is a way to evaluate the load pattern before and after the introduction of a new load tariff.

Exploitation Time

The exploitation time provides information about the shape of the customer's load demand curve. The time, calculated in hours, represents the required duration of maximum (peak) load needed to correspond to the total actual electricity usage during the same period, which can be represented by the equation (3). A high exploitation time relates to an even load demand – a preferable situation for the utility (North 2001).

$$\text{Exploitation Time (h)} = \frac{\text{Electricity Consumption}}{Load_{\max}} \qquad (3)$$

Exploitation time has more value for the utility than the household customer as is more complex parameter than load factor and would not provide meaningful information for the customer.

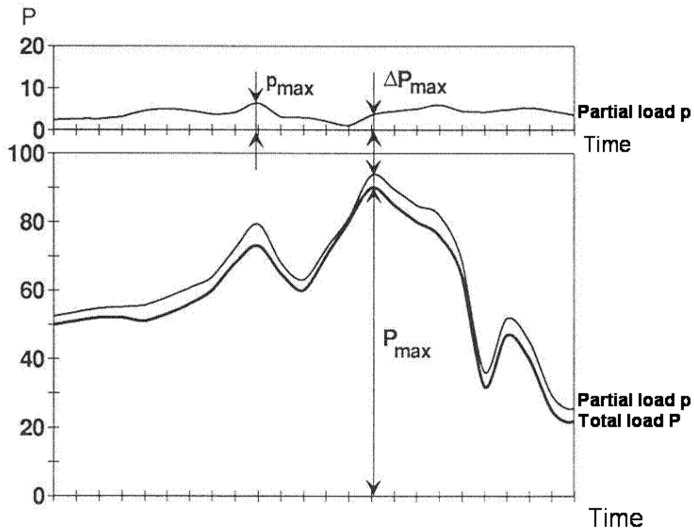
Superposition Factor

Superposition describes one specific customer's influence on a total utility load curve or the contribution of partial load to the total load. Superposition factor is the ratio between the partial load demand during the total peak and the maximum partial load during the same time period as it is expressed in Figure 3 and equation (4).

$$SF = \Delta P_{max}/p_{max} \qquad (4)$$

where:
ΔP_{max} = increase of total load peak value due to partial load **p**,
p_{max} = partial load maximum value

Figure 3. Superposition and Superposition Factor



Source: Pyrko 2004

The range of values that this factor can take is between 0 and 1, where a value of 1 would indicate, that the peak of the partial load coincided with the peak of total load. What the superposition factor doesn't tell is how big the partial load demand is that contributes to the maximum load of the system, doesn't tell the magnitude of the use of the specific customer.

Superposition factor is, of course, a more "utility oriented" tool. This factor could be the major decision driver to select customers for participation in DR programs. The factor identifies which customers should be addressed first and where the load management activities would actually give the desired results. Having this knowledge, for example, the utility could approach the specific customer, or group of similar customers, with the special proposals for DR actions (tariffs, load control programs, etc.). Obviously, it is necessary to look at many peaks to be able to determine if the peaks coincide by chance or if there is an evident correlation.

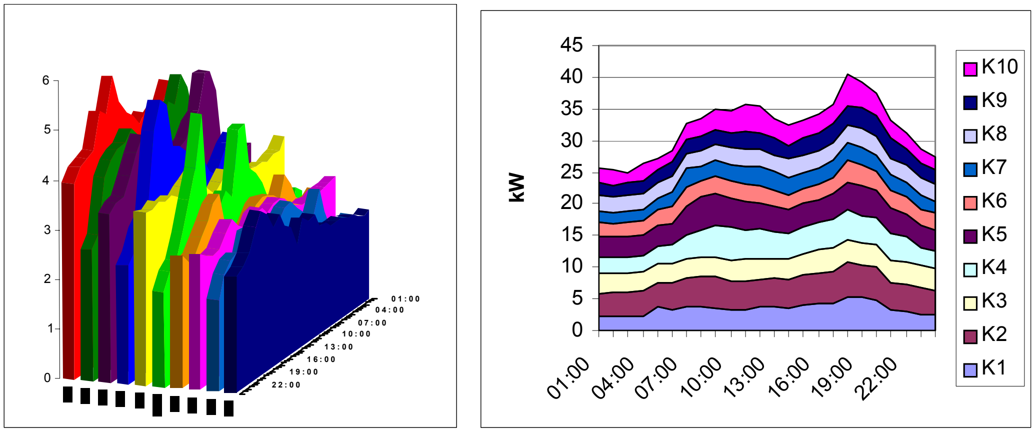
Examples of Ten Households

This study is exemplified with ten cases of households with electric space heating in Southern Sweden.

Our associated utility Skånska Energi AB has installed advanced metering system "CustCom" to all its customers (99% of those are residential houses)(Abaravicius, 2004). The system is able to provide automatic hourly measurements, as well as electricity control and information services. At the moment it is used only for measurements and billing purposes. Hourly use data is automatically collected by the utility and is available for each customer via Internet. The hourly data is available in form of tables and load curves during a specified period.

Figure 4 shows the typical daily load curves (average value during specific hour) and coincident load curve for the10 analyzed households during December 2003.

Figure 4. Households' Typical Daily Load Curves and Coincident Load Curve during December 2003



Source: Sernhed 2004

Table 1 shows an example of load factor and the exploitation time for 10 households in Southern Sweden calculated for period April 1, 2003 – Feb 15, 2004.

Table 1. Load Factors and Exploitation Time for 10 Analysed Households

Household	Total consumption	Average load	Load Factor	Exploitation time
	kWh	kWh/h		h
H1	16906	2,19	0,17	1339
H2	21910	2,84	0,24	1877
H3	16525	2,14	0,23	1798
H4	17506	2,27	0,22	1683
H5	18695	2,43	0,22	1698
H6	**13405**	**1,74**	**0,28**	**2128**
H7	**12757**	**1,66**	**0,29**	**2254**
H8	**13966**	**1,81**	**0,27**	**2060**
H9	11874	1,54	0,23	1770
H10	15422	2,00	0,22	1719

The example shows that households H6, H7, H8 have the highest load factors and highest exploitation times among the analyzed objects. From the load demand point of view, these customers could be seen as the most favorable for the utility. On the other hand, these households (together with H9) also have lowest total electricity consumption, and average load demands, that, in turn, decreases their significance for the total demand conditions of the utility.

Table 2 shows results of a superposition factor analysis performed for 10 households in order to observe which of them are mostly contributing to the utility peaks. The utility's ten highest hourly peaks within the analyzed period were selected and the superposition factors for the households were calculated. The results indicate that households H10, H4, H5, H6, H8 were mostly contributing to the selected utility peaks (SF ≈ 1,0). What superposition factor doesn't tell is how big the partial load demand is that contributes to the maximum load of the system.

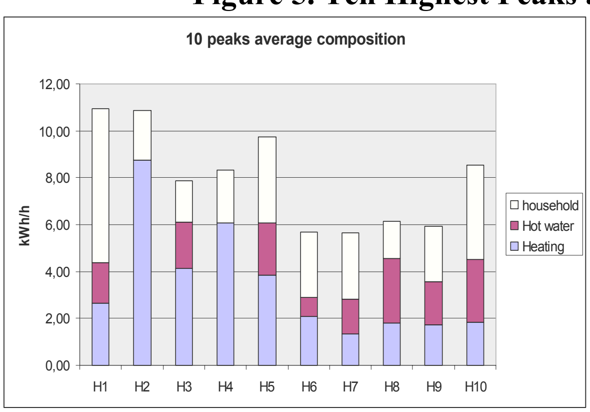
Table 2. Superposition Factor for 10 Analysed Households

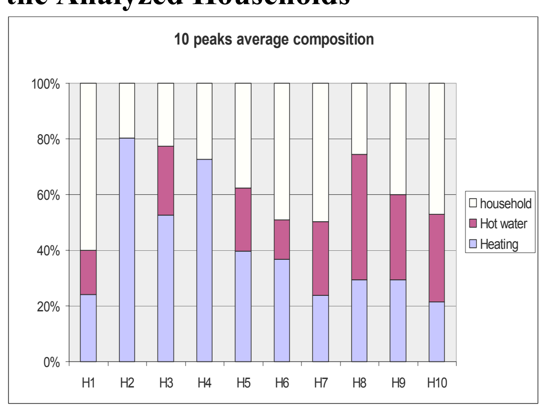
10 utility peaks												
date	kWh/h	Out. Temp.,°C	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10
2004-01-22 08:00	80387	-15	0,81	0,95	0,81	**1,00**	**1,00**	0,65	0,66	0,91	0,81	**1,00**
2004-01-22 18:00	76400	-9	0,78	0,79	0,89	**1,00**	0,59	0,70	0,82	0,78	0,89	0,80
2004-01-21 19:00	74019	-8,1	0,69	0,66	0,92	**1,00**	0,75	0,56	0,74	0,88	0,70	0,73
2004-01-21 08:00	73773	-9,8	0,78	0,86	0,76	0,83	**0,99**	0,55	0,59	0,86	0,57	**0,95**
2004-01-26 18:00	72202	-3	0,75	1,00	0,90	**0,95**	0,81	0,68	0,78	**1,00**	0,60	0,60
2004-01-27 18:00	71429	-4,3	0,66	0,92	0,82	0,81	0,76	0,64	0,94	**1,00**	0,56	0,93
2004-01-05 18:00	71128	-7,4	0,81	0,91	0,83	0,59	**0,97**	**1,00**	0,85	0,79	0,68	0,93
2004-01-23 08:00	70934	-3	0,88	0,86	0,81	0,86	0,82	0,66	0,55	0,68	0,55	**1,00**
2004-02-12 08:00	70614	-4,3	0,31	0,80	0,73	0,87	**1,00**	0,72	0,79	0,53	0,65	**1,00**
2004-01-02 18:00	69494	-3,9	0,74	0,89	1,00	0,92	0,59	**1,00**	0,86	**0,97**	0,71	**1,00**

What's Beyond the Peaks?

For experimental purposes two extra meters were installed to measure load demand for heating and hot water. Figure 5 provides the overview of the average of 10 highest peaks of every household and the peaks' composition. The available metering of partial loads allows insight into the origin of the peaks, i.e. whether it is a climate dependent or behavior dependent peak. The composition is presented in two ways – in kW, in order to see the peak value and as a share of the load demand.

Figure 5. Ten Highest Peaks at the Analyzed Households





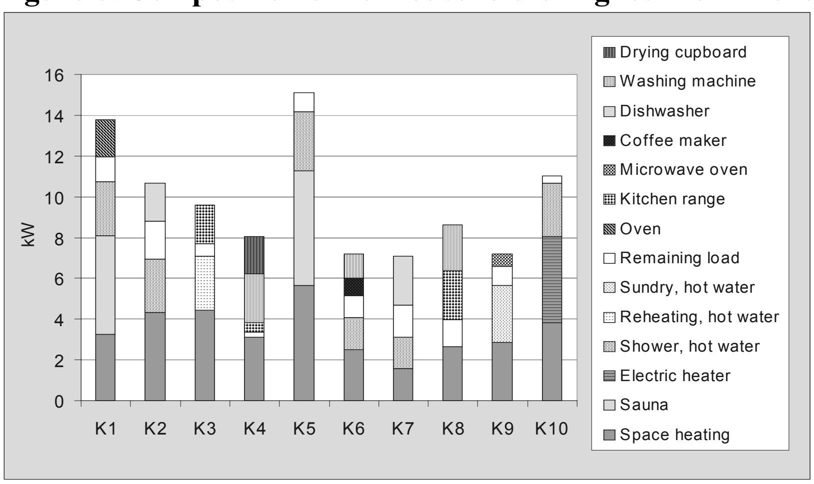
This information has primarily value for the customer as they could directly see what kinds of end-uses consume most energy. This kind of information could be treated as a specific utility service. It should be mentioned, nevertheless, that the method might be costly as it requires installation of extra meters.

The utility also benefits from this data as it provides good grounds and information to develop value-added energy services, as promotion of specific appliances, installation of storage and load control equipment, etc.

A very interesting and, in a way, unexpected result in Figure 6 is the electricity demand for household needs which can be as high as 60% of the total demand during some periods. Furthermore, these periods were measured during the winter season when one would normally expect the heating demand to take the highest share. The important conclusion therefore is that not only the climate (outdoor temperature), but the behavior related electricity use could be a serious cause of load peaks. Especially risky is the coincidence of both.

In order to get a more detailed energy use description, diaries were filled in for 4 days by household members. Based on this information and measurements it was possible to specify all end uses' contribution to the highest peak during the four-day period. The results are given in Figure 6 (Sernhed 2004)

Figure 6. Composition of 10 Household's Highest Peak Load



Source: Sernhed 2004

Heating Load

The measured load data for heating could be extended to various outdoor temperatures using the *regression analysis*. This is a good tool for a utility to predict the demand related to temperature variation, as well as to estimate the expected load savings by controlling (turning off or partial decreasing) load for heating in load management programs. Heating systems are normally the primary subject for load management/control programs as they have highest load demands and could be manipulated with the least negative consequences for a customer.

One interesting idea to look into is if the separate measurement of heating load could create a possibility to charge it separately. Different contracts for heat supply in this case could be developed. Consequently, it could stimulate for instance the investment in heat storage technologies, system automation, load control technologies, etc.

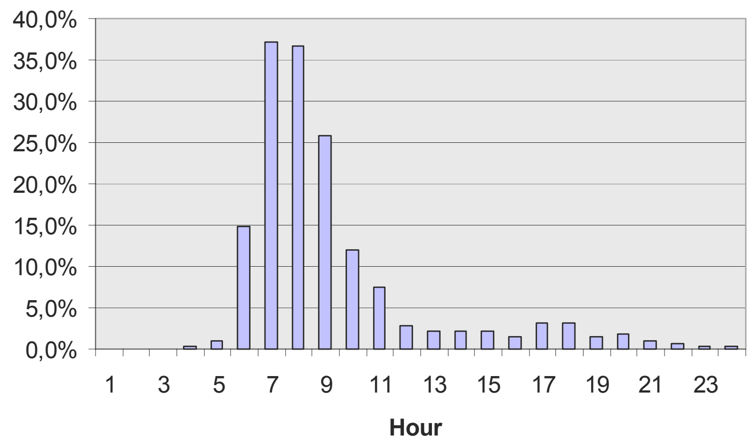
Hot Water Load

Hot water use has a tendency to increase during morning and evening hours in most households and thus contribute to the total load peaks. Similar conclusion could also be drawn from an analysis of probability that hot water boiler is on full power, presented in Figure 7.

An important question, when analyzing load demand for hot water, is when the hot water boilers are on full power. Having this knowledge it is easier to create load management strategies, as it gives a suggestion when to control the units in order to get a maximum load savings. Using the daily load curve and the hourly data, the following methodology for finding the probability if the hot water boiler is on full power was developed for our case studies: it is assumed that boiler is on full power if the hourly load exceeds 2,5 kWh/h. Every hour of the day through the investigated period is analyzed. Number of hours when the load reached this value is divided by the total number of recorded hours.

The result for one of the households (H5) is given in Figure 7. Values on Y axis show the probability (%) that the water heater is on full power versus the hours of the day (0-24). The pattern of load demand for hot water varies from household to household, principally depending on the behavioral factors. There is a tendency for the highest demand to occur during morning and evening hours, therefore these periods could have the highest potentials for load control.

Figure 7. Probability that Hot Water Load Is on Full Power during a Day



Concluding Discussion

New automatic meter reading technologies allow to measure more than the total electricity demand. High resolution load data is now available both for the customer and the utility. The open question remains how the data should be provided in order to make customer interested in better understanding their energy use? Is it sufficient only to make it available online? The research on this particular issue is on the way, however, it requires broad efforts and trans-disciplinary cooperation of engineers, economists and behavioral scientists.

The load analysis tools, touched in this paper, are not new. The novelty here is their use when analyzing residential load demand and their applicability in the residential market conditions.

Load curves, daily load curves, load factor, and superposition factor should be used as good representations of the household load demand. Load curve is more useful tool for the customer, while the duration curve is more useful for the utility. Load factor is a useful indicator both for the utility and the customer. However, the major shortcoming of the load factor is that it does not represent the magnitude of the consumption, i.e. the value of the highest load and average loads. For the utility, looking at just the load factor value makes it difficult to judge the load reduction potential for the specific customer and how would it influence total utility load. One interesting possibility is that the load factor can be used as a parameter when evaluating new electricity tariffs.

Even though ideal market development demands broad participation in DR programs, with the help of such a method as superposition, the utilities can start it with the households and their energy uses that contribute the most to their peaks.

Typical load curves provide valuable information for a utility for designing demand response strategies and new value-added energy services.

Partial loads measurement has primarily the value for the customer as they could directly see what kinds of end-uses consume most energy. This kind of information could be treated as a specific utility service. It should be mentioned, nevertheless, that it requires installation of extra meters. The utility also benefits from this data as it provides good information to develop value-added energy services, as promotion of specific appliances, installation of storage and load control equipment, etc.

Special attention should be given for the electricity used for heating (as the highest demand). One possibility is to measure and charge it separately. Different contracts for heat supply could be developed.

There's evidently higher interest for the utility in analyzing load demand or, in another words, it is a utility oriented process. It provides a utility an essential grounds, sources to create appropriate DR strategies (pricing, direct control, etc.).

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