Start point to savings – Better load demand analysis in commercial buildings

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Abstract

Existing installations and energy systems in most commercial buildings could be used in a more efficient way to provide savings – both in terms of energy and load demand. The key for effective operation is a thorough and detailed analysis of energy use patterns that creates essential baseline for energy savings and the development of demand response (DR) strategies.

The knowledge of energy demand variations is still very limited and the use of methods to analyse the load demand is rare. Many utilities have recently installed interval (hourly) metering even for smaller commercial users and households. This is a big step forward; however, experience shows that the data is being used only to a limited extent, mostly for billing purposes only.

This paper reports about a study conducted with the objective of developing a detailed load demand analysis for commercial buildings. The study results should provide essential information for the formation and evaluation of future DR and energy efficiency strategies. This study was performed in collaboration with IKEA and E.ON and contributes to an ongoing IKEA energy efficiency programme. Two sample department stores in Sweden were selected and analysed within this project. The demand data analysis covers almost 3 years period, 2004-2006.

This study contributes to new knowledge of energy use patterns (load demand) in commercial buildings. It proposes solutions of load-related problems, evaluates energy and load savings potential, identifies and analyses the needs, motives and barriers for participation in DR programmes. The study provides recommendations for ongoing and future efficiency and DR strategies and discusses the potential economic benefits from the DR measures.

Introduction

The major scope of this paper is load demand analysis in commercial buildings. Load demand is an important techno-economic issue both for electricity producers and for grid companies. Power insufficiency can occur due to fall in production or the limited transmission capacity in the grid. Power insufficiency can occur on both the supply and demand side and can have technical, economic and even political causes.

Commonly, system balance in the grid has been secured by expanding production and/or distribution capacity, importing electricity, or by facilitating changes in consumption patterns on the demand side. This has been done through various energy efficiency and demand response (DR) programs. DR is the application of available technical and economic mechanisms to balance energy demand and supply in a grid-based energy system. To be more specific, DR is a short term modification in customer end-use electric loads in response to dynamic price and reliability information (Watson et al, 2006). The primary goal of energy efficiency (EE) measures is reduction of energy use (expressed in kWh), while the goal for DR is the dynamic reduction of peak load demand (expressed in kW or kWh/h). The proper starting point for the achievement of both goals is a detailed and thorough analysis of consumption patterns. It can give essential information for savings strategies leading to energy and financial savings.

Residential, commercial and services sector account for around half of the total electricity consumption in Sweden

(Swedish Energy Agency, 2005). However, the existing knowledge about demand variation is inadequate. Interval (hourly) metering has been used for bigger commercial/industrial users for a long time, providing energy data, having potential to answer many questions and helping to design appropriate EE measures and strategies. There is a potential of at least 30 % decrease in energy use in commercial buildings (Alliance to Save Energy, 2007).

IKEA in Sweden has started a wide energy efficiency project which will last 2006-2009. This is a part of IKEA's social and environmental policy. A primary goal is energy use reduction by 15 % in all IKEA units in Sweden – department stores, warehouses and offices (totally around 50 buildings/units, around 1.000.000 m^2 floor area) (IKEA group, 2005). The first stage of the project included in-depth energy surveys in all IKEA buildings carried out by the energy company E.ON. Though the major focus of the program is energy efficiency (and alternative heating sources), the load demand and demand response issues are interesting both for IKEA and E.ON and will be considered. IKEA Sweden has not participated in DR programs so far. The information on DR issues has been rather limited at all decision making levels. It is expected that with the current energy efficiency programme the DR will become a greater priority for the company. Ventilation and lighting systems in buildings are assumed to be the major DR potentials in this case.

The objectives of the investigation presented in this paper are:

- To develop a detailed load demand analysis of two selected IKEA department stores and to compare it to total load demand of IKEA stores in Sweden.
- To discuss the link between planned energy efficiency and savings measures and DR possibilities.
- To identify and analyse different DR possibilities and constraints at the stores (considering techno-economic and social aspects).

Materials & methods

Both quantitative and qualitative methods are used – detailed demand data analysis and interviews. Two IKEA stores are analysed - one located in Stockholm area, and the second one located in Malmö in the southern part of Sweden.

Data collection and availability

The following review and analysis is based on the hourly electricity use data from years 2004, 2005 and 2006 Jan-Aug. The data was obtained through "Energidialog" (E.ON's interactive database on the web). Outdoor temperature data was obtained from SMHI (Swedish Meteorological and Hydrological Institute).

Data analysis

Several characteristics can be derived when analyzing load on the demand side to describe load demand conditions as (Abaravicius et al, 2006):

- Magnitude of energy use and load demand
- Variation of the demand in time

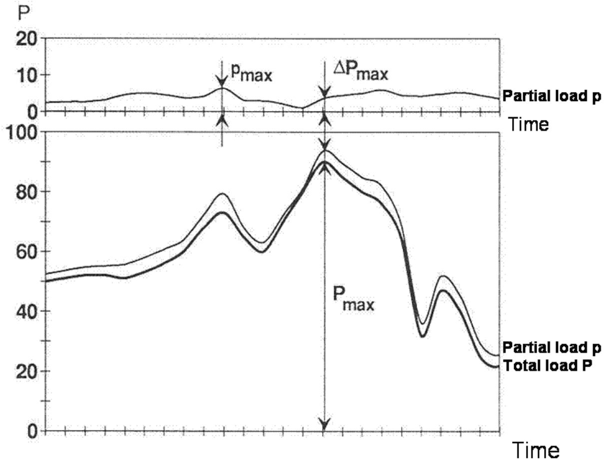

Figure 1. Superposition (Pyrko 2004)

- Minimum and maximum load demand values
- Duration of minimum and maximum load
- Contribution to the company's total load curve

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 (Pyrko, 2004).

The load curve illustrates the variation of load demand during a specific period and can be converted into a load duration curve showing the duration of a particular load demand.

Exploitation time: calculated for a specific object, is a ratio between energy use and maximum load demand during a given period.

The load factor is the ratio of the average load during a specific period of time to the maximum load occurring during that period.

The superposition describes one specific customer's influence on a total utility load curve i.e. the contribution of partial load to the total load. The superposition factor (SF) is the ratio between the partial load demand during the total peak (ΔP_{max}) and the maximum partial load (p_{max}) during the time period being considered (see Fig. 1).

Interviews

The interviews were performed with following stakeholders:

- Facility managers at the selected stores – these employees are responsible for energy use and systems maintenance at the stores.
- Technical manager of buildings' owner IKEA Fastigheter (IKEA Properties) – this employee is coordinating energy related questions of all IKEA buildings in Sweden. Facility managers of each specific building report to him.
- E.ON energy advice – consultants who performed the energy inventory for selected IKEA buildings.

Table 1: Facts about Stockholm and Malmö stores (IKEA, 2006)

	Stockholm	Malmö
Year of construction (extension)	1965 (1998-2001)	1970 (1998)
Area, m^2	55000	24515
Electricity use (2005), MWh	6944 (126,3 kWh/m^2)	3792 (154,7 kWh/m^2)
Subscribed electric load, kW	-	1150
District heating use (2005), MWh	3937	1445
District cooling use (2005), MWh	1364	-

Table 2. IKEA Stockholm is located in Vattenfall's grid area and the fees are following (Vattenfall, 2006)

Fixed fee	Variable fee
Monthly fee – 16 000 SEK/month [1680 EUR/month]	Monthly load fee – 10 SEK/kW, month [1,06 EUR/kW, month] (Highest recorded hourly load demand value during the charged month)
	Monthly load fee (High load demand period) – 27 SEK/kW, month [2,85 EUR/kW, month]
	Transmission fee – 2 öre/kWh [0,21 EUR cent/kWh]
	Transmission fee (high load demand period) – 5 öre/kWh [0,53 EUR cent/kWh]

Table 3. IKEA Malmö is located in E.On's grid area with following grid fees (E.On, 2006)

Fixed fee	Variable fee
Yearly fee: 7000 SEK/year [739 EUR/year]	Transmission fee: 3,9 öre/kWh [0,41 EUR cent/kWh]
Subscription fee: 467 SEK/kW, year [49 EUR/kW, year]	Transmission fee (high load demand period): 6,5 öre/kWh [0,69 EUR cent/kWh]

Energy use in IKEA stores

GENERAL FACTS

There were a total of 13 stores in Sweden in operation during years 2004-2006.

On weekdays IKEA stores are open 10.00-20.00, holidays (weekends) 10.00-18.00. On the last Saturday of every month they are open up to 20.00. The stores are closed 6 days per year (New Year's Eve and Day, Midsummer Eve and Day and Christmas Eve and Day).

Energy to the stores is supplied in forms of electricity and district heating (for heating and hot water). The store in the Stockholm area is also supplied with district cooling. The analysis reported in this report will be limited to focus on electricity use. Total electricity use in all IKEA stores in Sweden in 2004 and 2005 reached around 43 and 46 GWh respectively.

SELECTED STORES (STOCKHOLM AND MALMÖ)

Two IKEA stores, exposed to slightly different climatic conditions, were selected for the further analysis. One is located in Stockholm area (central Sweden) and another one in Malmö city (Southern Sweden).

It was not possible to get the real data on installed capacities of all specific end-uses in the analysed buildings. The facility managers were not able to specify for example the installed electric capacity of the heating system (circulation pumps, etc.).

The store in Stockholm has an installed capacity for ventilation fans reaching approx. 300 kW. In the Malmö case, the manager could not specify the exact installed capacity of ventilation fans. An assumption was made that the installed capacity for ventilation fans in Malmö store was about 150 kW (the store in Stockholm is around twice as large).

The calculated average load demand for lighting in all IKEA stores in Sweden is around 14 W/m^2 (IKEA, 2006). Based on this number, the calculated installed capacity for lighting in Stockholm and Malmö stores are 770 and 343 kW respectively.

The Stockholm store is connected to district cooling system, while the Malmö store uses electricity for cooling. The installed cooling capacity in the Malmö store reaches 1 MW (IKEA, 2006).

Electricity costs

Energy price

The electricity price is fixed for all IKEA stores (no Time of Use or other type of rates). Electricity is purchased from the utility E.ON.

Grid tariffs

The stores are located in different grid areas, belonging to different energy companies.

High load demand period: November - March weekdays 06-22 h. Normal time: April – October all time and November - March weekdays 22-06 h and weekends (holidays)

The Stores' operation schedule

The approximate operation schedule in the analysed stores is following (based on interviews at both stores):

5.00 the product flow starts, transport. 6.00 -7.00 unpacking of goods.

Lighting and ventilation fans are on (ground, basic).

Different personnel start at different hours, staring from cleaning, packing-unpacking goods, administration work.

10.00 store opens

Full commercial lighting and all ventilation fans are on.

Cooling is on immediately after the lights are on in summer (outdoor temp over + 15 °C).

20.00 store closes

Full lights are on for at least half an hour after closure.

Table 4. Electricity use characteristics at IKEA store in Malmö and Stockholm

	Malmö		Stockholm		All stores in Sweden	
	2004	2005	2004	2005	2004	2005
Total use, kWh	3 733 894	3 792 064	6 993 538	6 944 000	42 858 443	46 045 769
Max load, kW	1159	1070	1392	1498	9836	10547
Min load, kW	68	75	64	176	1310	1251
Aver load, kW	425	433	796	787	4879	5256
Load factor	0,37	0,40	0,57	0,53	0,50	0,50
Exploitation time, h	3222	3544	5024	4636	4357	4366

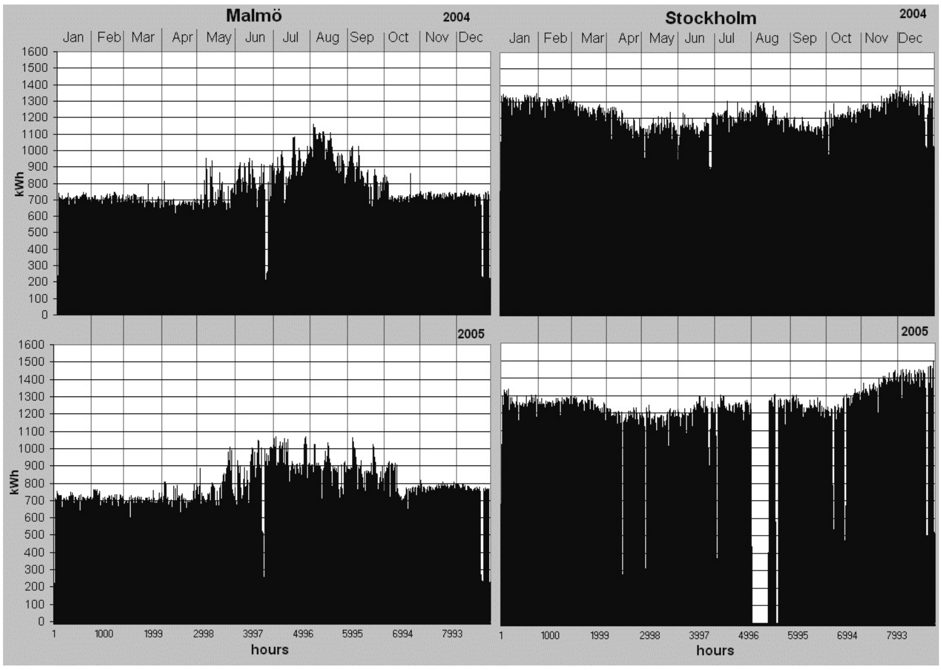

***Figure 2**. Load curves for Malmö and Stockholm stores for the years 2004 and 2005 (some data from Stockholm store is missing in 2005).*

Some ventilation is periodically operating through the night. Electric trucks are charged after 23.00 in Malmö case and in the periods 10-20 and 0-5 in Stockholm case.

Load demand analysis in IKEA stores

In load demand analysis performed within this study some defined tools and factors mentioned previously were used. Load curves, typical load curves and duration curves are based on hourly load data.

Electricity use pattern in the stores is quite constant day by day, naturally dependent on opening hours. The stores have three principal load shapes: (1) operating on weekdays, (2) operating on holidays (weekends) and (3) closed.

Electricity use

Table 4 shows some electricity use statistics and analysis results for IKEA stores in Malmö and Stockholm as well as IKEA Sweden's total electricity use for 2004 and 2005.

In the Malmö case the peak load value in year 2004 was recorded on August, 4th and in the year 2005 it was on July, 30th. In the Stockholm case in the year 2004 it was on December, 3rd and in the year 2005 it was on December, 30th.

Annual load curves

In the Malmö store, the highest load demand values occur during summer months (see Fig. 2) because electricity is used for cooling purposes. Since there is no electric heating, there are no peaks during winter period. The load demand is not correlated to cold outdoor temperature.

In the Stockholm store, the electricity use is rather even all year round. The major end use is for lighting and ventilation system which is relatively independent of the season. Since there is neither electric heating nor cooling, there are no significant peaks during cold winter or hot summer periods.

The major difference when looking at the duration curves of both stores (Fig. 3) is the shape of the curves during highest load hours. In Malmö case, 10 % of highest peak lasted for 87 and 190 hours in 2004 and 2005 respectively. In Stockholm case 10 % of highest peak lasted for 807 and 374 hours in 2004 and 2005 respectively. These numbers show that the Stockholm store's duration curve is more flat during maximum load periods, which is also reflected in the exploitation time values given in Table 4.

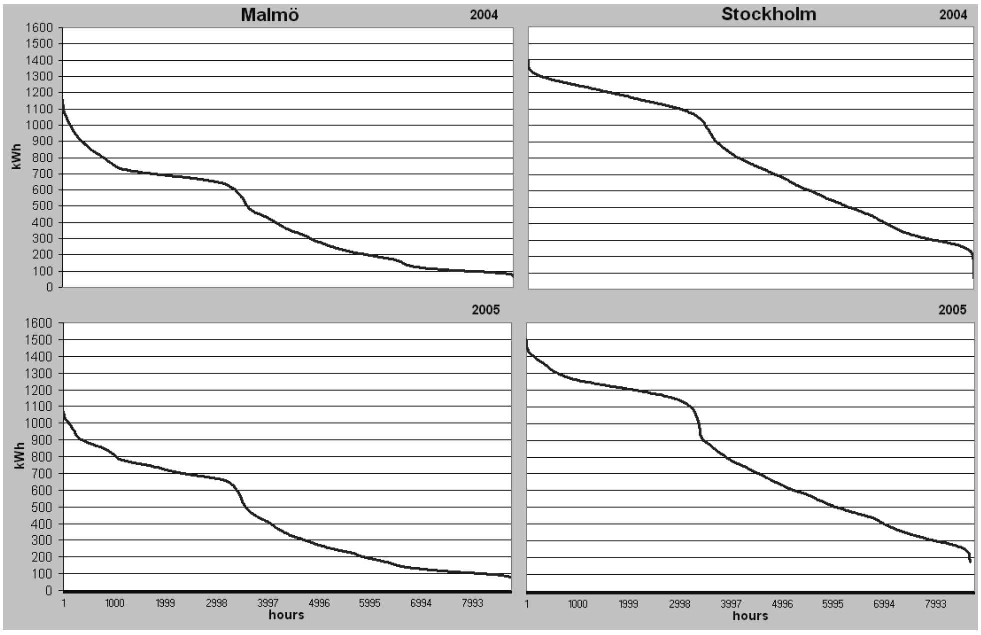

Figure 3. *Load duration curves for Malmö and Stockholm stores for years 2004 and 2005*

Typical daily load curve

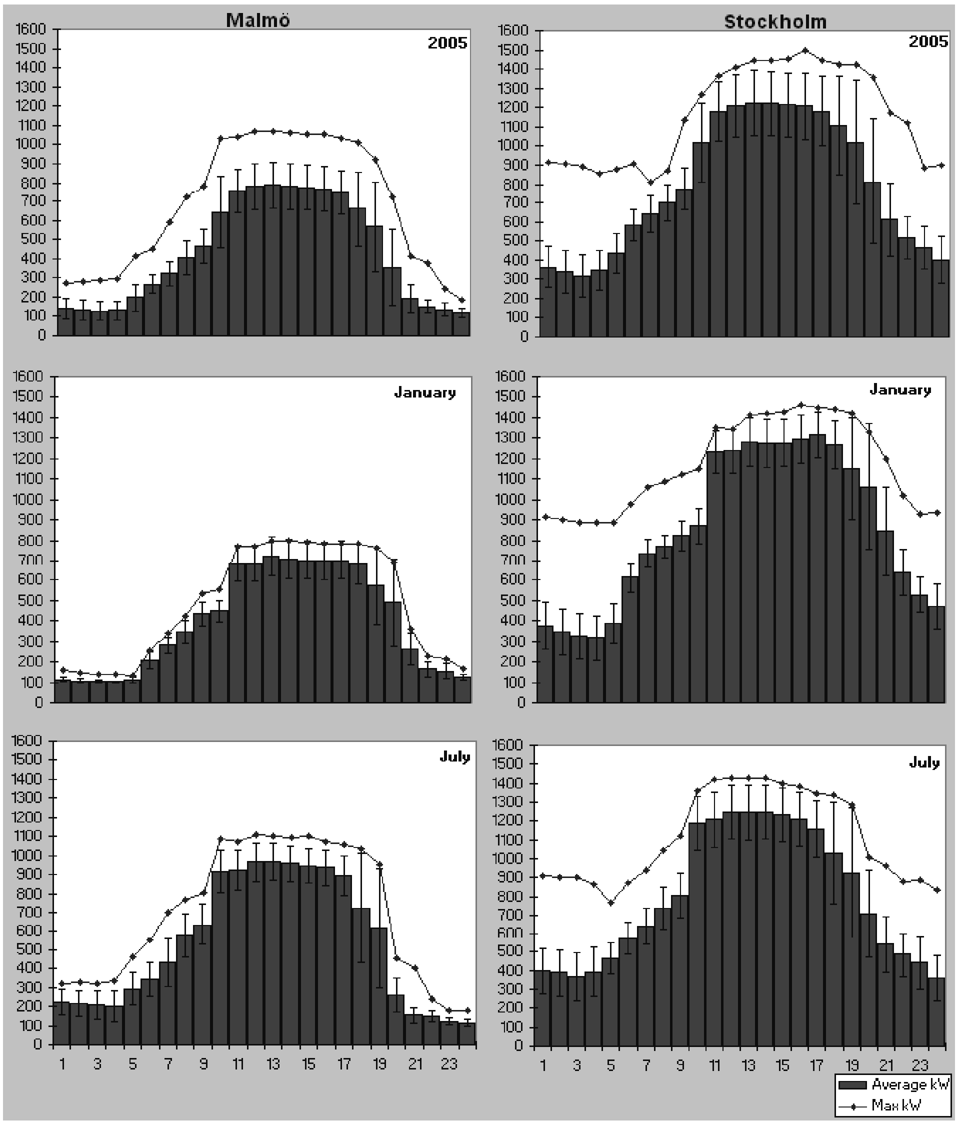

Figure 4. *Typical daily load curves for Malmö and Stockholm stores for year 2005 and for January and July months (based on data from years 2004, 2005 and 2006).*

LOAD DEMAND COMPARISON

Total IKEA stores load in Sweden

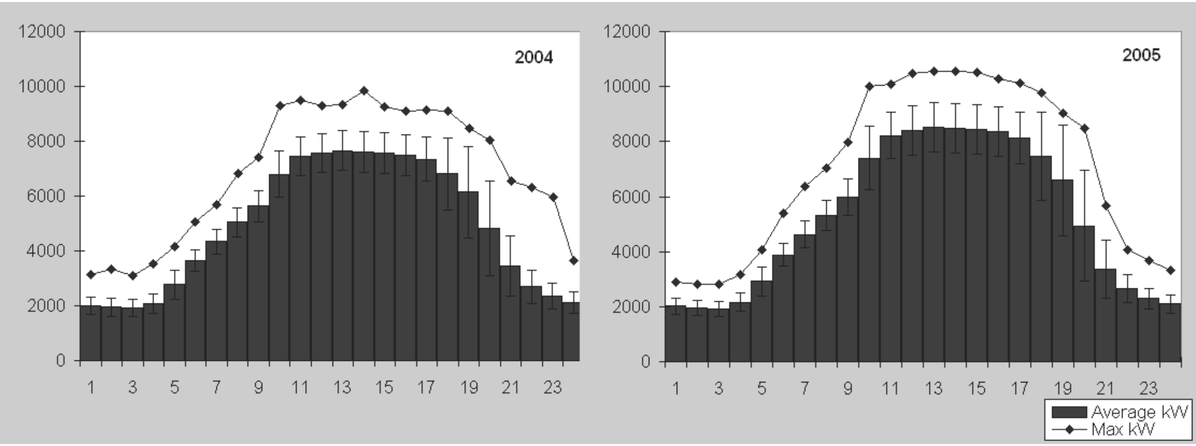

Figure 5. *Typical daily load curves for all stores in Sweden for years 2004 and 2005.*

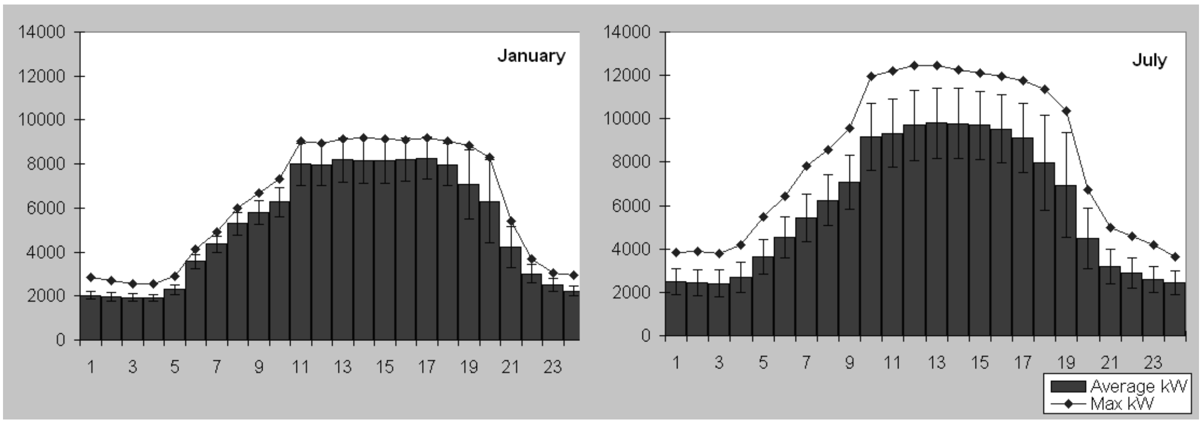

Figure 6. *Typical daily load curves for all stores in Sweden for January and July (based on data from years 2004, 2005 and 2006).*

Peak loads

Peak load values for analysed period were determined. In year 2004 it was August, 4th, in year 2005 it was July, 12th.

All the highest peaks during the analysed period (2004, 2005) occurred in summer. They are related to high outdoor temperatures as some stores are using electric cooling systems.

Dimensionless typical load curves

Hourly load demand data from the investigated objects were used in order to expose the variation of load demand and its deviation from the typical load curve. Figure 7 shows relative hourly load curves (ratio of load demand and average annual load demand) for IKEA Sweden totally and the two investigated stores. The Stockholm store follows the total curve very close. The load curve for Malmö shows about 20 % higher load demand during opening hours, but the load curve shows lower load demand when the store is closed. This difference can be explained by a considerable load demand for cooling during summer months in Malmö.

Malmö and Stockholm stores' contribution to total peaks

The results of superposition factor analysis (as defined before) for data from 2006 show that the highest peak loads in both analysed stores directly contributed to the total peak load of the whole company (see Table 5, the superposition factor = 1). Those peaks occur at high outdoor temperatures during summer.

Load pattern deviations

In order to find periods when the load pattern differs from the typical load curve for the object the hourly load data were used. Figure 8 shows one example of the calculated difference between maximum and minimum hourly load demand during

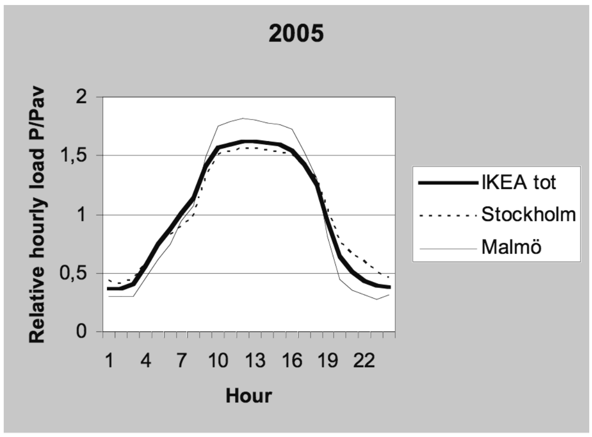

Figure 7*. Dimensionless (relative) hourly load curves for the stores in Malmö and Stockholm compared with IKEA Sweden's total load curve.*

Table 5. Superposition factor calculated for the Stockholm and Malmö stores during 3 highest peaks of all IKEA stores in Sweden 2006

	All stores	Stockholm					Malmö				
	P_{max}	ΔP_{max}	T_{out}	p_{max}	T_{out}	SF	ΔP_{max}	T_{out}	p_{max}	T_{out}	SF
	kWh	kWh	ºC	kWh	ºC		kWh	ºC	kWh	ºC	
2006-07-07 11:00	12444	1350	30,5	1350	30,5	1,00	1079	26,3	1079	26	1,00
2006-07-06 11:00	12281	1346	28,9	1346	28,9	1,00	1071	28,3	1071	28	1,00
2006-07-27 12:00	12272	1410	26,9	1410	26,9	1,00	1070	28,1	1070	28	1,00

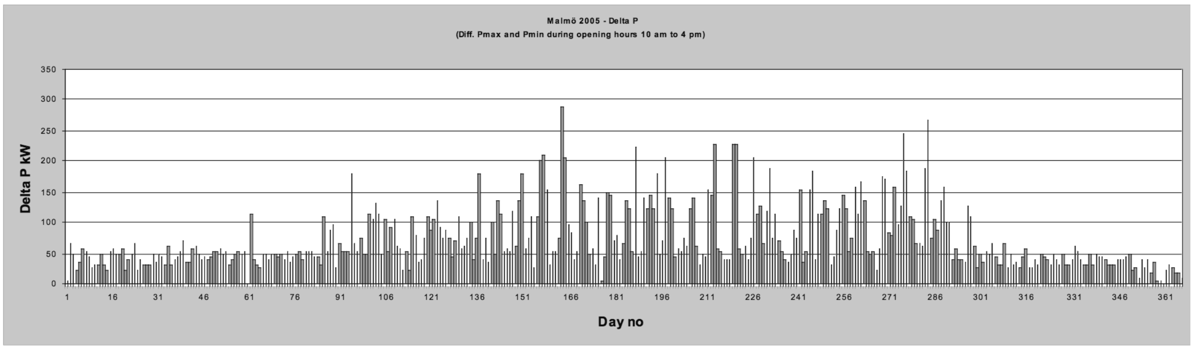

Figure 8. *Difference between maximum and minimum hourly load demand during opening hours 10 am – 4 pm, Malmö 2005.*

opening hours for the Malmö store. This analysis provides an opportunity to find the days and periods when this difference is significantly high, which can reveal the problems that occur in the installations and devices. It can also express that there is a possible potential for load, and thereby energy, savings.

Energy savings and Demand Response possibilities in IKEA stores

The facts and arguments discussed in this part of the paper are based on the information obtained in the recorded interviews with the facility managers of the two selected stores.

DECISION MAKING AND INFORMATION

Energy related decisions are taken by a store "steering committee" consisting of 6 members (store manager, financial manager, interior manager, customer service manager, restaurant manager and personnel manager). The facility (technical) manager is not included, but can give suggestions for approval of the store steering committee. IKEA Properties (in Swedish "IKEA Fastigheter") as an owner of the building also makes energy related decisions and investments. Energy control and automation systems belong to the IKEA properties. The chief administrator and facility manager are representing IKEA Properties.

The major obstacle in energy related decision making is an "interest conflict" between the steering committee and the building owner IKEA Properties. The store management staff pays energy bills and naturally is interested in lowering energy costs. However, they are not motivated to make significant investments in energy efficiency measures or load demand saving as all the equipment belongs to building owner. Therefore, when the "low costs" savings potential is used, there is a dilemma to invest in more expensive measures, (e.g. renovation of ventilating system, improving building insulation, etc.).

IKEA Properties is not aimed at getting profit from IKEA sales; however, all the investments in buildings done by the owner have to be compensated by IKEA sales.

Another constraint is the lengthy decision making process. The facility manager has to wait for the response from the IKEA Properties representatives. One typical example is the question of thermal insulation improvement in the Stockholm store which has been waiting for a decision for about 4 years.

When it comes to everyday maintenance of the building systems, the "conflict" could also arise between the interior staff (personnel responsible for exhibiting and sales) and facility manager. The interior manager and designers naturally prioritize the increase of sales and attraction of the products and not the energy savings, so it is in fact rather difficult to convince them to think in energy saving terms.

The facility managers' knowledge of load demand measures is rather general and insufficient. They acknowledge the importance of the issue and they are aware of possible load problems on national level in future. However, they have not worked with DR questions so far. At present, mostly energy efficiency and energy saving issues are prioritized and space heating is considered to have the biggest saving potential. The managers have no information on DR provided by their electric utilities. However, they believe that they could get this information from energy suppliers if demanded.

Proposed energy savings measures in the stores and possibilities for Demand Response

After energy auditing performed by E.ON, several technical electricity savings or efficiency measures were proposed for both stores (IKEA, 2006):

- *Ventilation system:* installation of frequency converters and pressure controllers for ventilation fan motors, operation time control of ventilation fans.

- *Heating system:* pressure controller and frequency converter for radiator pump, operation time control of circulation pump.
- *Cooling system (Malmö case)*: cooling media pump exchange, pressure control and flow regulation.
- *Lighting system*: time control of lighting and occupancy sensors.

All these efficiency measures have a potential to decrease load demand as well. If the frequency converters would be installed, instead of presently possible on/off control, it could partially decrease the ventilation possibly without significant deterioration of the indoor comfort. The planned operational time control for those systems could be easily adjusted to specific load management strategies.

Low energy lamps are already used in the stores. Separate control channels for different groups of lighting are also used in both stores.

CONSTRAINTS FOR PARTICIPATION IN DEMAND RESPONSE PROGRAMMES

It is difficult to design specific measures which would not interfere with customer comfort and sales, which is the primary function of the store. A general conclusion of the facility managers was that they "cannot turn off more than they do today", or "they found it difficult to find any loads to control". At present, the managers do not see any significant possibilities to save load during peak demand hours as, according to their experiences, any reductions in comfort would be noticed immediately.

The major constraints for participation in DR programs are the following:

- Interference with the main functions of the store
- Slow decision making process
- Required investments in equipment
- Lack of time and resources

The decision to participate in the DR programme should be taken by the store steering committee and IKEA Properties. The work would probably be carried out by technical managers, sometimes even with the help of other employees.

HVAC

According to the managers, there is no possibility to temporarily stop space heating circulation or implement any other measures here. Shutting the ventilation off almost immediately affects the personnel and leads to loud complaints. Installation of converters is recommended as significant energy savings measure; however, it would require significant investments with payback time about 4 years and that is too long in the present situation.

Lighting

Any types of measures on lighting are complicated to perform. It is directly related to the functions of the store. It is possible there could be some short term lighting interruptions for example when the personnel are having a breakfast break or in similar situations. The problem afterwards, however, is that the energy efficient lamps need to warm up before they reach the full lighting capacity.

Other

In the Stockholm store case, load guards were installed in some areas, but could not be used effectively. The trial uses were unsuccessful, as resulted in strong reactions from personnel (there were specific examples from restaurant personnel who complained when the ventilation and some furnaces were off).

In general, there is a lack of motivation to save energy. The sales' staff has no motivation to save energy and has no "connection" to energy use. Any effect on comfort is immediately reported and the better service is demanded.

An interesting example of the energy attitudes and behaviour is the case with heat losses through open goods storage area gates in one of the stores. The facility manager is trying to convince personnel to use sensors to open these automatic gates. The personnel find it more "convenient" to have them constantly open and tend to "cheat" the sensors inventing very "sophisticated" methods to do this.

POTENTIAL DEMAND RESPONSE BENEFITS

Economic benefits for IKEA stores due to load demand savings at present conditions are:

At present tariff situation in the Malmö case one tariff component relate to actual load demand value and could provide economic benefits if the subscribed load level was decreased.

In the Stockholm case, it is also one component in the tariff - monthly load demand fee. It is set according to the highest recorded hourly load demand value during the charged month. Savings, if load demand was decreased, would be different during high load demand and normal period.

In both cases the savings from transmission costs could be achieved by decreasing the overall energy use or shifting part of the use to low load demand period (22-06 hour). The decrease of subscribed load demand for example by 100 kW in the Malmö store would save 46 700 SEK/year (3 890 SEK/month or 428 EUR/month). The decrease of monthly peak demand value by 100 kW in the Stockholm store would save 2 700 SEK/month or 297 EUR/month).

Electricity use in the IKEA stores (as well as in other similar type retail stores) is rather even all year round. The major end use at both analysed stores is for lighting and ventilation systems and their use is relatively independent from the season as the stores do not use electricity for heating and the building envelopes are not designed to use the daylight effectively. Nevertheless, in Malmö store the load peaks during warm summer days are mostly due to electric cooling systems.

Electricity use in the IKEA stores is mostly related to the operating hours of the stores. The highest demands occur between 10 – 20 on weekdays and 10-18 on weekends and holidays. However, the activities in the stores start already from about 5 am and continue at least several hours after the store is closed.

Cold winter weekday mornings (7-9 am) and weekend (holiday) evenings (17-21) are the times when peak load problems normally occur in Swedish electricity system. These are the periods when the demand reduction actions are desirable. Since the stores start the activities already form 5 am, and open only at 10 am, it might be assumed that the potential load control actions between 7 and 9 am would not hasve negative influence for the customers. Weekend afternoons from this point of view are more sensitive, however, after 18 h, when the store is closed (or even earlier), the actions might be possible.

Conclusions

The described demand analysis gives detailed information about load patterns in department stores. Electricity use in the stores is quite constant day by day but naturally dependent on opening hours. The stores have three principal daily load shapes: (1) operating on weekday, (2) operating on holiday (weekend) and (3) closed.

The analysed differences between minimum and maximum load demands could be treated as indicators of possible technical problems resulting in energy losses. The next step should be the clarification of what is behind those specific peaks. This analysis gives an opportunity to find the days and periods when this difference is significantly high, which can reveal the problems that occur in the installed devices. It can also send a signal that there is a potential for load (and thereby energy) savings.

Load demand on yearly basis is more constant at the Stockholm store. In the Malmö case the values are higher in the summer time due to the use of electricity for cooling, while the Stockholm store is connected to a district cooling system.

Both stores are normally contributing to the total demand peaks of all IKEA stores in Sweden. In the Malmö case it is slightly more significant.

The interviews of IKEA personnel explained specific factors behind energy use pattern. Low economic motivation, "interest conflicts" between building owner and sales representatives, lack of information from energy supplier are identified as the major constraints for DR.

There are some theoretical possibilities of cost savings due to a decreased subscribed load value in the Malmö case, and a decreased maximum peak in the Stockholm case. The researchers suggest that IKEA should consider the possibility of renegotiating their electricity supply contract with E.ON, with special conditions for specific stores.

Already planned energy efficiency improvements have the potential to increase demand responsiveness as well.

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