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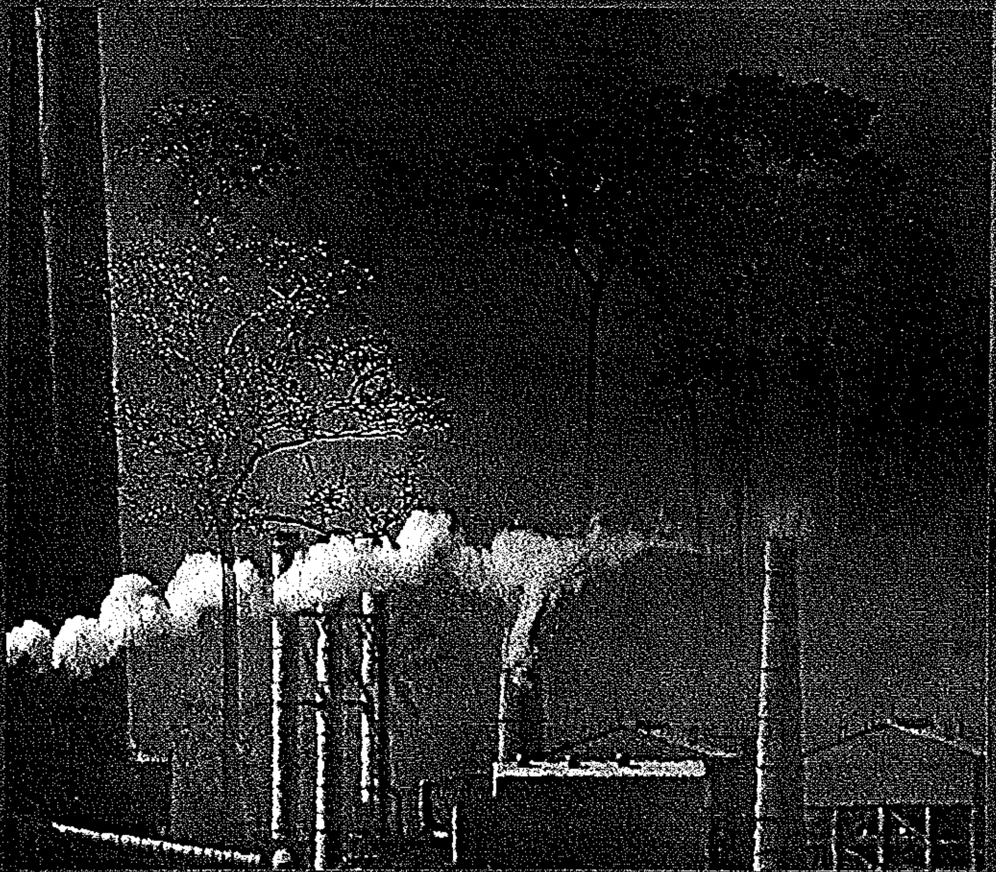

De oorsprong van CO_2-emissies ten gevolge van energieconversie

een analyse van wieg tot graf

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Administratie - Redaktie:
KBVE, VUB - TW
Pleinlaan 2, 1050 Brussel
tel: (02) 629 28 19

Verantwoordelijke uitgever:
X. van Merris, Algemeen voorzitter
VUB - TW- KBVE
Pleinlaan 2
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De oorsprong van CO_2-emissies ten gevolge van energieconversie: een analyse van wieg tot graf

Methodologie

Specifieke verbruiken en afnamepatronen

CO_2 en energiedragers

Productiemix en afnamediagrammen

Externaliteiten

Survey of specific electric consumptions and consumption profiles of domestic appliances

Tony Van Gestel, Bart De Moor, Lieven De Lathauwer, Philippe Lemmerling, Jeroen Buijs and Wouter Favoreel, research group ESAT-SISTA, Dept. of Electrical Engineering, Katholieke Universiteit Leuven
Lucien Vanderick and André Deprêter, LABORELEC (Electrabel)
Luc Hoornaert and Marc Crepel, ELECTRABEL

Keywords: electric consumption, consumption pattern, seasonality, domestic appliance

Samenvatting

In deze studie werd het huishoudelijk elektriciteitsverbruik in de residentiële sector gedetailleerd onderzocht. In de studie werd gebruik gemaakt van kwartuurmetingen van de elektrische deelverbruiken in de lage-energie woning Pleiade en van kwartuurmetingen van het totale elektriciteitsverbruik van een representatief staal van 250 residentiële klanten in België. Gedurende het eerste stookjaar werd de Pleiade woning elektrisch verwarmd met een gemengde accumulatie- en directe verwarming, gedurende het tweede stookjaar werd verwarmd met een bivalente gas- en directe elektrische verwarming. De meetgegevens van de verbruiken van de twee stookjaren laten toe het energieverbruik en de CO_2- emissie voor beide systemen te vergelijken. In een tweede fase van het project werden de verbruikspatronen van de verschillende toepassingen in de Pleiade woning bestudeerd. Dit leverde interessante informatie op zoals bijvoorbeeld wanneer de toestellen gebruikt worden en wat hun aandeel is in het verbruiksprofiel van het totale elektriciteitsverbruik in Pleiade. Deze studie werd afgerond met een onderzoek naar het verbruikspatroon van het totale huishoudelijke elektriciteitsverbruik in de residentiële sector. De residentiële klanten werden onderverdeeld in vier categorieën: klanten met accumulatieverwarming, met directe verwarming, met elektrische boilers en klanten zonder elektrische verwarming. De verbruiksprofielen uit deze studie worden gebruikt in de programma's VERBCO2 en Promix, die ontwikkeld werden in het kader van het CO_2-project.

Introduction

In this survey a detailed study of the electricity consumption in the residential sector was made. Based upon detailed measurements of the gas and electricity consumption of the heating installation in the low-energy dwelling Pleiade [1,2], a comparison was made between gas and electric heating. Secondly, the consumption patterns of the domestic appliances in the Pleiade dwelling were studied in more detail. Finally, the electricity consumption of four important consumer categories was investigated based upon an extended survey directed by Electrabel N.V. The four categories are: residential clients with electric storage heating, clients with direct electric heating (but without storage heating), clients with electric boilers for hot water production (but without electric heating) and finally all other clients, i.e., all clients without electric heating or electric hot water production.

This paper is a summary of the results presented in [3] and is organized as follows. In the next Section the comparison between the energy consumption of the gas and electric heating in the Pleiade dwelling is made. In the third Section, a detailed survey of the energy consumption in the Pleiade dwelling is made. In the fourth Section, the energy consumption of the 4 categories is discussed. Conclusions are drawn in the last Section.

Comparison between gas and electric heating in the Pleiade dwelling

The Pleiade dwelling was heated with mixed storage and direct heating during the 1995-1996 heating season and was heated with a bivalent natural gas and direct electric heating during the 1996-1997 heating season. By using both the measurements of the electricity consumption of the electric heating and of the gas consumption of the gas heating, both heating systems are compared concerning the energy consumption and the CO_2-emission.

The energy consumption is compared with respect to the following coefficient [3, 4, 5]:

$$C = \frac{\text{kWh}}{W_{\text{nom}} \cdot \text{annum}},$$

which is called the specific consumption per Watt nominal heat loss and per annum. The specific consumption is the total energy in kWh needed for the heating of the dwelling. The specific consumption is divided by the nominal heat losses of the dwelling under a standard temperature difference between the outside (T_{out}) and the inside (T_{in}) temperature. The dimensions of the coefficient are kh/annum. For a dwelling in the Belgian climate zone II, the heat and ventilation losses can be written as $P_{th}(T_{in} - T_{out}) = P_{th}$ 30K. For an average heating season in this climate zone, the number of degree days (this is the sum of the temperature difference over all days in the heating season) is equal to 2066 Kdays. Hence, ideally the coefficient is:

$$C = \frac{P_{th} \cdot 2066\, K_{day} \cdot 24h}{P_{th} \cdot 30\ K \cdot annum \cdot day} = 1.653\ {}^{kh}\!/_{annum}.$$

...eat losses of the heating increase the coefficient, while overnight temperature reduction and solar gains decrease the value of the coefficient.

For the Pleiade dwelling, the coefficient was calculated as follows. The electricity consumed by the mixed storage and direct electric heating was measured during the first heating season (1996-1997) and the total amount of consumed electricity was calculated. During the second heating season (1997-1998), both the amount of consumed natural gas and the amount of consumed electricity of the bivalent heating were measured. For the amount of natural gas, an equivalent amount of kWh was calculated. Both total (equivalent) specific consumptions ...re normalized towards the standard ...verage 15/15 heating season. Given W_{nom} [1, 2], $C_{elec} = 1.13$ and $C_{gas} = 1.33$ were obtained. This indicates that the mixed electric heating system is more efficient, which can be partially explained by the fact that with electric heating, specific rooms of the dwelling are heated, while with the gas heating zones of the dwelling are heated, and hence, more energy is consumed.

In [6], the CO_2-emission per kWh for two scenarios was calculated: for the scenario of the year 1997 and of the year 2005. For the consumption of natural gas by the bivalent heating, the emission of CO_2 per Nm^3 natural gas was obtained from literature. For a standard heating season, the calculations resulted in the following emis-

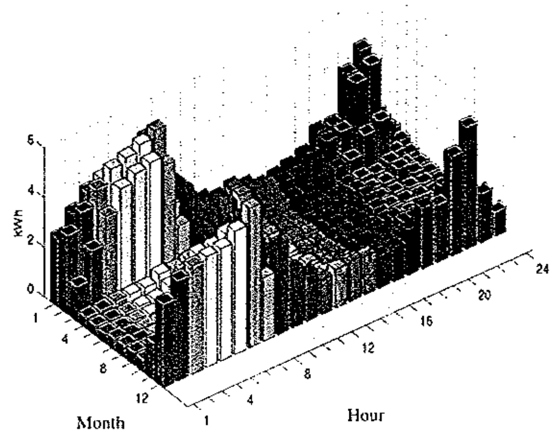

Fig. 1: Consumption pattern of the total electricity consumption in the Pleiade dwelling (electric heating included). Both the daily patterns and the seasonality pattern are dominated by the electric heating.

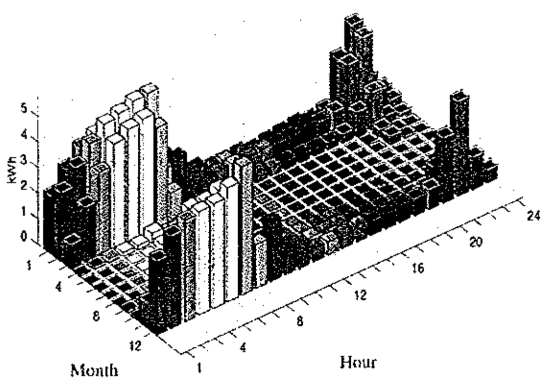

Fig. 2: Consumption pattern of the mixed storage/direct electric heating in the Pleiade dwelling. The consumption follows the heating season. For reasons of efficient energy use, the storage heating accumulates the energy at the end of the night.

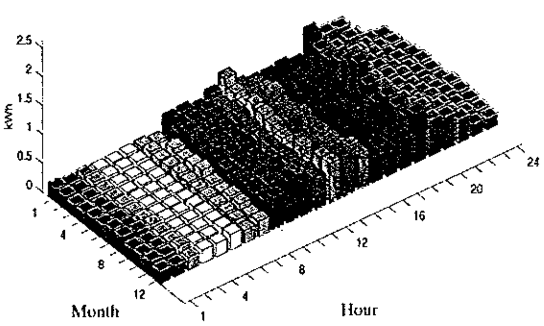

Fig. 3: Consumption pattern of the large domestic appliances: the consumption peaks in the morning and early evening. The relative important consumption during the night is due to the fridge and freezer.

sions: 2478 kg (2408 kg) CO_2 in the 1997 (2005) scenario for the bivalent gas - electric heating and 2863 kg (2388 kg) CO_2 in the 1997 (2005) scenario for the mixed electric heating. In the 2005 scenario, the CO_2-emission of electricity is lower than in 1997, because of changes in the production plants. The difference between both heating systems concerning the CO_2-emission is not significant in the 2005 scenario.

However, extrapolation of these results towards all Belgian residential clients should be interpreted carefully, since one of the main goals in designing the Pleiade dwelling was the minimization of the energy consumption. In most Belgian houses, the efficiency of the heating installation is expected to be significantly lower, e.g., because of overdimensioning and irregular maintenance.

Electric consumption patterns in the Pleiade dwelling

In the Pleiade dwelling, the partial electricity consumptions of the different appliances are monitored in detail. The most important partial consumptions are: the washing machine, the dishwasher, the tumble drier, the fridge, the freezer, the cooking appliances (inductive cooking ring, oven and microwave oven), the sockets (TV, radio, hi-fi, alarm clock, ...), the lighting and the ventilation. The electricity consumption of all these appliances is integrated and read out at each quarter of an hour, resulting in a detailed database of the time dependency of the consumptions. These time dependencies were studied on a daily, weekly and monthly basis. Studying the daily and weekly dependencies reveals at which time of the day and on which day of the week, respectively, the appliances are used. The seasonality of the consumptions is studied by comparing the consumption patterns of the different months. The seasonality indicates how much the consumption of the appliance is related to the season of the year.

In Fig. 1, both the daily and monthly dependencies of the total consumption in the Pleiade dwelling are depicted. On the x-axis, the different months are labeled from 1 (January) to 12

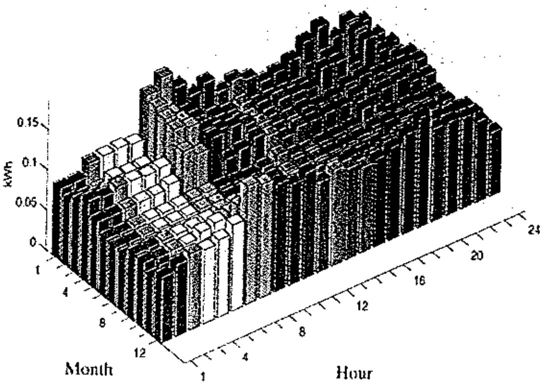

Fig. 4: Consumption pattern of the ventilation: the ventilation in the Pleiade dwelling is relatively less important. The pattern follows mainly the heating season.

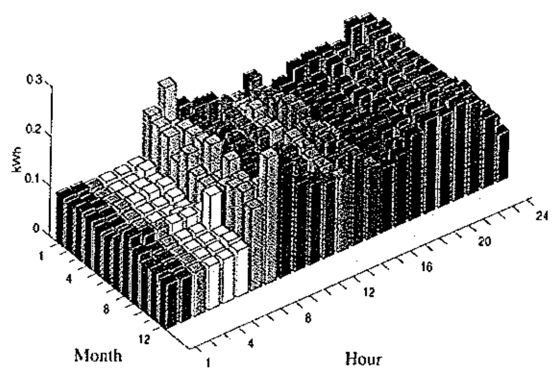

Fig. 5: Consumption pattern of the sockets: the main consumption of the sockets are the electrical and electronic appliances (TV, hi-fi, etc.). The consumption clearly peaks in the early morning and in the evening. There is a relatively important consumption during the night, which is explained by the consumption of the measurement apparatus and by the consumption of appliances which remain stand-by all over the time.

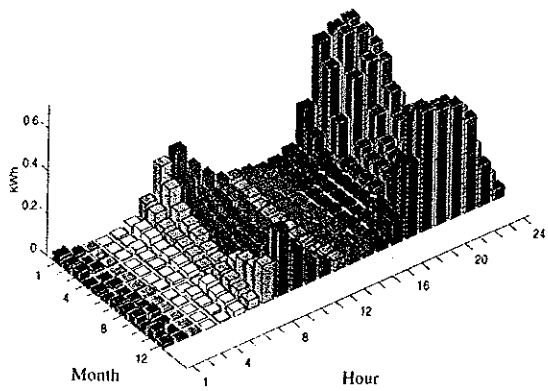

Fig. 6: Consumption pattern of the lighting: together with the electric heating is the lighting the most important source of seasonality in the Pleiade dwelling.

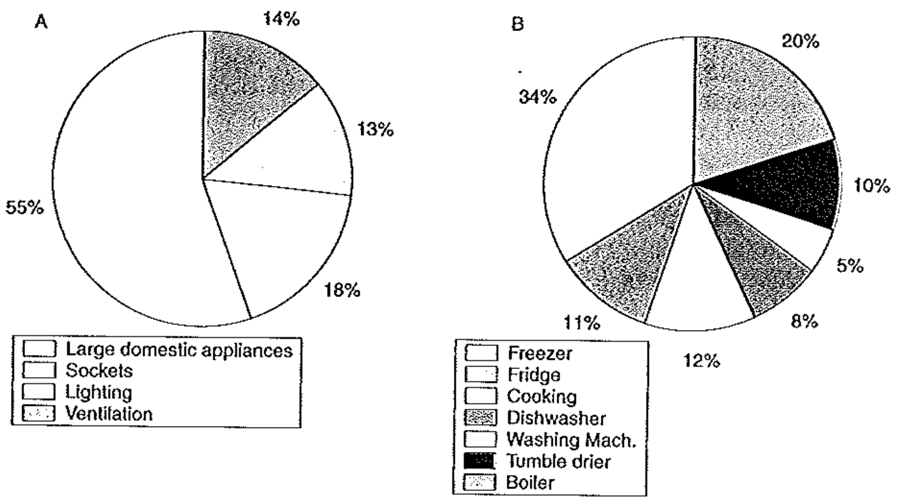

Fig. 7: Relative share of the different appliances.
A: relative importance of the non-heating consumptions: large domestic appli- ces 55%, sockets 18%, lighting 13% and ventilation 14%. The large domestic ppliances consume the largest part of non-heating domestic energy consumption.
B: Relative share of the different large domestic appliances: freezer 34%, fridge 11%, cooking appliances 12%, dishwasher 8%, washing machine 5%, tumble drier 10% and the small electric boiler 20%. The combination of fridge and freezer consumes almost one half of the consumption of all large domestic appliances. The consumption of the small electric boiler in the kitchen is also important. Appliances like the washing machine and the tumble drier have a large peak consumption, but their average consumption is rather low with respect to that of the fridge and the freezer.

(December), while the 24 consumptions of the 24 hours of the day are labeled from 1 to 24 on the y-axis. The corresponding total consumption in kWh for month x and hour y is depicted on the z-axis. The total consumption of Fig. 1 is the sum of the consumption of the heating (Fig. 2), the large domestic appliances (Fig. 3), the ventilation (Fig. 4), the sockets (Fig. 5) and the lighting (F 6). These figures illustrate that th main causes for seasonality in the Pleiade dwelling are the electric heating and the lighting. Also note the non-zero consumption during the night: this is explained by the consumption of the fridge and freezer, the consumption of the measurement apparatus and the slumber consumption, which is the sum of small consumption of LED's, clocks and stand-by appliances. Each of these consumptions is small, but they are present in many modern electrical appliances and their sum is an important, but almost hidden consumption. The consumption patterns are used in the program VERBCO2, which was developed by research group 3 in phase 1b of the CO_2-project.

The relative contribution of the four subgroups (without heating) in the total consumption is shown in Fig. 7.A. This pie chart illustrates that most of the electricity is consumed by a relatively small number of appliances. Also the ventilation has a rather important contribution; this is due to the high isolation with controlled air conditioning (and heating in the case of the bivalent heating) in the Pleiade dwelling. The relative contribution of the different large domestic appliances is shown in Fig. 7.B. This figure illustrates the important contribution of the consumption of the fridge and freezer to the total consumption. Together, they consume 45% of the total consumption of the large domestic appliances. In Pleiade, a small electric boiler was placed under the sink in the kitchen for the local production of hot water. This electric boiler has an important electricity consumption.

Residential electric consumption patterns

The survey was concluded with investigating the daily, weekly and monthly consumption patterns of the total consumption of the four categories defined in the introduction: storage heating, direct heating, boilers and other clients. The database consists of quarter hour measurements of a representative sample of 250 residential clients in Belgium. These measurements were extended with an inquiry concerning demographical issues and concerning the electric appliances used by the consumer. By statistical differencing, consumption profiles were obtained for the storage and direct heating and for the electric boilers. The resulting profiles are depicted in the way as above. The profiles of the consumption patterns depicted in Fig. 8, 9, 10 and 11 correspond to the consumption of the appliance storage heating, direct heating, boilers and all the other (domestic) appliances respectively. These profiles are used in the program Promix, which was developed in the framework of phase 1b of the CO_2-project.

The consumption pattern of the appliance Storage Heating in Fig. 8 shows that the storage heating starts reloading (accumulating) in the first part of the night. Since heat is lost in the second part of the night, it would be better to start reloading as late as possible within the night period with tariff reduction, as in Fig. 2 in Pleiade. The consumption of the appliance electric boilers (Fig. 10) peaks when the reduced tariff period starts, which is again not optimally from the viewpoint of minimal energy consumption. The consumption of the clients with Other Appliances but no electric heating or electric boilers shows a morning, noon and evening peak. The evening peak is the largest during the winter season, mainly due to the lighting. However, the lighting is only responsible for about 50% of the seasonal variation in the daily consumption of this category. Other factors explaining the seasonal variation are holiday seasons and the seasonal dependent use of appliances, e.g. the seasonal use of tumble drier.

Conclusions

In this survey, the electricity consumption of the residential clients in Belgium was studied. In the first part of the study, the electricity consumption in the Pleiade dwelling was analyzed. A comparison between a mixed storage and direct electric heating and a bivalent gas and direct electric heating was made, indicating that electric heating consumes less kWh than the bivalent heating. In 2005, the CO_2-emission of both heating systems is not significantly different. Investigating the consumption pattern of the different electric appliances yields that the seasonality of the total consumption pattern in the Pleiade dwelling is caused by the electric heating and the lighting. An important conclusion is also that there is an important slumber consumption from the measurement equipment and from the stand-by of several (small) appliances. A survey of the electricity consumption of the residential clients in Belgium is made and consumption patterns are estimated for the appliance storage heating, direct heating, electric boilers and for the sum of all other appliances. These consumption profiles are compared with those of the Pleiade dwelling. This comparison learns that there are significant differences between the consumption patterns, concerning e.g. the time of day when the storage heating is reloaded or the seasonality of the consumption. The consumption patterns are used by the programs VERBCO2 and Promix, which were developed in the framework of the CO_2-project.

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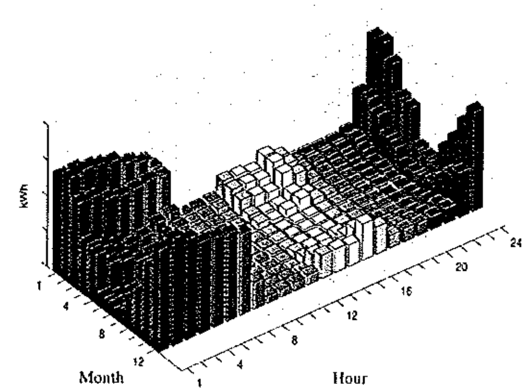

Fig. 8: Consumption pattern of the appliance storage heating. Note that the accumulation of energy starts in the beginning of the night. Contrary to the heating in the Pleiade dwelling (Fig. 2), the accumulation is not shifted towards the end of the night.

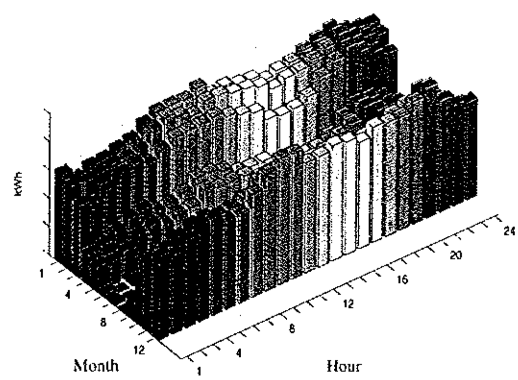

Fig. 9: Consumption pattern of the appliance direct heating. The seasonal dependency is explained by the heating season, while the daily pattern is explained by the presence of the inhabitants.

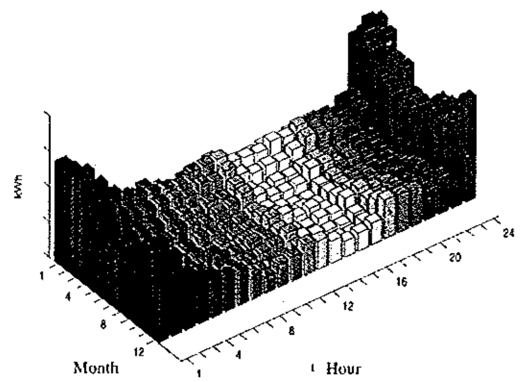

Fig. 10: Consumption pattern of the appliance boilers. This pattern clearly shows that the water is mainly heated at the beginning of the night, when the price of electricity is lower.

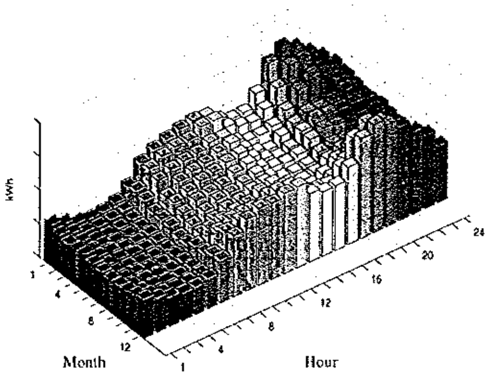

Fig. 11: Consumption pattern of the total consumption of all the other appliances. The seasonality of these appliances is partly explained by electric lighting and partly by seasonality of the usage of the appliances.

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