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Electric load behaviour and DSM potential of office buildings

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ABSTRACT

Due to the rising use of fluctuating renewable energy production, electricity production curve in the future will not be able to follow the demand curve anymore. Therefore, time-critical, variable charges are likely to be introduced. Whereas large consumers of electricity already have to pay attention to this issue – the peak demand is measured and cost effective for customers with a consumption higher than 100,000 kW h or connection power more than 50 kW [1] – the topic will become relevant for other customers in the future. Due to the roll-out of smart metres, it is very likely that time-relevant tariffs will become standard for all kinds of users, which means that the moment of electricity consumption will be cost-relevant. This paper deals with the electric load behaviour of office buildings and their potential to use demand side management (DSM) to optimise load behaviour. Because of use during the day, when prices are usually higher than during the night, office buildings mainly demand electrical energy during periods of high prices. By identification and utilisation of DSM potential, considerable sections of the demand can be shifted to hours with lower prices. Concerning integration of photovoltaic systems, two aspects has to be taken into account. When PV is an additional option to reduce electrical energy demand during high prices, on-site produced electricity should be also used on-site and therefore it has to be assured, that demand does not fall below PV-production. Another possibility to shift loads is to use thermal or electrochemical storage systems.

1. Introduction

Electric energy cannot be stored large-scale without transformation into another form of energy (e.g., chemical, thermal, potential). Therefore, it is necessary to have a balance between the provided power from producers and the power required by consumers at any point of time. At present, this balance is mainly reached by adjusting the production to the required power level. Due to the rising amount of renewable energy generation facilities, a paradigm change is foreseeable, and this issue will be transferred, at least partly, to the customers in the medium-term future. Facilitating the load shifting potential of customers is commonly called demand side management (DSM).

Due to the fact that demand charges are obligatory for consumers with an annual consumption above 100,000 kW h or a connection power higher than 50 kW, DSM is now mainly used in the industrial sector [1] The expansion of the load profile measurement to all consumers [2] allows the usage of time-related, load-critical tariffs for all customers.

Energy prices at electricity stock exchanges are built separately for each hour. As the price is always created at the equilibrium of supply and demand, when normally the demand is higher during daytime than nighttime, electricity is expected to be more expensive in the daytime. This assumption is confirmed by a look at the historic price patterns at the Energy Exchange Austria [3].

Within this context, the load behaviour of office buildings has been developed on the basis of an example building with various variants of applications and building physics characteristics. In a further step, the DSM potential of the building and the resulting interdependencies and cost effects can be analysed.

2. Methodology

2.1. The building

The basis for the load profile development is a standard office building with three floors with identical plans, according to Fig. 1 [4]. The floors each consist of an open-plan office and several individual and team offices, a staff room, and traffic areas (corridor, staircase). The *U*-value of the opaque building envelope (vertical

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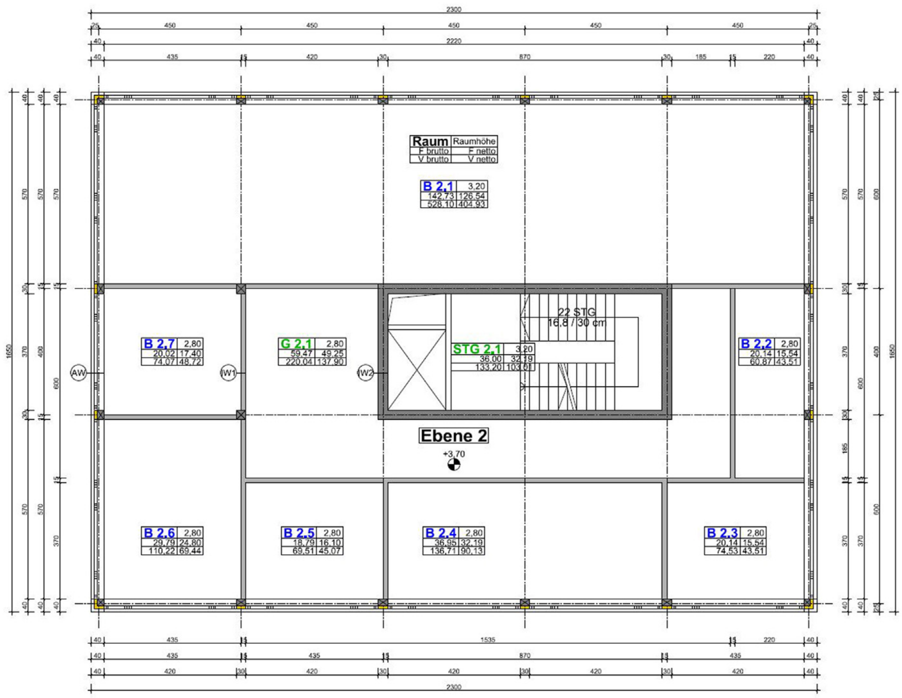

Fig. 1. Floor plan of the standard office building [4].

as walls and horizontals as floors, roof) was set with 0.15 W/m^2 K, those of the windows with 0.7 W/m^2 K, and a 60% share of the building envelope.

2.2. Electrical consumers

According to Brauner et al. [5] electrical consumers can be classified into three categories according to their potential for load shifting.

Devices that can use any sort of internal or external storage mechanism can often be used in a timely flexible way without influencing the core benefit. Refrigerators, for instance, work within a specific temperature range and can be operated time-flexibly within this range.

Applications whose operation is chronologically non-critical offer another option for the utilisation of DSM potential. Here, it is usually important to have a certain result at a given moment (e.g., dishes are cleaned next morning), but not when the process that leads to the result occurs. Nevertheless, the specific requirement has to be taken into account. For example, dishwashers, which are used in continuous operation in gastronomy, are not suitable for DSM.

Electrical consumers with a high connection between function and moment of operation are not suitable for DSM (e.g., lighting). Nevertheless, efficiency measures among these consumers do influence the load behaviour of the whole system as well.

Electrical load curves were generated for three different versions of technical building equipment. Variant A represents a building for which, as far as possible, applications without DSM potential – that means with a high connection between function and moment of operation – were used (e.g., desktop computers rather than laptops). Heat supply is achieved with a non-electrical heat producer and there is no active cooling in summer.

In Variant B, devices with DSM potential (either with internal storage mechanism or chronologically non-critical operation) were used whenever possible. Workplaces are equipped with laptops, which can switch to battery operation during times of high electricity prices. Heat supply is managed, to a great extent, by electricity (air–water heat pump), and, in summer, the temperature of the building is lowered by a compression chiller.

Variant C is quite similar to Variant B, only some energy-saving potential was realised (free cooling when the outside temperature was less than the room temperature, and high-efficiency electric lighting).

Other power consumers (phones, printers, projectors, cookers, dishwashers, refrigerators, auxiliary energy of air conditioning, and hot water supply) were modelled independently from the technical building system equally in each variant. Nevertheless, interdependencies were taken into account (e.g., production curve of heat supply influences the load curve of auxiliary energy).

2.3. Virtual electricity price

Hourly rates of electricity at the Energy Exchange Austria (EXAA) must be considered as only energy prices. End customers have to pay network charges, taxes, and other charges. Within this work, the electricity price with all its components (energy price, grid utilisation, and network loss charges, taxes, and other charges) is considered variable according to the fluctuation of the energy price. Therefore, all further analysis was made based on the stock exchange prices at EXAA. As there is only one price component included, no conclusion about real prices is possible. Despite that, prices of different moments can be evaluated in relation to each other. For all considerations, the stock exchange prices of 2008 were used [3].

2.4. Compilation of the load curves

According to ElWOG [1], for the calculation of load-dependent grid utilisation and network loss, charges for large-scale consumers are averages of every quarter hour. Therefore, this method is used for further investigation as well. Synthetic weather data for a year in Graz was set with the building simulation tool TRNSYS 16, and used for all load curves. It consists of data for global irradiation and

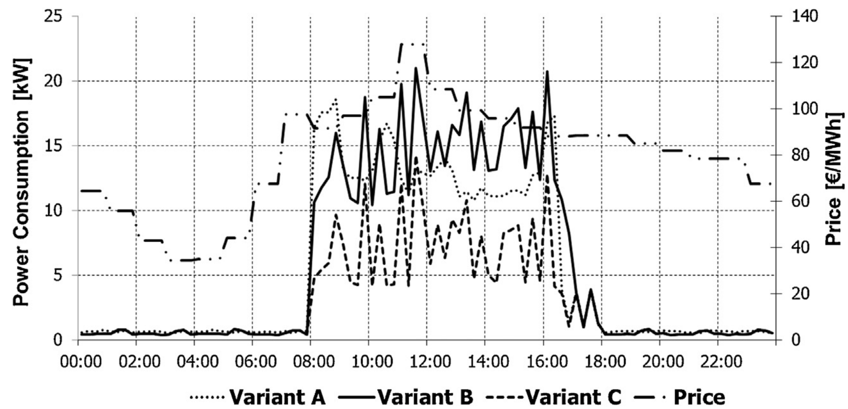

Fig. 2. Standard load curves without utilisation of DSM potential on a summer day.

outside temperature for each period of 15 min. In addition, with TRNSYS 16, a thermal load curve for each building variant before and after optimisation was built [6].

The user behaviour, in particular the presence of the employees at their office desk, was simulated with a random matrix and retained for each variant. Numbers from the literature were used for the coefficients of likelihood, for example 0.7 [7] for the presence of an employee in an individual office. This means that the user spends 70% of his working time in his office using the infrastructure there. Outside of these usage periods, depending on the time of day and the settings of the device, the electric devices can remain active, in a mode of reduced power consumption (sleep-mode) or in power off-mode. The working time was set from 08:00 am to 4:30 pm.

The load curves for each appliance were created using data from the literature, combined with user behaviour (plus some weather data). The load curve for the whole building is the result of the sum of the load curves for the single appliances in the respective variant. An example of this process will be shown exemplarily in the following for the lighting of an individual office.

According to DIN 18599-10 [7], the minimum illumination at office workplaces is set at 500 lx. The electric valuation power is the basic value of the load curve for lighting. It is defined as the connected power of the lighting installation in the respective area and is given as a specific unit in W/m^2. For very efficient concepts, it reaches approximately 8 W/m^2 [8]. To determine the natural illumination in buildings, the coefficient of daylight is helpful. It is defined by the illumination at a certain point at a specific level in the building in relation to the horizontal illumination outside with the unspoiled celestial globe. [9]

The coefficient of daylight can be determined as an average value for a room or a control area within the room, with the help of light simulation software (here DIALUX 4.9). The horizontal illumination with the unspoiled celestial globe can be derived approximately from the global irradiation by multiplication with the factor 125 [10]. The efficiency of the lighting control system is ultimately considered with a factor based on DIN 18599-4 [9]. This factor identifies the chance that lights are turned off when the user is absent or when there is an adequate supply of daylight. For example, there is a difference between the coefficients of manual lighting control and control with the help of a presence sensor. In addition, it was specified that if the lighting was turned off by a user, it would only be turned on again if natural illumination was lower than the minimum illumination. Due to that, the viewed interval is influenced by the previous interval. With this information, the electric load consumption for each 15-minute period can be identified.

2.5. Standard load curves

The summarised standard load curves for the different versions of technical building equipment without the utilisation of DSM potential is shown in Fig. 2 (summer day) and Fig. 3 (winter day), as well as the virtual electricity price for each hour. It can be seen that, in all cases, the majority of the electric energy is consumed during the daytime, when the price is typically higher than in the nighttime.

3. Optimising potential

3.1. Variant A

With Variant A, only the load shifting potential of refrigerators and dishwashers are usable. In addition, the hot water circulation pump is turned off when the building is not in operation. For lighting, automatic dimming is taken into account, which means that only the difference between natural illumination and required illumination must be provided by the lighting system. Figs. 4 and 5 show the effect of these measures for a summer day and a winter day.

The total consumption drops, mainly due to the optimisation of the lighting control from 26,292 kW h/a to 21,710 kW h/a. The virtual electricity price after optimisation is 7.75 ct/kW h (7.95 ct/kW h before). Virtual annual costs are €1683 (€2090 before).

3.2. Variant B

In addition to the optimisation actions of Variant A, Variant B utilises the storage capacity of the laptops. Furthermore, according to Bukvic-Schäfer [11], the thermal storage capacity of the building itself is used. During the heating period, the building is preheated to a higher temperature level outside the operation time, which leads to a lower power consumption during the high-tariff period in the daytime. During the cooling period, the procedure works conversely, so that, during the night, the building is chilled down to reduce the consumption during the day. Figs. 6 and 7 show the modification of the load curve due to these measures.

The overall consumption changed only slightly (optimised 37,791 kW h/a, standard: 38,405 kW h/a), such that the two effects nearly offset each other. On the one hand site, the improvement of efficiency in lighting leads to lower energy consumption. On the other hand, the preheating and cooling of the building causes higher temperature differences and the energy for heating and cooling raises from 18,720 kW h/a to 22,442 kW h/a. Due to the lower virtual price (6.31 ct/kW h rather than 8.09 ct/kW h), the

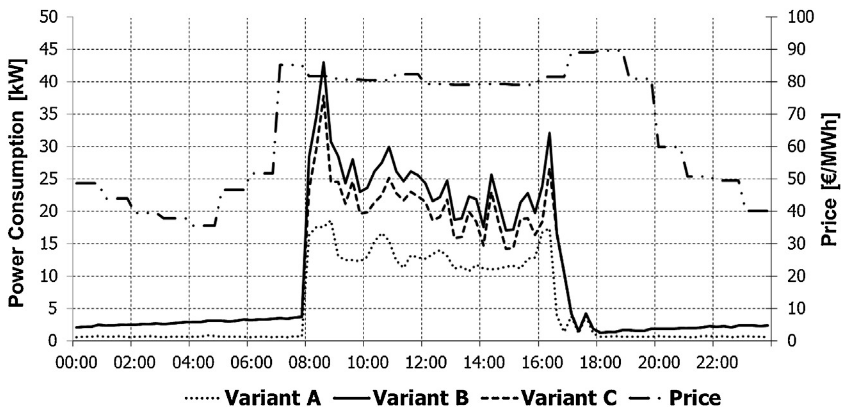

Fig. 3. Standard load curves without utilisation of DSM potential on a winter day.

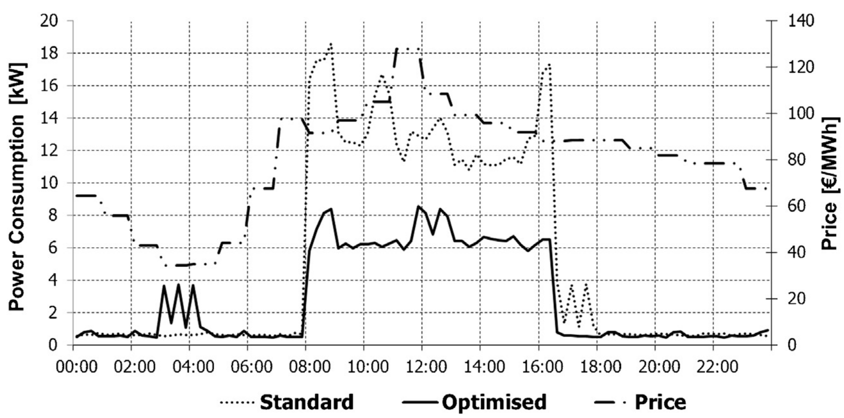

Fig. 4. Optimisation by utilisation of DSM potential for Variant A on a summer day.

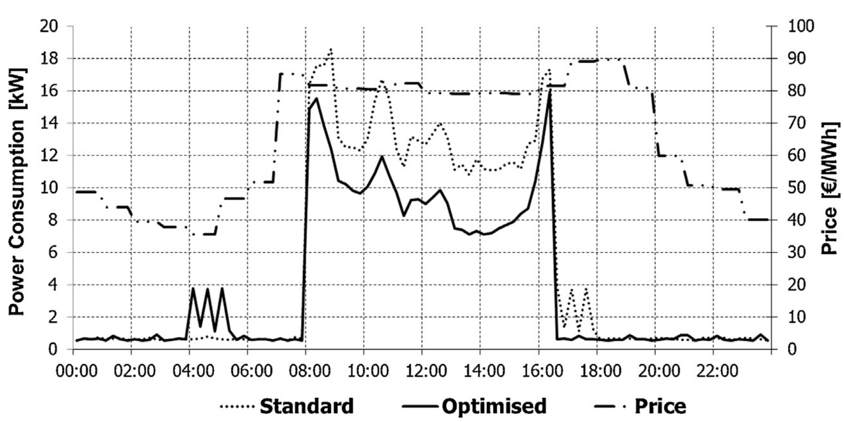

Fig. 5. Optimisation by utilisation of DSM potential for Variant A on a winter day.

annual electricity costs for heating and cooling shrink from €1514 to €1416.

3.3. Variant C

Variant C uses the same optimisation measures as Variant B. Despite that, due to the different basic variant, other results have to be expected. Due to lower temperatures during the night, it is very likely that the shifting of the cooling to the night hours leads to a higher share of free cooling. Figs. 8 and 9 show the consequences of the measures in Variant C.

When the winter day shows a nearly similar picture to variant B, active cooling in summer can be substituted with free cooling during the night. Because of the more efficient lighting system in Variant C, there is a lower reduction potential in lighting. The savings in the field of free cooling and lighting are overcompensated by the higher energy consumption in heating. Therefore, overall consumption rises from 28,478 kW h/a to 29,781 kW h/a. Due to the lower virtual energy price, the annual costs are lowered from €2196 to €1986.

3.4. Discussion

Electric load behaviour and DSM management will have a central role after the changing tariff structure, and with a greater amount of fluctuating power generation. The load behaviour of

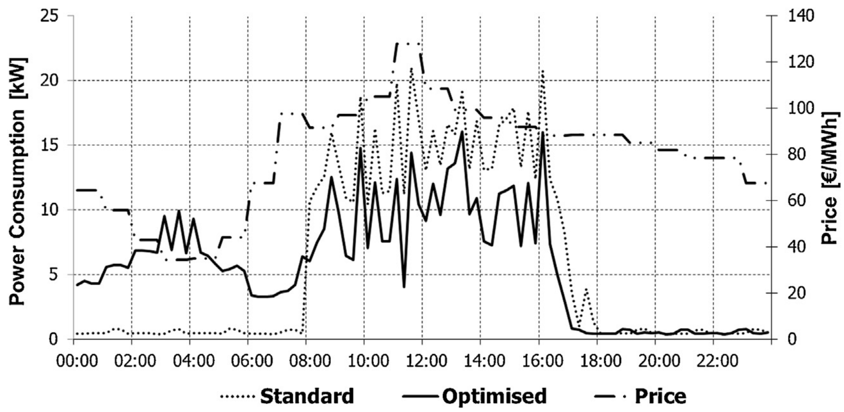

Fig. 6. Optimisation by utilisation of DSM potential for Variant B on a summer day.

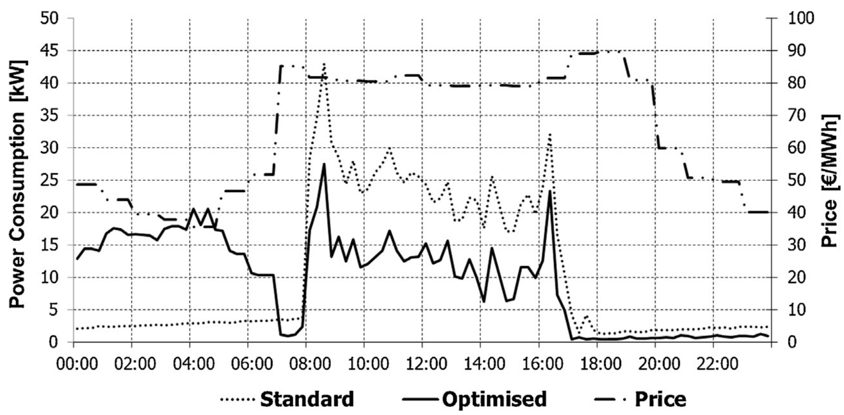

Fig. 7. Optimisation by utilisation of DSM potential for Variant B on a winter day.

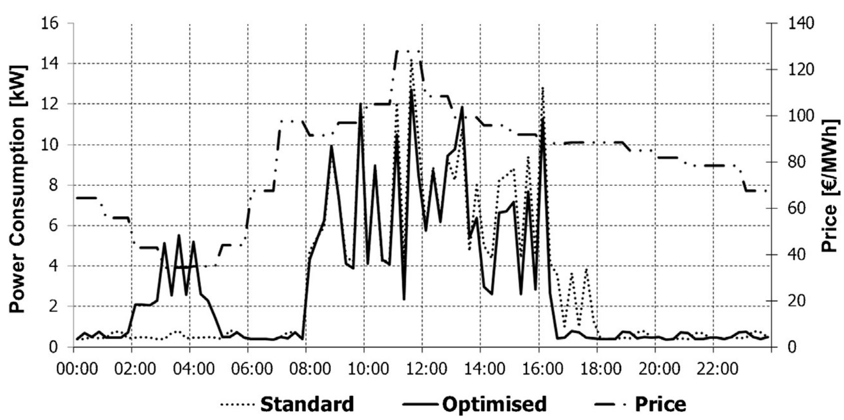

Fig. 8. Optimisation by utilisation of DSM potential for Variant C on a summer day.

office buildings without optimisation shows that the majority of electricity is consumed during times of high prices. By utilising DSM potential, sections of the electric consumption can be shifted to times of lower prices without affecting the user in a negative way. Not only measures of load shifting, but also measures of efficiency influence the load behaviour of buildings. In addition, the potential for optimisation is highly dependent on the technical building system. Table 1 shows a comparison of the results of all

Table 1
Virtual electricity price and costs of the variants.

Variant	Electricity demand in (kW h/a)		Ø Virtual price in (ct/kW h)		Electricity costs in (€/a)	
	Standard	Optimised	Standard	Optimised	Standard	Optimised
A	26,292	21,710	7.95	7.75	2090	1683
B	38,405	37,791	7.98	6.67	3065	2521
C	37,791	29,781	7.71	6.67	2196	1986

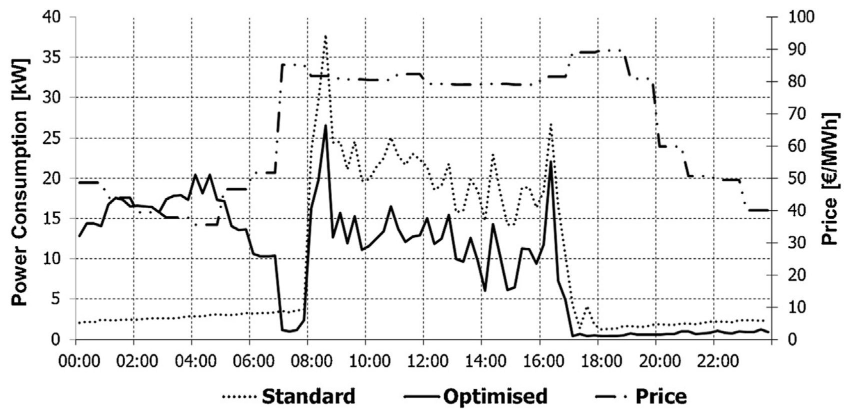

Fig. 9. Optimisation by utilisation of DSM potential for Variant C on a winter day.

Table 2
On-site used electricity of a 10 kW$_p$ photovoltaic system.

Variant	Share of high tariff demand in % without PV		Share of high tariff demand in % with PV		Share of on-site usage in %	
	Standard	Optimised	Standard	Optimised	Standard	Optimised
A	93	89	89	80	75	73
B	94	69	92	57	75	74
C	94	70	88	56	72	68

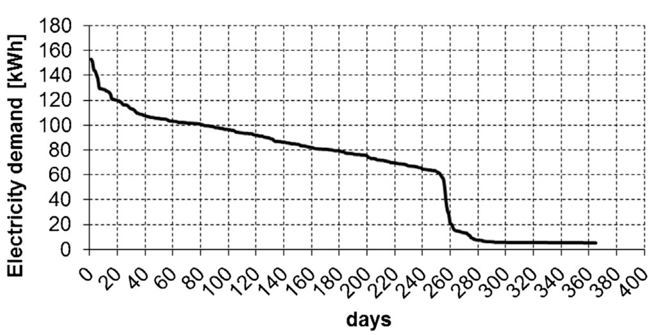

Fig. 10. Electricity demand during high prices (6 am to 10 pm) for modified Variant B.

analysed variants. It is obvious that highly electricity-dependent heating and cooling leads to high storage potential of the building itself. The increasing demand through shifting thermal loads could be minimised using separate, more efficient thermal storage units.

Using electrochemical storage units could be another possibility for utilising lower energy prices during the nighttime. Fig. 10 shows the electricity demand of a modified optimised building Variant B (using the thermal load curve of the standard variant) during the time of higher energy prices (according to the service fees from 06:00 am to 10:00 pm) for each day of the year, ordered by amount.

The diagram shows an amount of over 60 kW h for nearly 260 days of the year and over 80 kW h for about 160 days. Using an accumulator with a usable capacity of 80 kW h and loading it at 02:00 am would lead to a virtual electricity price of 4.3 ct/kW h.

When using photovoltaic production, it should be considered that, for surplus feed in tariffs, it is normally more economic to use the electricity on-site than to provide it to the network operator. Investigations with a 10 kW$_p$ photovoltaic system show an impact of load shifting measures to the share of on-site used electricity, which is shown in Table 2. Otherwise, it can be seen that the amount of electricity demanded during the time of higher energy prices (06:00 am to 10:00 pm) shrink in any case due to the photovoltaic production during the daytime.

It can be seen that photovoltaic systems help to reduce the demand during times of high tariffs in all Variants. Otherwise, the on-site usage is lowered due to the utilisation of DSM potential, which can also be avoided by the selective use of electricity by consumers with load shift potential during daytime.

3.5. Conclusion

The topic of this paper is the electric load behaviour of office buildings. Due to the rising usage of fluctuative producing renewable energy generating facilities, in the future electricity production will not be able to follow the demand anymore. Therefore time critical, variable charges are likely to be introduced.

The reflection of the individual consumers were made with help of correlation of literature. In addition, historic price patterns at the Energy Exchange Austria [3] and weather data from a building simulation tool were used. User behaviour was simulated randomly.

Three variants of the building were investigated. Variant A includes mostly applications without DSM potential, Variant B whenever possible applications with DSM potential. Variant C is nearly equal to Variant B but includes further energy efficiency improvement measures.

Because of the using during the day, when exchange prices are higher than during nights, office buildings mainly demand electrical energy during high prices. This fact is valid unattached from the building equipment. By identification and utilisation of demand side management potential, considerable parts of the demand can be shifted to hours with low prices.

Another possibility to shift loads is to use storage. There are different types of them. Electrochemical storage systems can be load up during low prices and the stored energy can be used during high prices. When using heating or cooling systems, which are highly dependent of electrical applications, thermal storages can also be useful for electrical load shifting. In this course, either the building itself or a separate storage facility can be used. Another measurement to reduce energy consumption during high prices is the integration of photovoltaic systems.

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