HI-SMART: HIGHER EDUCATION PACKAGE FOR NEARLY ZERO ENERGY AND SMART BUILDING DESIGN

MODULE #5

CHAPTER 7: ANALYTICAL DEMAND-SIDE MANAGEMENT

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5.7.1 INTRODUCTION

Present chapter focuses on application aspects of smart meters. Smart meters alone are unable to save energy, it should be integrated to a building energy management concept. It is a tool to provide feedback on building operation and use and thus provide valuable information to detect operation errors and can initiate saving actions. The effective use of smart meters is highly related to users' behaviour and behavioural change. It is a tool for demand side management. Smart meter data analytical methods are presented including time series data and statistical methods. Case study examples will show practical applications of demand side analytics.

However, it is not the objective of current chapter to discuss grid interaction aspects of smart meters.

ASSESSMENT OF UTILITY BILLS

Before discussing the perspectives of smart meter data analytics, limitations of conventional methods based on consumption bills are to be noted.

Conclusions by evaluating consumption data can be drawn as follows:

- the actual past consumption of the building and each subsystem,
- the combined development of the energy quality of the building and consumer behavior,
- assess the impact of an intervention on energy consumption.

An essential condition for the evaluation of consumption data is the right quality and quantity of data.

For high quality results, it is advisable to perform long-term, short-step (e.g. hourly) measurements with the help of external sensors, smart (more popularly known as "smart") measurement systems, and a building management system.

Monitoring data analysis is often not possible, therefore utility bills (gas bills, heat consumption bills, electricity bills) are evaluated instead.

For utility bills to produce effective results, long term (usually at least 3 years) data collection is needed. Unfortunately, this is not always possible, the bills may no longer exist. In some cases, evaluating bills is very difficult, possibly impossible. Some of these problematic cases are listed:

- The user has a contract with annual reading and thus the monthly consumptions cannot be separated. It is then not possible to separate winter and summer consumption, which makes it impossible to separate gas consumption for heating, hot water and cooking in the case of gas.

- The building has been newly built or has undergone a major redesign or function change recently.
- The building (part) is intermittent (possibly unused) and the method of use is not regular or traceable.
- The consumption of the building (or building part) is not measured by a separate submeter.
- The energy source comes from a doubtful source and the consumed quantity cannot be reliably traced on the basis of invoices (e.g. bottled gas use, wood burning or other solid fuel).

Even if the above problems do not exist, there is often a need to separate the impact of building quality and consumer behaviour. This can usually only be done by additional calculation or cost and time-consuming monitoring.

When evaluating bills, it is often necessary to normalise consumption data by weather data. This requires weather data (e.g. heating degree days) determined by the billing period and geographical location, which in some cases is a cost, as the data must be purchased.

An important step in the evaluation is to separate the data by object of consumption (e.g. auditing of the part of the building). This is not a problem for electrical submeters, otherwise it might be possible only by additional calculation. In principle, it is possible to estimate by room volume, floor area, headcount, etc., but these are distorted. For heating and cooling sub-measurements, we should take into account the problem of heat flows between units.

Data segregation should also be broken down by purpose: for example, gas bills by heating, DHW and cooking, or electricity by office equipment, refrigeration and ventilation. This can be helped by evaluating the monthly development of the bills (no cooling in winter, no heating in summer, DHW, cooking all year round), but often a survey and calculation of the building and equipment is required. When separating the DHW heat from the heating, it should be taken into account that there may be several weeks of downtime or reduced operation in summer (holiday) or slightly higher DHW heat demand in winter than in summer (longer showers in winter with warmer water, resulting in higher distribution heat losses). The use of each energy source should be analyzed on the basis of billing data and compared with the calculated data. It is important that the compared calculation and measurement data refer to the same intervals (e.g. in the case of monthly invoices, a monthly calculation is advisable, in the case of an annual reading, the annual calculation method used for certification is sufficient).

RECOMMENDATIONS AND MEASURES TO CHANGE CONSUMER BEHAVIOUR

Influencing consumer behaviour is not essentially a technical task, but it is up to the auditor to highlight the behavioural problems that contribute significantly to waste. The measures themselves may be free of charge, but in any case, time-consuming and resource-intensive. For all activities aimed at influencing consumer behaviour, the term 'demand side management' (abbreviated as DSM) is used. Some key elements of the DSM toolkit are related to data monitoring:

- For non-residential buildings develop an energy management structure within the institution. Measures for change should be organised by institutional management identifying the institutional managers, staff and control processes best suited to influence them.
- Confrontation of users with measured and expected consumption data (so called "analytical DSM"). In experience, this is the most effective means of persuasion and thus of achieving behavioural change. For example, if we use figures to show that consumption outside working hours is no less than during working hours, this can be very convincing.
- Information on consumption. Regularly inform building users (e.g. quarterly) about consumption developments, e.g. in the form of newsletters in non-residential buildings.
- A specific case of the preceding point is the use of a display in a clearly visible common space, which informs users in a user-friendly way about the current and past development of consumption (e.g. by using smart meters). An alternative might be to give workers' computers access to the data (Figure 5.7.1).

Figure 5.7.1.: Applications for easy-to-understand visual display of consumption data on different IT devices

Experience has shown that the measures listed can be very effective, but over time, old habits gradually return. It is therefore important to repeat some of the measures from time to time in a campaign-like way so that the impact is lasting.

5.7.2 MONITORING AND SMART METERS

During monitoring, measurements and data recording are carried out over a longer period of time, even by sampling per minute, using monitoring instruments installed. This includes increasingly common smart meters. Monitoring allows experts to perform high-precision analyses. The longer time range enables tracking non-steady state processes, consumer habits and make much more accurate assessments. Statistical evaluation of data eliminates certain discrepancies that reduce the accuracy of ad-hoc measurements.

Monitoring is a time-consuming and costly activity. It has a high demand for instruments and, in some cases, a need for IT background. The more detailed the recording, the more accurate the picture of the operation of the building. The most important data to be measured are generally:

- Meteorological data, mainly external temperature. Low-cost measurement can provide an excellent basis for temperature bridge corrections. It would be worth measuring solar radiation data many times, but its cost is high.

- Internal temperatures in rooms with characteristic functions. The low-cost measurement also provides useful data on the control of the heating and cooling system and on the hydraulic balancing of the systems. It is important to carefully select measuring points, especially if only a few sensors can be accommodated. Frequently used, high-traffic spaces should be preferred and it is important that they are placed in a place free of disturbances (e.g. away from exposed surfaces, cold corners, heat sources) in the residence zone. At the same time, it may be appropriate to place sensors in rooms with unfavourable conditions. Also, make sure that the instrument is not at risk of damage.
- Electrical metering: Depending on the existing network, it may be low cost or higher cost. Connecting to the main meter is subject to permissions and therefore time consuming. It may be worthwhile to install submeters by building (or system) parts, or by main equipments, which requires thoughtful design and its feasibility depends on the structure of the system. The electricity generated by any solar cells shall be measured separately, which is typically achieved at the inverters.
- Gas consumption meter: Installation is costly and time-consuming (permissions needed). If more than one device uses gas, it may be appropriate to use heat consumption meters to measure the heat energy generated by subsystems, although this also can be a very costly solution.
- Heat meters: it can also be an expensive item, but it is often easier to implement than gas metering. Consideration should be given to the use of internal temperature meters to assess the problem being investigated.

TIME SERIES ANALYTICS

Time series analytic methods aim at monitoring the evolution of energy consumption over time. The measured consumption data can be compared with the expected consumption (calculated, modelled consumption – Figure 5.7.2) and, in the event of a deviation, it is easier to identify operational errors. The great advantage of time-series analysis is that it is easy to interpret and therefore can be very convincing for non-expert users.

The disadvantage of time-series analytics is that only time is considered as independent variable, the effects of other factors (e.g. external temperature effect) are ignored.

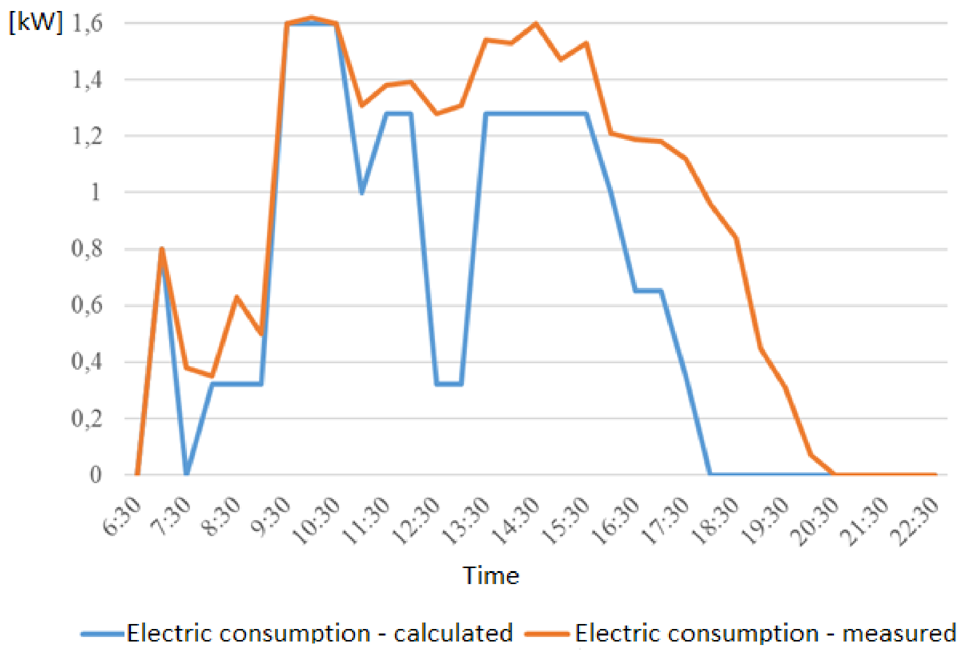


Figure 5.7.2.: Comparison of calculated and measured energy use over time

Here are some examples of applications. Figure 5.7.3 shows the distribution of presence during a working day, based on the data of the check-in registration system of a municipal office. The building is not used on weekends. Based on this type of analysis, it is possible to determine the periods during which most of the equipment should be switched off. If we compare this with the development of electricity consumption (Figure 5.7.4), we can state that although consumption decreases at night, it still accounts for about a quarter of peak consumption during the day. It is worth checking to see if this is justified or if some equipment is not working unduly. If so, what solution can be used to address the problem: minor improvements may be required (e.g. the development of centrally disconnectable electrical circuits), but it may be enough to change only the usage patterns (e.g. regularly disconnect certain equipment, which can be done by the janitor or cleaner). It can also be observed that there is a local peak consumption between 3:00 and 4:00 a.m. The reason for this is definitely worth investigating. It may be justified, but it may be eliminated. One of the means of identifying the reasons may be the installation of additional electrical submeters in order to find the floor or equipment responsible for unjustified consumption. A more cost-effective solution may be to temporarily cut power to a sub-group at night and analyse the impact on consumption. Analysis of weekend consumption is also necessary, and it is even worth paying attention on public holidays to see if consumption decreases to an appropriate extent.

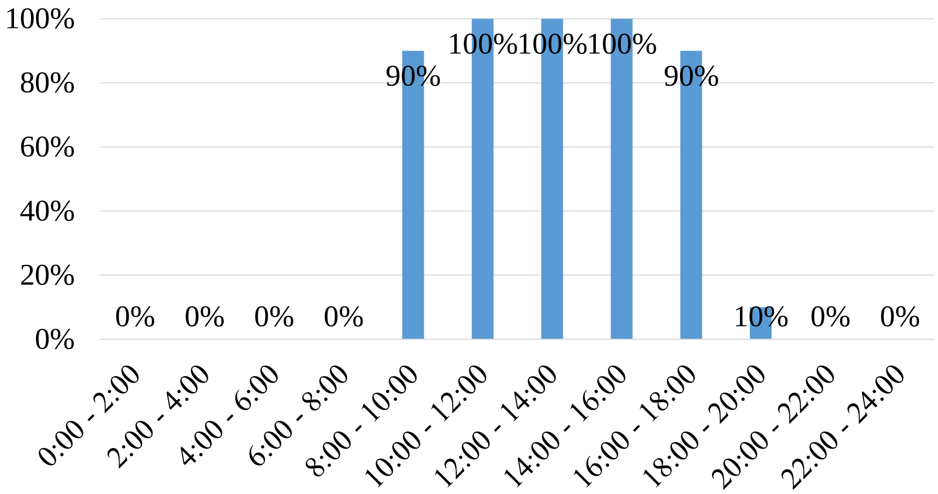
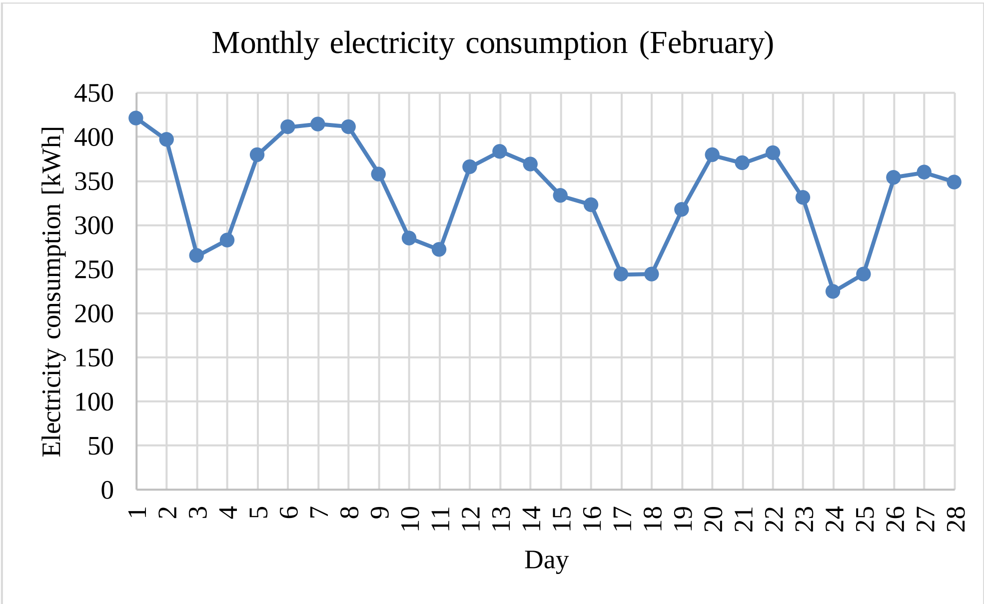


Figure 5.7.3.: Presence pattern in a municipal building



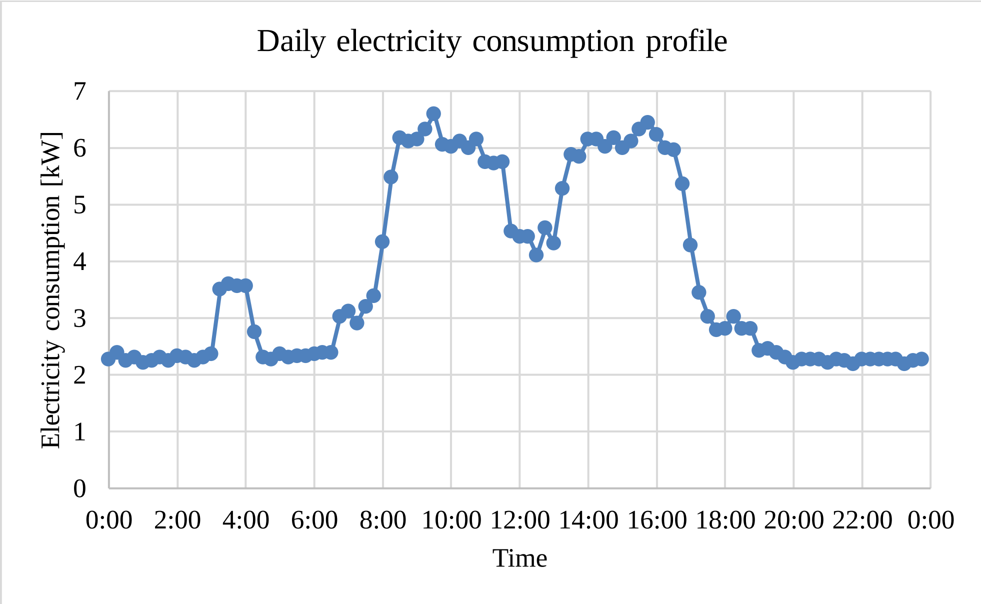


Figure 5.7.4.: Monthly and daily development of electricity consumption in a municipal building

An example of correct operation can be seen in Figure 5.7.5, which shows the weekly evolution of the electricity consumption of a kindergarten. The weekend is marked by framing. It can be seen that at night and at weekends it falls significantly. In this building, appliances that need to operate at night (e.g. alarms, refrigerators) are connected to a separate circuit, the rest is switched off with one power switch each night. At the same time, weekend heating set-back in the same building is not implemented properly, as shown in Figure 5.7.6, so there is energy saving potential here with simple reprogramming.

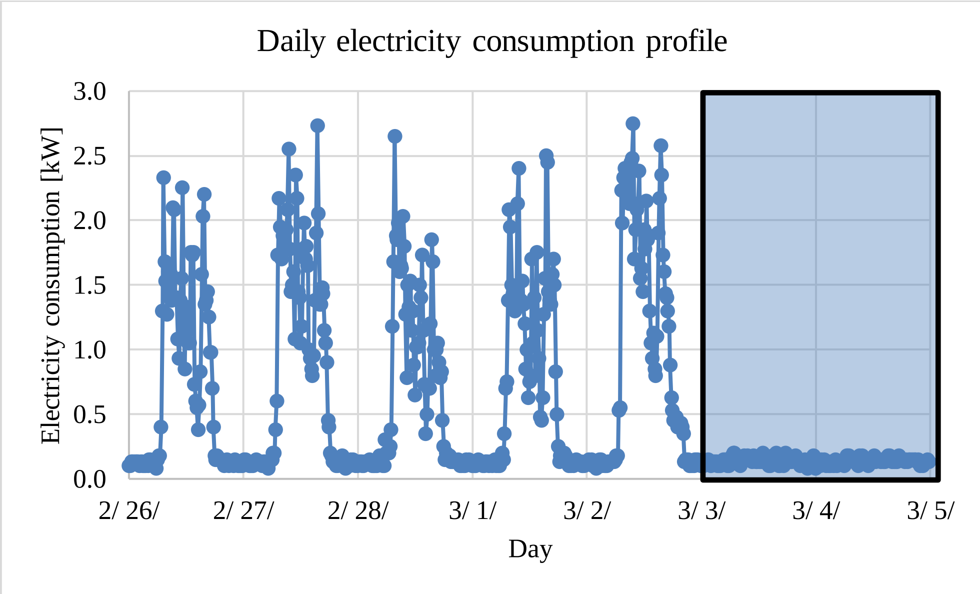


Figure 5.7.5.: Weekly development of electricity consumption in a kindergarten building

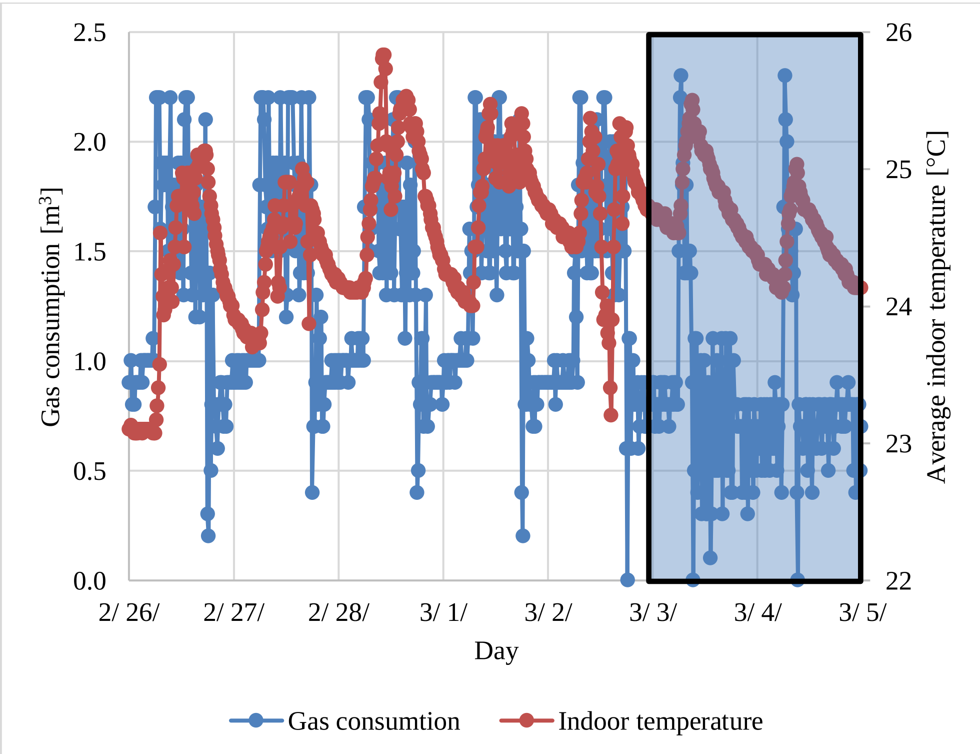


Figure 5.7.6.: Weekly evolution of gas consumption and air temperature in the same kindergarten building

Figure 5.7.7 shows the development of gas consumption in a school building. The boiler has two-point control, the figure shows the on and off cycles. However, due to the dense switching cycles, it is difficult to draw conclusions about the correctness of operation from this curve. The development of temperatures (which can be measured at a much lower cost) says much more than that, which can also be read from the figure. It can be seen that between 19.00 in the evening and 5.00 in the morning there is a reduction in heating at night despite the fact that the boiler is switched on regularly (albeit for shorter intervals). At the same time, it can be stated that the internal temperature is unreasonably high, ranging from 24 to 26 °C. Heating cost savings of up to 20% could be achieved by reducing the temperature while still accepting an acceptable level of comfort.

The following figure (Figure 5.7.8) shows the evolution of temperatures in the same school over a two-week period. Weekends are indicated by framing. It can be seen that the heating cycles also persist on the weekends, which is completely unnecessary. During in-depth interviews in the building, it was stated that the thermostat was programmed to have a heating cut over the weekend, meaning the maintainers were convinced that everything was working well. Without monitoring, this error would not have been revealed. Thus, significant cost savings can be realized with simple reprogramming. Such diagrams are very convincing for operators and decision makers.

From the same diagram we can also conclude that the heating system is unbalanced, as it is continuously 2 degrees warmer on the second floor than on the first.

It is important to note that daily temperature cycles can be affected not only by the heating program but also by solar radiation, so it is worth analyzing cloudy days separately.

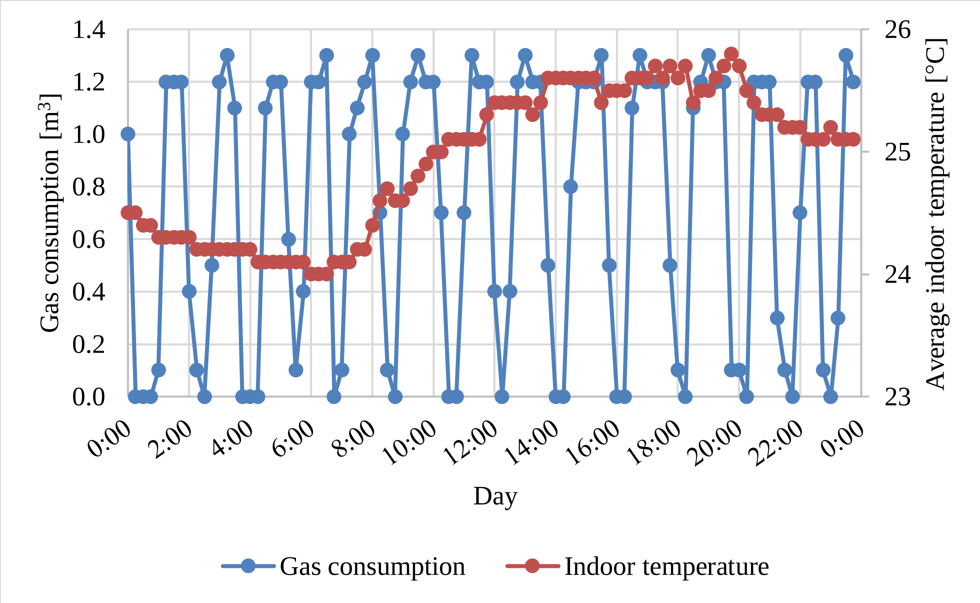


Figure 5.7.7.: Daily evolution of gas consumption and internal air temperature in a school building

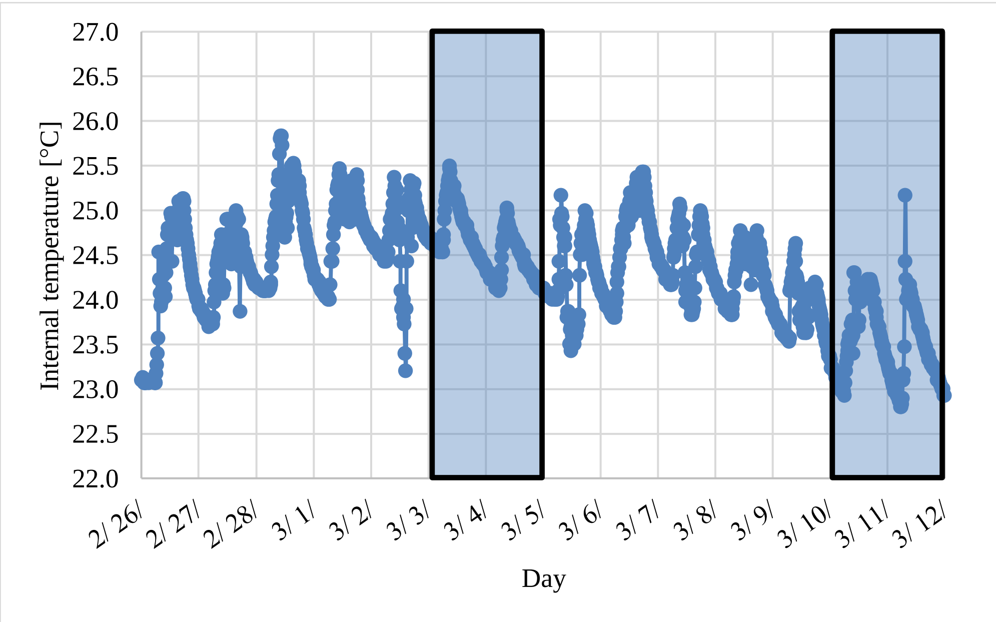


Figure 5.7.8.: Evolution of internal air temperatures in the same school building over a two-week period

A particularly interesting case is shown in Figure 5.7.9, Figure 5.7.10 and Figure 5.7.11. In another, otherwise very modern kindergarten, preliminary interviews said that the heating is properly programmed, i.e., both night and weekend heating reductions are implemented. However, the measurements in February-March show just the opposite. The heating really works according to a program, but the heating only takes place at night and on weekends, and the heating is reduced during working hours. However, since even then the temperature does not go below 21 °C, no one noticed the problem. On Sundays, temperatures raised as high as 28 °C when the building was empty.

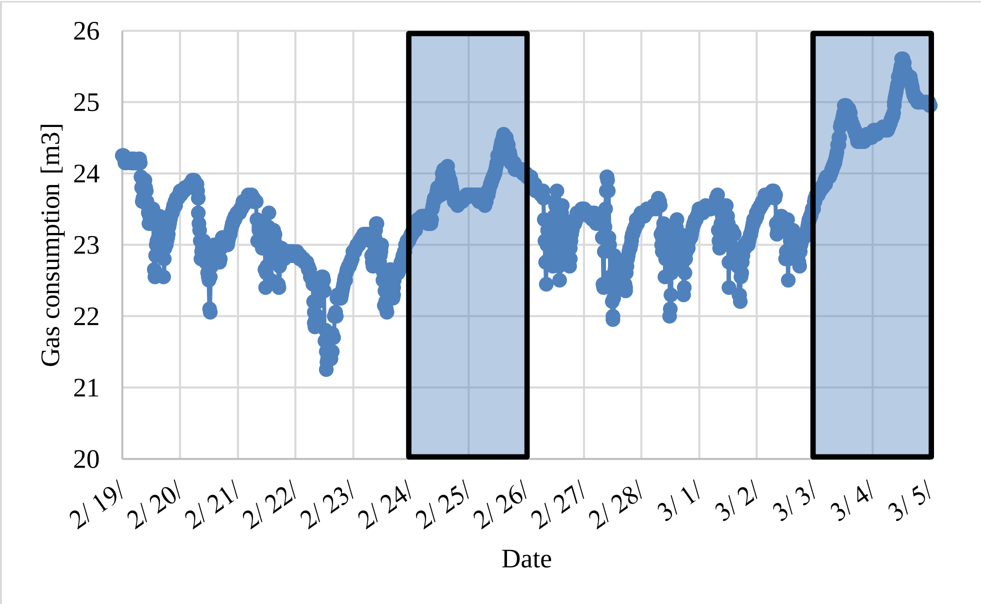


Figure 5.7.9.: Evolution of internal air temperatures in another kindergarten building over a two-week period

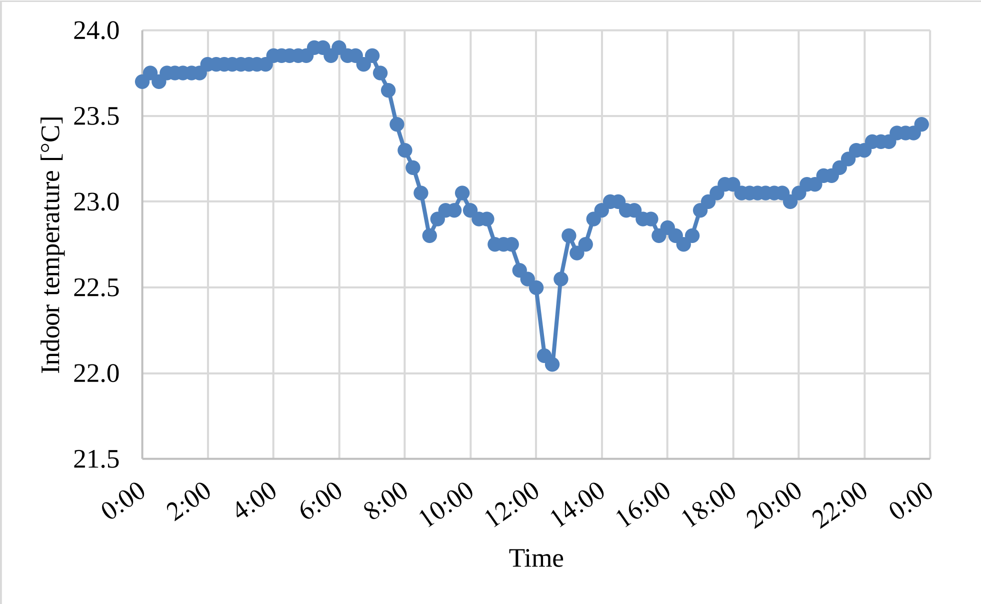


Figure 5.7.10.: Evolution of internal air temperatures in the same kindergarten building on a Wednesday

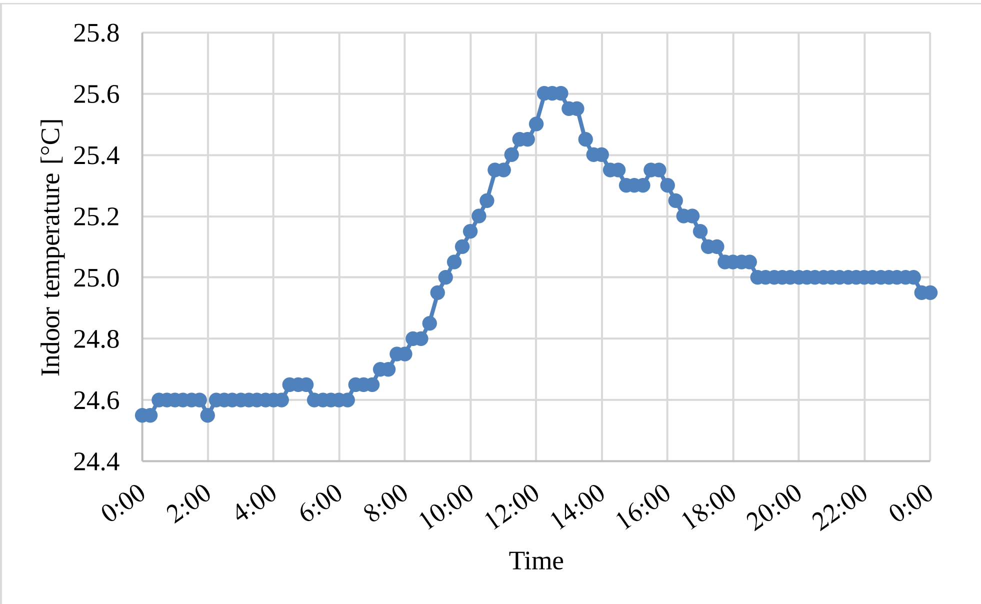


Figure 5.7.11.: Evolution of internal air temperatures in the same kindergarten building on Sunday

Monitoring also provides the possibility for further analysis. For example, taking into account peak periods and valleys, a more efficient hot water circulation schedule may be possible, based on an analysis of HMV consumption data. Deeper statistical analyses can reveal interesting correlations.

STATISTICAL ANALYSIS OF MONITORING DATA[1]

Based on the statistical analysis of consumption data measured to estimate the energy consumption of a building, a model can often be set up. Below is an overview of some commonly used statistical methods that can help you set up your model.

Energy consumption usually depends on parameters that change over time. These parameters are called predictor variables in statistics. In a simpler case, consumption is significantly influenced by a single predictor variable and the relationship is linear. An example is the relationship between the number of visitors in a game room and the energy consumption of gaming machines. The correlation between the weekly energy consumption over time is shown in Figure 5.7.12, the correlation between the weekly number of visitors and the energy consumption is shown in Figure 5.7.13.

[1] The chapter is based on source: Methodollogy for energy—efficiency measurements applicable to ICT in buildings (eeMeasure) D1.2 Non-residential methodology – project deliverable

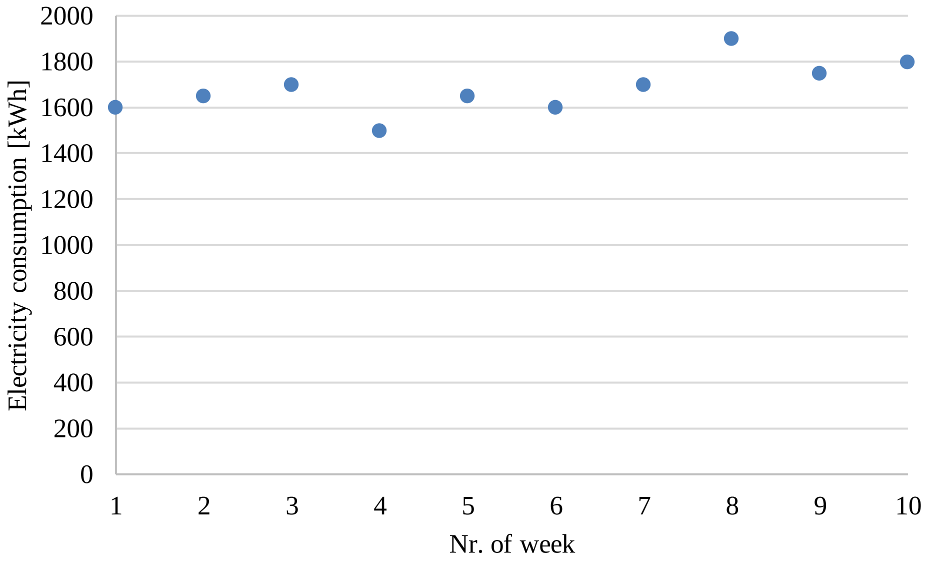


Figure 5.7.12.: Weekly energy consumption as a function of time

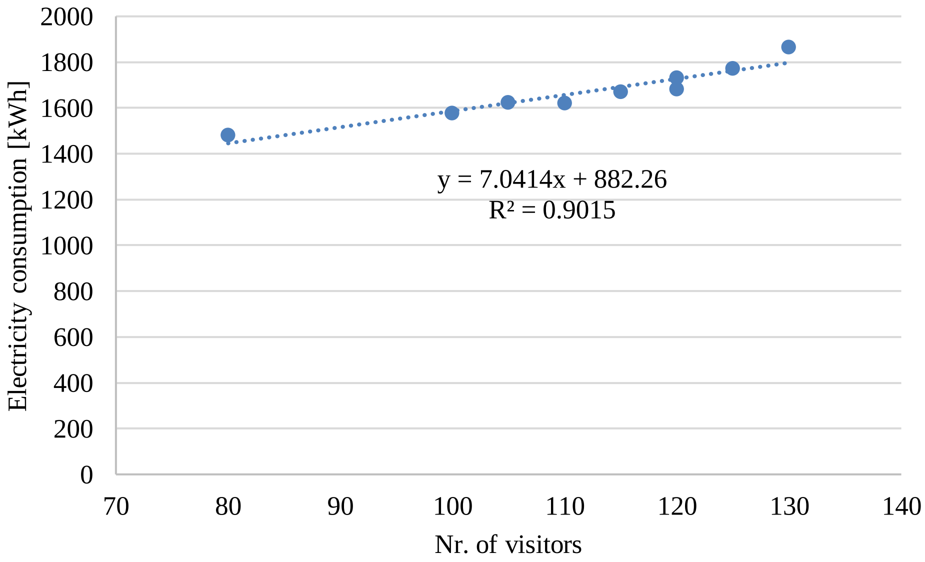


Figure 5.7.13.: Weekly energy consumption of slot machines depending on the number of visitors

We can find the correlation between the number of visitors and consumption using the least squares method. (Correlation analysis is also suitable for searching for a linear function, but other types of functions can be searched for using the least squares method.) In this case, a linear regression is $R^2 = 0.90$, which means that energy consumption is determined by the number of visitors up to 90%, and other factors to 10%.

Based on the regression line function, future consumption can be estimated, as shown in Figure 5.7.14. In the figure, the predicted values from week 11 are indicated by red dots. If the gaming machines are at the beginning of week 11, the actual measured consumption (marked in blue) will be lower than estimated and the amount of savings will be shown by the green sections connecting the red and blue dots.

A similar example is shown in Figure 5.7.15: here we analyze the impact of upgrading a building based on measured heat consumption data. To do this, a reference period before renovation must first be defined, ideally based on measurement data of at least three years prior to the renovation measures. Based on the statistical analysis of this period, we establish a functional relationship (e.g., a regression line) between the intervention-independent predictor variables (primarily outside temperature) and consumption. After the time of the intervention, the consumption that would have developed without the intervention should be estimated using the regression function. Ideally the post-intervention period should also be long enough (ideally 3 years, which is rarely possible in practice). The difference between the reference consumption calculated for the period after the renovation and the actual consumption gives the energy saved. This is the actual energy saved since the renovation, no further adjustment is required. Of course, the estimation error must be taken into account, which is due to the fact that the regression line has an R^2 less than 1, and other external factors can cause a deviation from the estimated reference consumption (e.g. changed consumer habits).

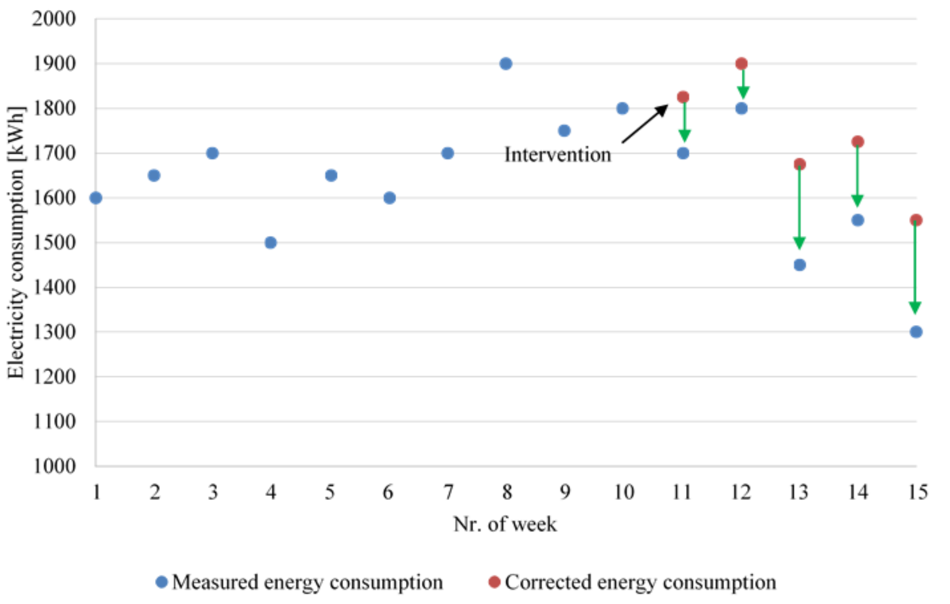


Figure 5.7.14.: Interpretation of energy savings in case of modernisation

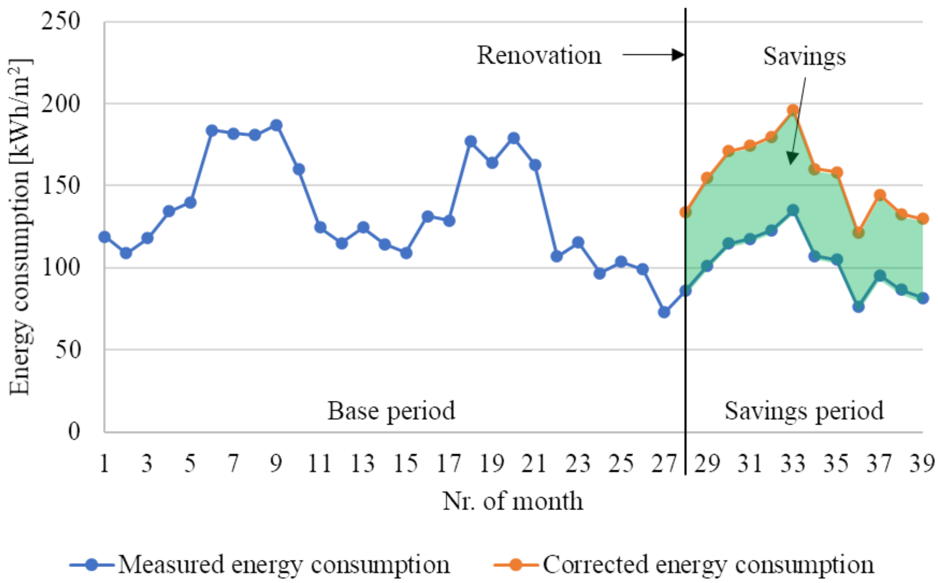


Figure 5.7.15.: Analysis of the impact of an intervention: comparison of reference consumption with actual consumption after intervention

R^2 is a good indicator of the function relationship, but it is not sufficient to determine whether the model you have set up is accurate enough. The outlier shown in Figure 5.7.16 may be due to a measurement error or may indicate that other predictor variables should be considered (for example, extended opening hours may be the reason).

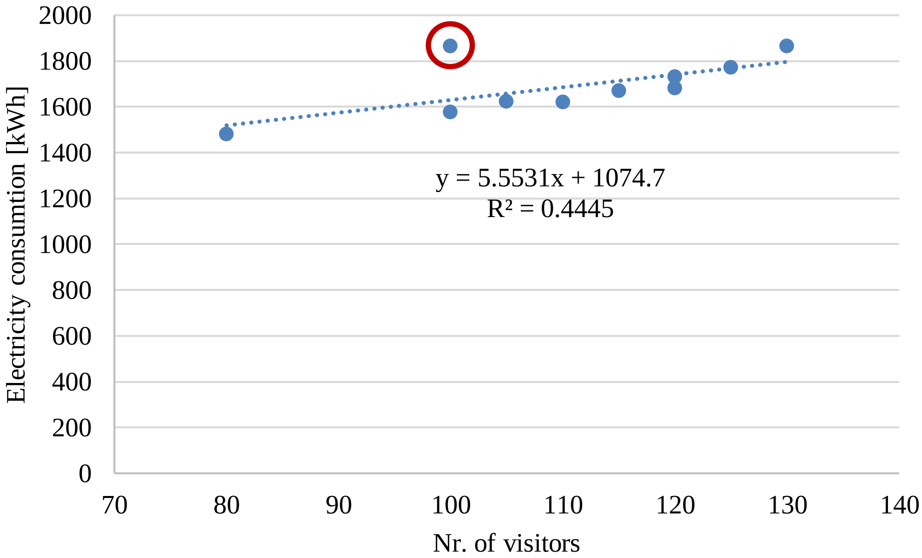


Figure 5.7.16.: Outlying data

It is also possible that the relationship appears to be linear, as shown in Figure 5.7.17: here we plotted the monthly energy demand of artificial lighting in a public building as a function of the number of daylight hours. The value of R^2 is 0.88, which is relatively high, but if we look more closely at the points, we can see that if the number of daylight hours exceeds 390 hours, the energy demand for lighting no longer increases. The relationship is better reflected in Figure 5.7.18, where there is a breakpoint in the line. A new line has been laid for the points below 390, so that $R^2 = 0.91$, which indicates a stronger relationship, but does not itself reflect that the new function covers reality much better. Checking the physical phenomenon can give a better explanation: if the number of hours of daylight reaches the opening hours of the building, then there is no need to illuminate in spaces with natural light. Therefore, the number of hours without natural light during opening hours is a better predictor than the number of daylight hours (Figure 5.7.19).

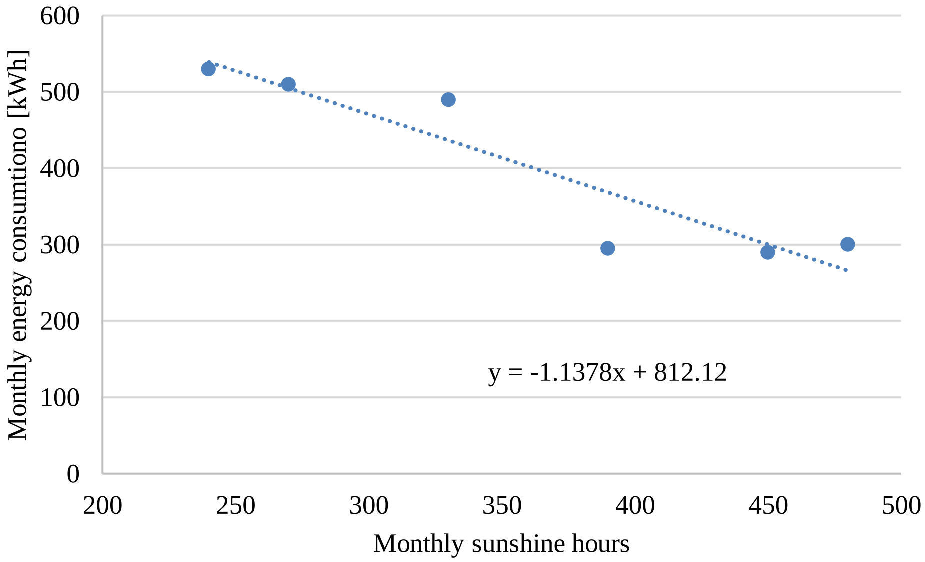


Figure 5.7.17.: Energy consumption of lighting depending on the number of daylight hours, linear regression

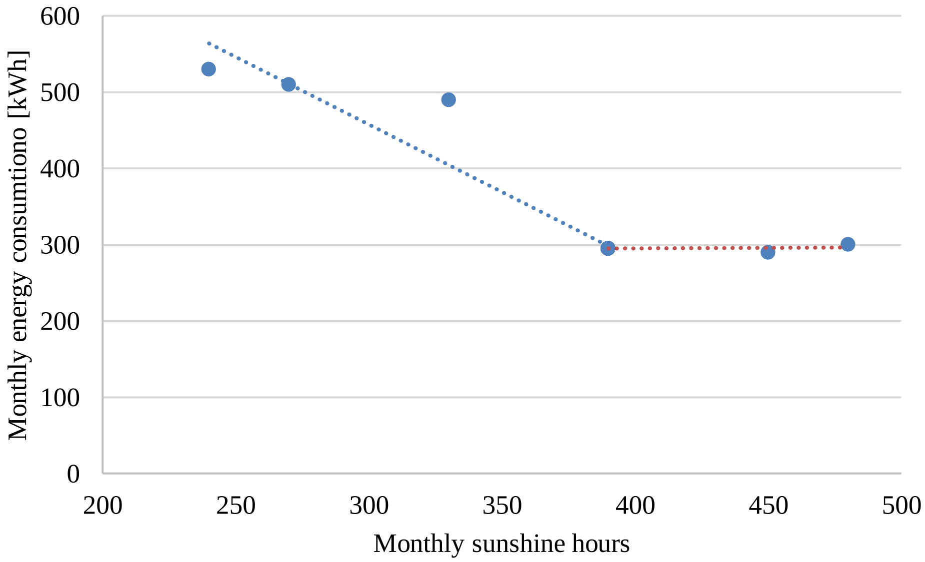


Figure 5.7.18.: Energy consumption of lighting depending on the number of daylight hours, adjusted function connection

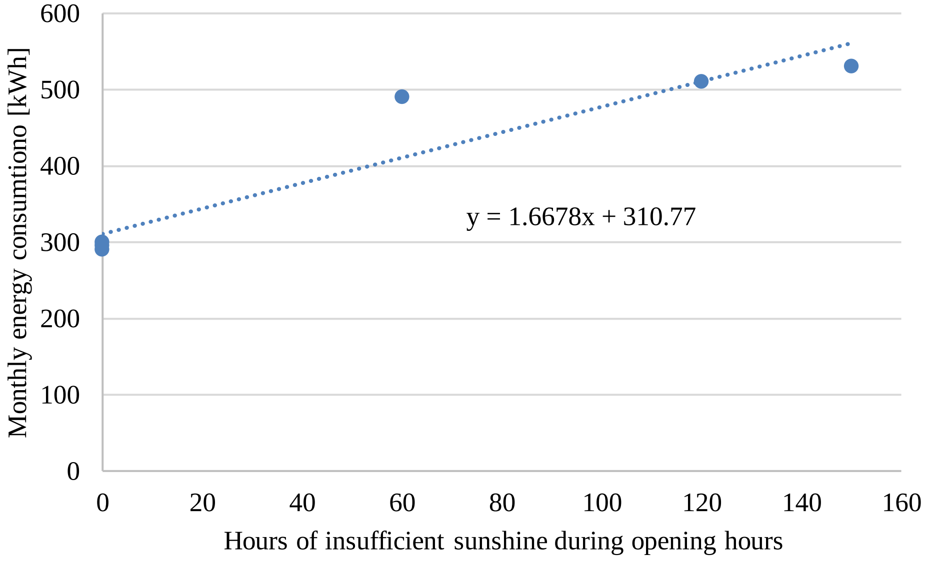


Figure 5.7.19.: Energy demand for artificial lighting depending on the number of hours without natural lighting during office hours

A similar problem is when the daily use of thermal energy is plotted as a function of the average daily external temperature. We find that up to a certain external temperature, the relationship between temperature and consumption is linear, but above this it takes a constant value. The breaking point is the heating limit temperature, above which there is no heating energy demand, only heat consumption for other purposes (e.g. hot water).

„ENERGY SIGNATURE"

The essence of the "energy signature" method is to plot the measured thermal energy consumption per unit period as a function of the external average temperatures of the given periods. This gives an array of points on which a regression line can be placed. In case of a sufficiently high correlation, the heating consumption can be estimated based on the equation of the regression line.

Figure 5.7.20 shows an example in daily breakdown. We can conclude that up to a certain outside temperature, the relationship between temperature and consumption is linear, but above this it assumes a constant value. The breaking point is the heating limit temperature, above which there is no heating energy demand, only heat consumption for other purposes (e.g. hot water).

The „energy signature" method can serve multiple purposes:

- we can compare and visualize calculated and measured energy consumption (Figure 5.7.21),
- it can be used to determine the actual heating limit temperature on the basis of measured data, from which the start of the heating season can be predicted; the length of the heating season is important for heating degree days calculations as well,
- it can be used to predict heating energy needs in function of external temperature,
- it can be used to calculate the real outdoor design temperature (Figure 5.7.22),
- it can be used to determine the reference energy consumption for analyzing the impact of an intervention (i.e. to calculate what the consumption would have been like if the intervention had not taken place),
- we can directly compare the energy consumption of pre- and post-intervention periods comparing the regression lines' characteristics (Figure 5.7.23).

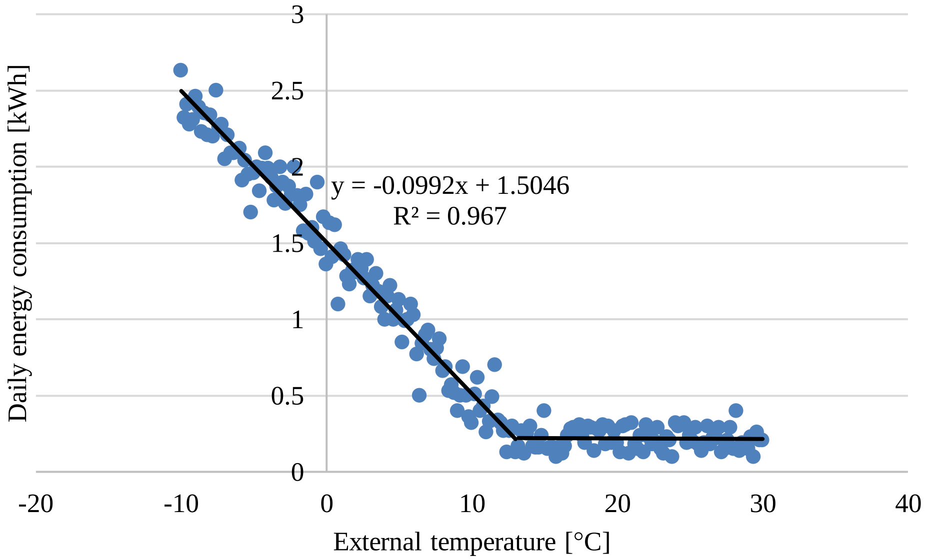


Figure 5.7.20.: "Energy signature" - Daily heating energy consumption depending on the average daily outdoor temperature

If the correlation is strong enough, it can be stated that the effect of the external temperature is decisive for heating consumption. A weaker correlation means that consumption is also significantly affected by other factors. In such a case, it is necessary to consider what other independent variables may have an impact (e.g. on weekends set-back operation, significant solar gains, volatile consumer behaviour, in addition to heating, other non-constant consumers are also measured).

The advantage of this method over degree days correction is that here the correlation coefficient shows how strong the effect of the external temperature on consumption is. In the case of thermal correction analysis, we only correct the external temperature, but we do not see how strong the dependency relationship between the two quantities is.

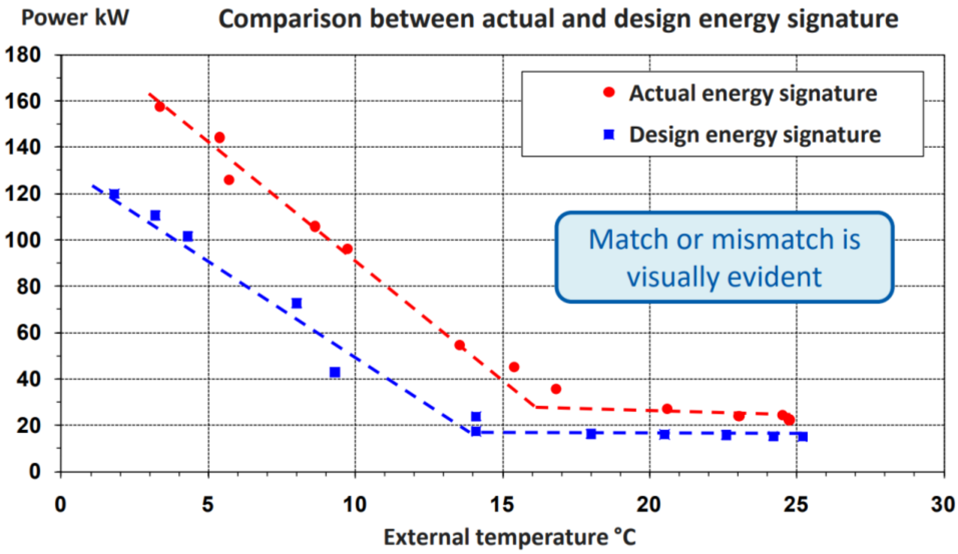


Figure 5.7.21.: Comparison between actual and design energy signature [1]

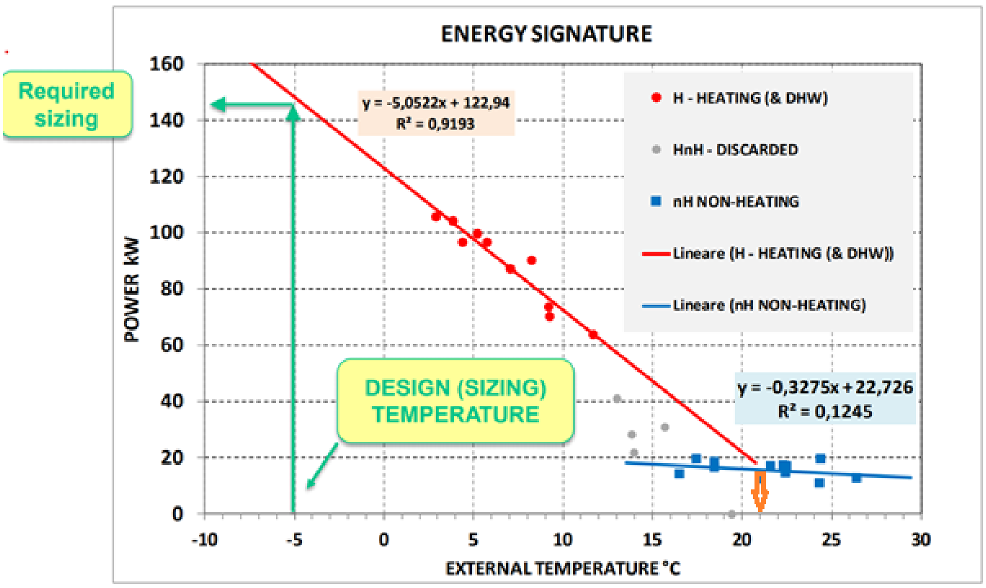


Figure 5.7.22.: Determining the real design outdoor temperature and the balance point temperature [1]

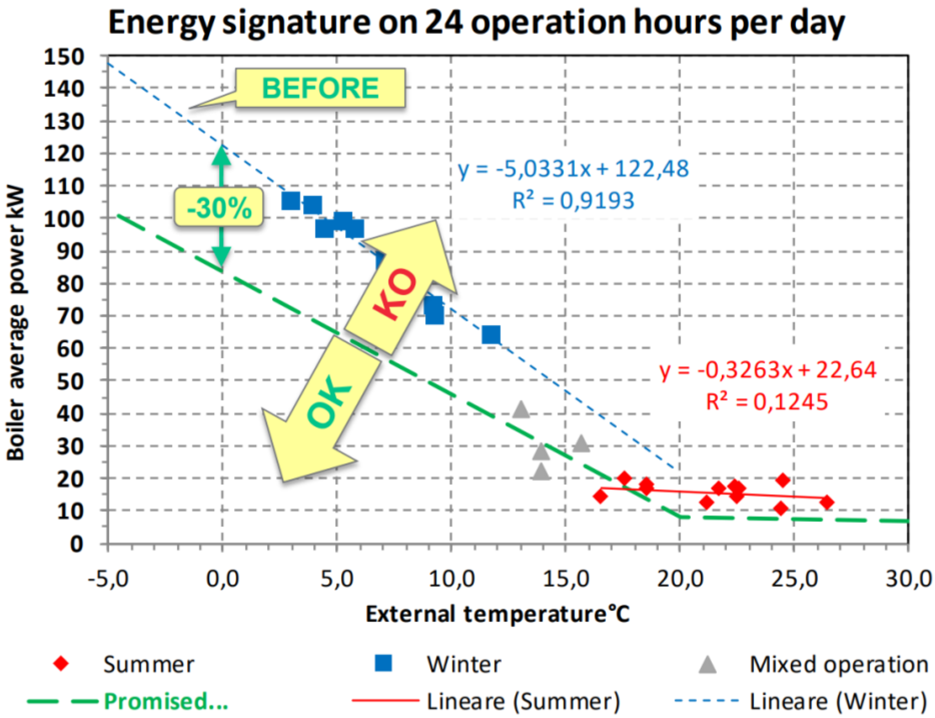


Figure 5.7.23.: Comparison of consumption before and after an intervention [1]

5.7.3 REFERENCES

[1] L. Socal, EPB standards on heating and domestic hot water systems: advanced features and tips & tricks, BUILD UP Webinar series Webinar 6, 2020.

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