Importance of sunny days for the determination of heat consumption

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***Abstract*—**This contribution describes research focused on calculation of heat consumption for part of the town during the winter season. It is based on historical data analysis in the view of the nature of the sun activity and day type. Whole research consists of two major steps. First step describes obvious relation between heat consumption and outside temperature. The relation is expressed in linear formula and then improved it by the inclusion of the information about sun activity during a day and day type. The second step, concerned with dissimilarities, is about separation of sunny and common days, weekend days and week days and then description of the heat consumption individually for these varieties of days. This contribution also shows simple method of substituting sun intensity measurement with comparison of temperature differences.

Keywords*—Common day, consumption, heat, hot water, temperature, sun.*

I. Introduction

NOWADAYS, more than any time in the past, the price of heat produced by heating plant must be considered. Even global warming is often mentioned but the energy necessary for warming during the winter season doesn't decrease too much. In fact, there is a decrease, but it is more just due to better buildings isolation than to the reduction of demand.

Most of the heat producers and distributors of heat are using weather compensation curve to control input temperature of hot water (denote qualitative part of supply), supposing growth of heat consumption with outside temperature fall [1]. This is without questions right, verified by long time experience and practical use [3].

This research is based on hypothesis that heat consumption is not simple function of outside temperature only but amount of consumed heat is affected by other factors [4]. Of course, temperature has unsubstitutable role but other factors should be considered, at least to sharpen the weather compensation controls.

This paper will show several experiments striving to prove significance of sunny days and day type. It is obvious that the sun warms buildings and sunny day brings savings in heat supplies. Also if people work, usually during the week days, they probably do not require as much heat energy as during the weekends. So, what about reducing hot water temperature in pipes during these days? Surprisingly, it is not so common. Usually temperature probe is placed in a shadow spot and is irresponsive to this charge. The only reaction comes late and it is due to higher temperature of surrounding air. And is this enough? In the event of weekdays and weekend day usually differential presser control takes effect.

Recognizing weekend and weekday is obviously pretty easy but exposing the temperature probe to sun is evidently wrong way. So, let's think about finding a way to add "factor of sun" into weather compensation control and try out calculating consumption individually for weekdays and weekends. However, first look into the behavior of consumption and heating schedule [3], [5].

II. Heating Schedule

Let's consider general situation in which heat distributor (producer) is preparing heating schedule for next day(s). First of all the accurate weather forecast is needed. Usually just prediction of the outside temperature course is used. Base on this, distributor prepare heating schedule. Heating schedule mostly mean, expecting hot water as a heat transfer fluid, when and what temperature to distribute into town agglomeration to reserve needed energy for expected consumption.

Trial heating schedule is shown in following pictures. Fig. 1 shows outside temperature prediction for one day and Fig. 2 shows appropriate heating schedule. Necessary to explain, that amount of fluid in good balanced systems is controlled automatically following differential pressure.

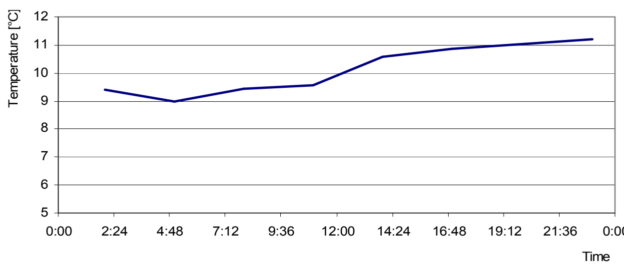

Fig. 1 Weather forecast (temperature) for one day

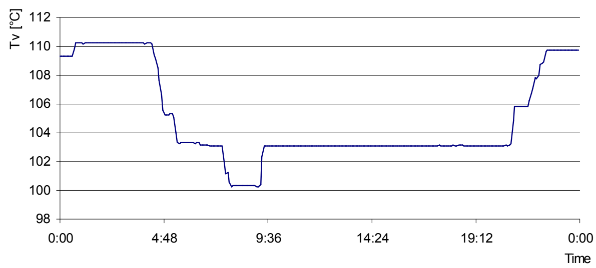

Fig. 2 Heating schedule for particular day

Control based on outside temperature is well know and verified method. And it is also obvious, that outside temperature has most important role in this control process. Considerations about other meteorological influences were also often presented [8], [13], such as blowing wind, rain, shining sun, etc. aments the heat requirements. All those influences, included in the control, can improve final result [13]. Nevertheless, most of these influences are reflected in outside temperature naturally, but after all, for example shining sun is not just warming air which, as mentioned, reflects in outside temperature, but sunset does not mean temperature increase for buildings. Especially modern and well isolated houses are able to keep energy acquired from the sun for long time and this behavior must be definitely considered in heating schedule.

Buildings considered as consumers have “simple” behavior but people are living inside and make all calculation much more complicated. To be fair to people, weather is not just outside temperature, so beside guessing and observing human behavior the weather condition has to be better considered.

For this research we generalize human behavior into weekend and weekdays tracking. From the weather condition we added sunshine. Following variants are going to be described - see Fig. 3.

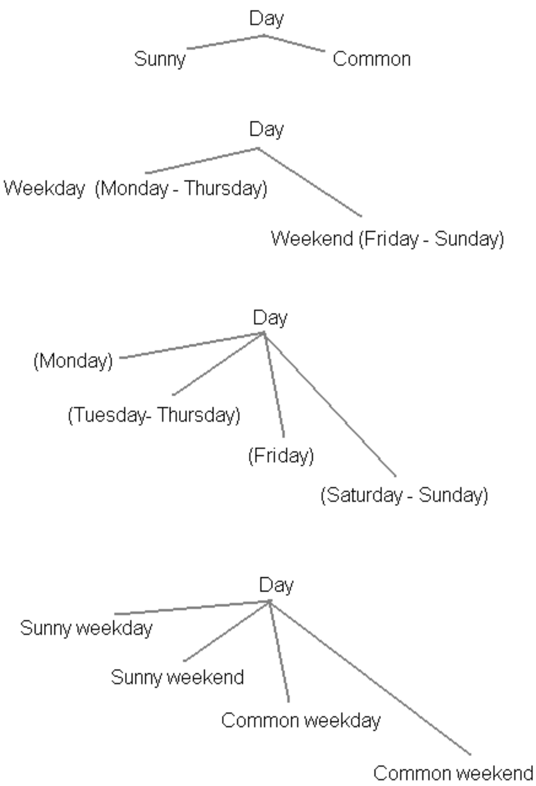

Fig. 3 Four variant of heat consumption research

III. CONSUMPTION SURVEY

Returning back to out example, what else we need to consider improving our heating schedule from Fig. 2, which made use of just the outside temperature?

First at all, we need to know quality of our heat consumers, which is not easy to measure and which is also changing during the years.

The way we chose and now we are presenting in this contribution is to utilize records of measured data, so our survey was mostly based on the historic data analyze. Our data come from regional heat-distributor company. The part of middle sized city was chosen with monitored winter season 2007/2008. Range from 1st of November 2007 to 31st of March 2008, to be specific.

The chosen part can be described as fourteen house station (*HS*) connected to the one heat exchanger (*HE*). Whole area is about one square kilometer. See Fig. 4 and 5.

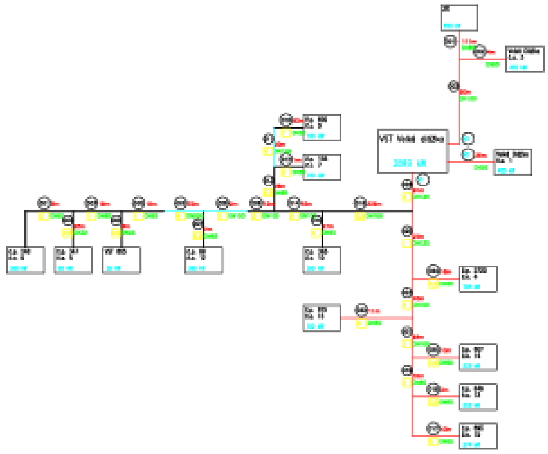

Fig. 4 Schematic consumers lay-out

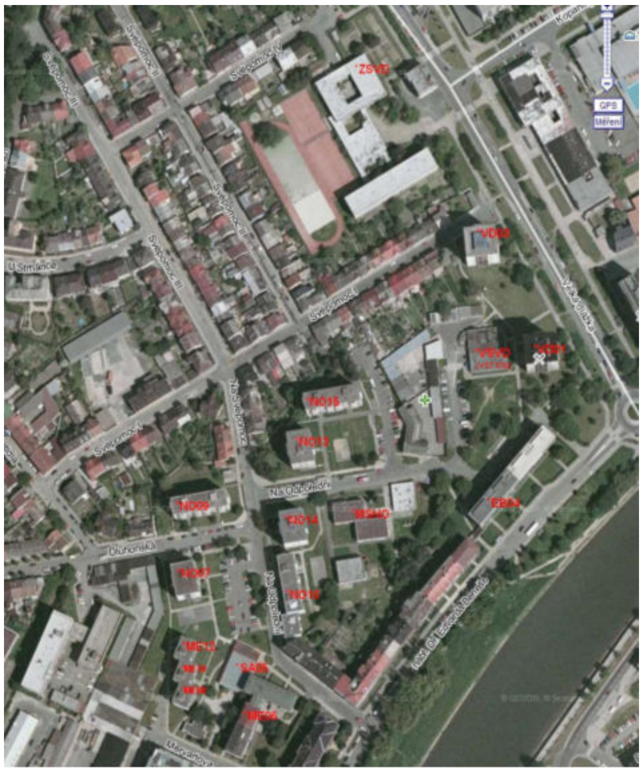

Fig. 5 Chosen location and its *HS* in satellite view

There is an outside temperature probe monitoring surround of *HE* and also each *HS* has its own temperature probe. Those probes are source for weather compensation control running on each *HS*. The *HE* has also this kind of regulation but our experiment is now focused just on *HS* heat consumption. The comparison between significantly sunny days and common days will be presented.

A. Conditions

First let's have a look at the figure below. It shows average outside temperature for each day in monitored interval. This will be significant part of our later experiment.

Note: These temperatures were measured on *HE*, northern side with whole day shadow.

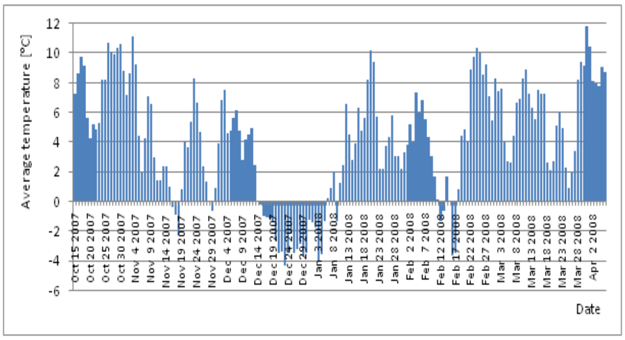

Fig. 6 Average outside temperatures 2007/2008

The picture above shows almost regular course of outside temperature for the Czech Republic. Maybe November and January were little warmer, but with the cold December we have nice sample period for our research. Also it is important to add, that day with average temperature below 12 degrees is considered as a day when heat supply is requested. There are of course additional terms, but for our example the chosen period suits well.

Besides the outside temperature we needed data describing day consumption and information about heating schedule applied on these days. Because there was no direct information about consumed head for each *HS* we had to process simple calculation utilizing amount of "shipped hot water", its temperature on input and temperature of return. See (2) where temperature ΔT is obtained as a difference T_{in} - T_{return}. Consequently, with regard to following, calculation is not exact. It neglects time delay and then we can not unambiguously describe consumption from midnight to midnight to define accurate day. Also particular buildings are different; they have various thermal isolation qualities, constitution of people living inside differ, consequently to describe exact consumption is quite complicated task. For our experiment is sufficiently enough to calculate immediate supply oriented to return water temperature. More accurate explanation will be handled in chapter IV.

B. Sunshine effect

For the first experiment we needed to know the sunshine intensity or at least information describing this kind of condition for particular day. As expected, the heat producer does not measure sun intensity and so there were no record connected to available data source. To purchase these missing data from meteorology institute were that time uselessly complicated and expensive. Also from running analysis we already had some suspicion and ideas how to obtain simplified information from available sources.

Basic analysis showed that temperatures measured on *HS* occasionally considerably differ.

The reason could be:

- The probe is near the source of heat, such as open cellar window and so on,
- the probe can be broken,
- the probe is inappropriately installed (exposed to the direct sunshine).

The subsequent tests comparing characteristics showed, the sun was the main reason. The knowledge of this disadvantage enabled the possibility to pick the dependent and independent *HS's* temperature probes.

Following figures show temperature measured on each *HS* with 5 minutes period during the sunny days. On those pictures can be seen apparent course diversity of blue, green and light-blue curve. To be more accurate there were also shifts during the year, the peek expands in time and boost in late spring. Explain above mentioned, we can look on sky and think about earth rotation around the sun and subsequently realize the length of daylight during a winter, fall and spring. Contrast to hardly nine hour during a December (daylight starts about 7 AM and sunset came soon after 4 PM) and April with the daylight for at least 12 hours. Valid for Czech Republic, as a location research took a place.

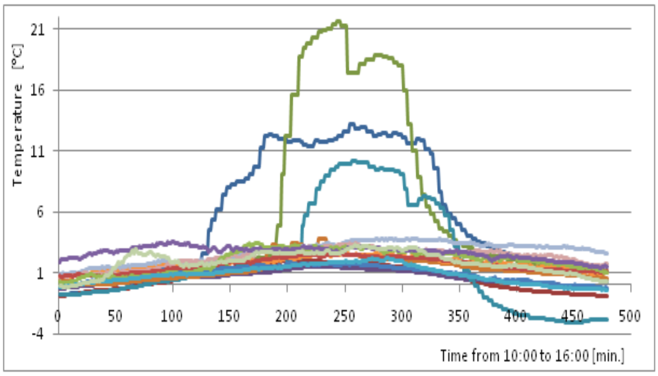

Fig. 7 Temperature course at 28.11.2007

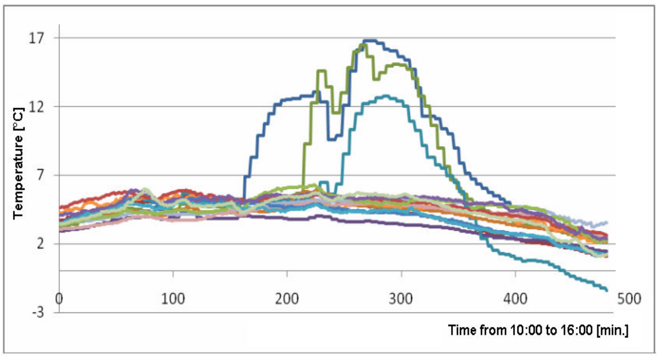

Fig. 8 Temperature course at 8.1.2008

A. Advantage of disadvantage

As mentioned before and also figures above shows, some temperature probes are affected by the sun. Also from the time course it can be seen, that orientation of those affected probes to the sun slightly differs as mentioned earlier. Nevertheless, this disadvantage gives possibility to obtain information advising us whether day was sunny or not and eventually estimation of the intensity.

B. Sunny-Day Function

- Two *HS*, without affection of the sun, was chosen as referential for shadow temperature. (HS_{x1}, HS_{x2})
- Other two *HS*, significantly affected, was used as for comparison. (HS_{y1}, HS_{y2})

The HS_{xy} temperatures were calculated as average value from time 10 AM to 4 PM.

Then result Su can by obtain by this formula:

$$Su = \frac{(HS_{y1} + HS_{y2})}{2} - \frac{(HS_{x1} + HS_{x2})}{2} \quad (1)$$

Days when Su is significantly higher than zero can be though as sunny. “Significantly higher” value divides days into two categories:

- Significantly sunny
- Common

The value selected to perform this division is Su higher than value 2.

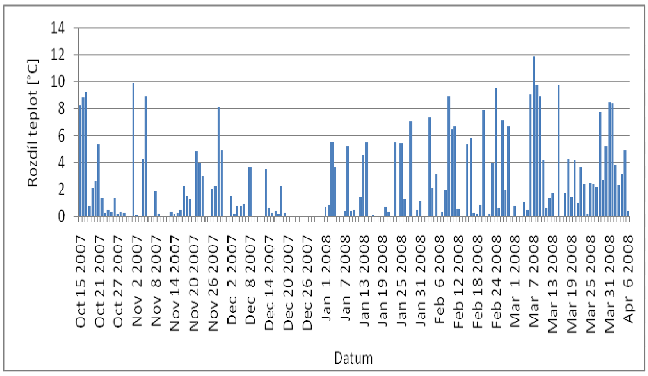

Fig. 9 Calculated Su for chosen period 2007/2008

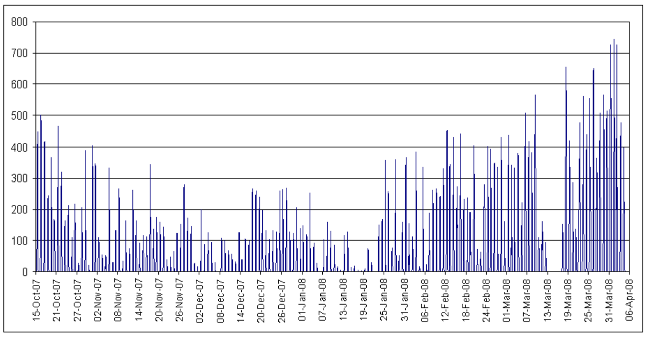

Fig. 10 Measured sun intensity 2007/2008

Previous pictures show sun activity which was calculated and measured. For subsequent processing just *Su* calculated values has been used because during the survey the measured data were not available. The measured intensity was obtained later and now serves just as an example for comparison. See Fig. 9 and 10. There are slight differences between these courses but this will solve subsequently.

IV. Relation between Consumption and Outside Temperature

Let’s presume that consumption is defined by:

$$E = m * cwh * \Delta T \qquad [W.h] \quad (2)$$

where:

cwh specific thermal capacity [(W.h)/(kg.K)] is equal to 1.163

ΔT temperature [°C]

M weight [kg]

From the equation above we can assume that decline in the outside temperature, supposing constant inside temperature, cause consumption rise.

Some above mentioned *HS* records immediate consumption (5 min. periods). We took one of these records and looked for relation between outside temperature and consumption.

Consumption and temperature were traced as a value of day sum. See Fig. 11.

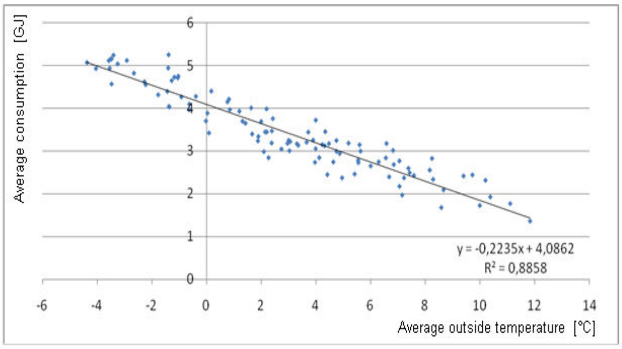

Fig. 11 Relation between outside temperature and consumption

Acquired linear function:

$$Ed = -0,2235 * Tdv + 4,0862 \quad (3)$$

where:

Ed determined value of consumption [GJ]

Tdv average outside temperature [°C]

Considering relation as linear we can perform simple comparison between measured and calculated consumptions.

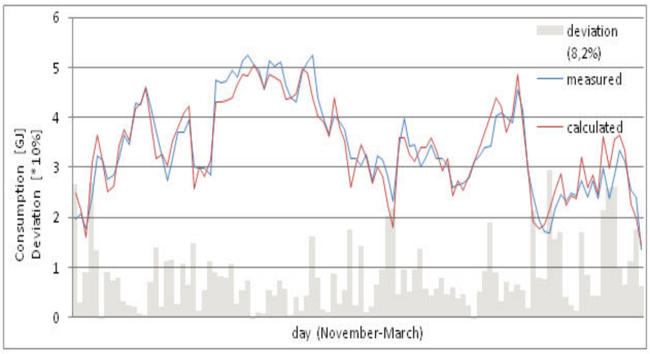

Fig. 12 Measured and calculated consumption (one relation)

A. Factor of the particular weekdays

If we assume, even though the behavior of the object is almost independent of human activity, that people have a higher temperature requirements for their houses at a time when they are at home, and vice versa at a time when away from home, because of savings or other reasons, they reduce temperature needs.

A.I Week spitted into four groups

To expect above mentioned, the relation between consumption and temperature has been divided into four sub-groups.

1) *Saturday, Sunday* as a weekend day, when the assumption that the average person spends more time in their homes and therefore require more comfort and thus may be linked to higher consumption of heat.
2) *Tuesday, Thursday* as a typical working day, with lower requirements for heat
3) *Monday,* even if it could be considered as a work day was made independent because it can play a role in building momentum after a weekend days.
4) *Friday,* this day was made independent, relying on the assumption that the end may be part of a weekend (people working in remote locations, students from colleges already spend time at home, etc.)

The same procedures as in the previous section give us following function:

$$\text{Sa, Su} \quad E_d = -0{,}2102 * T_{dv} + 4{,}1704 \quad R^2 = 0{,}8913 \tag{4}$$

$$\text{Tu, Th} \quad E_d = -0{,}2308 * T_{dv} + 4{,}0319 \quad R^2 = 0{,}8556 \tag{5}$$

$$\text{Mo} \quad E_d = -0{,}2235 * T_{dv} + 3{,}9180 \quad R^2 = 0{,}852 \tag{6}$$

$$\text{Fri} \quad E_d = -0{,}2267 * T_{dv} + 4{,}2206 \quad R^2 = 0{,}9488 \tag{7}$$

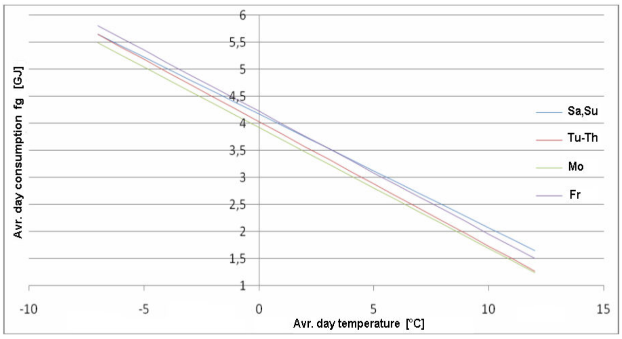

Fig. 13 Four relations

To apply those four relations to calculate several months course we got following results – see Fig. 14.

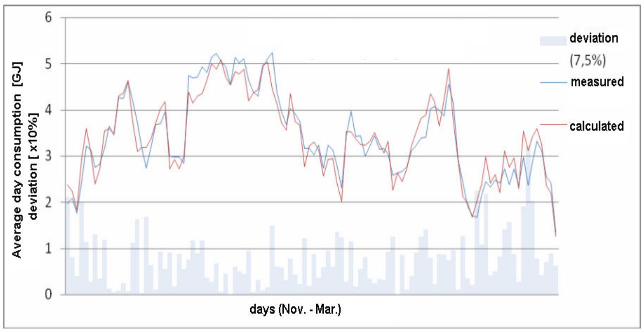

Fig. 14 Applied four relations and compared with measured course

The charts above shows that the introduction of the four functions means improve at the level of 1%.

A.II Week spitted into two groups

Despite the introduction of the four functions in week mean improve in deviation; from a statistical point of view it does not seem too be appropriate.

If we are considering Monday and Friday as separate groups and use the sample data for one heating season, we come to number around 20 samples in these groups. We worked with very small sample size, depending on the nature of the group after Friday introduced a simplification rule, which created only two groups, Monday to Thursday and a Friday to Sunday.

Repeating the already mentioned procedure has been derived the following functions:

$$\text{Mo-Th} \quad Ed = -0{,}2319 * Tdv + 4{,}0125 \quad R^2 = 0{,}8691 \tag{8}$$

$$\text{Fr-Su} \quad Ed = -0{,}2181 * Tdv + 4{,}1912 \quad R^2 = 0{,}9097 \tag{9}$$

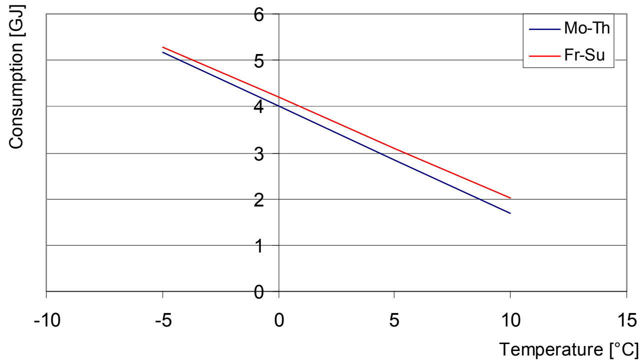

Fig. 15 Two relations

To apply those two relations to calculate several months course we got following results – see Fig. 15.

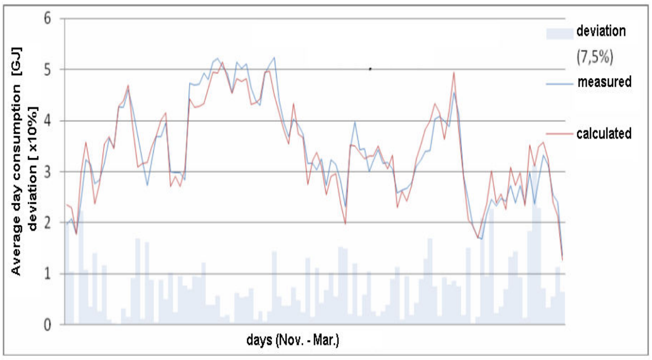

Fig. 16 Applied two relations and compared with measured course

The chart above shows that the introduction of the simplification rules mean only minimal changes in deviation. For the original distribution of the value, the deviation was 7.504 % and after the application of rule 7.519 %, so changes in the order of hundredths.

To look closer Fig. 13 and 15, the expected behavior was approved. The consumption during the weekend days is slightly higher which is not such epochal find, many companies already control head supply separately for weekends and weekdays using individual compensation curve for these intervals.

V. Relation between Consumption and Outside Temperature Reflecting Sunny Days

As shown in chapter III we build the mechanism to divide our database, used in preview experiments, into two groups:

- significantly sunny days,
- common days,

than relation between outside temperature and consumption was traced again. We focused to describe consumed head again, first to apply new rule, then extend the already tested methods with this new rules to improve final results.

Acquired linear functions for:

Significantly sunny

$$Ed = -0{,}2035 * Tdv + 3{,}9317 \qquad (10)$$
$$R^2 = 0{,}8633$$

Common

$$Ed = -0{,}2326 * Tdv + 4{,}1806 \qquad (11)$$
$$R^2 = 0{,}8997$$

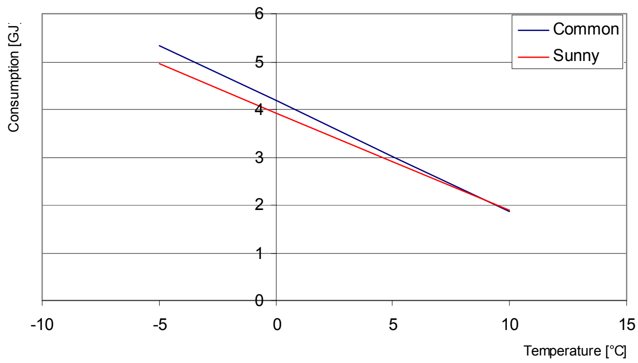

Fig. 17 Linearized consumption for common and sunny days

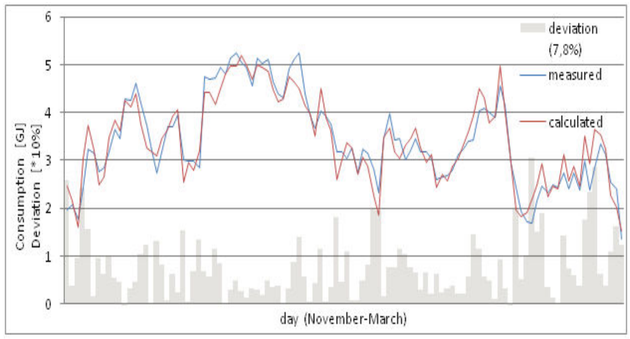

Fig. 18 Measured and calculated consumption (two relations)

When comparing the deviation of this method with the method without consideration of sunshine, we get about 0.5% more accurate.

A.I Sunny/common and factor of the particular weekdays

In previous chapter we showed importance of dividing weeks at least into two parts and seeking consumption individually for them. The last experiment was an effort to refine methods sunny / common days by a factor of the particular weekdays.

The same procedure as in previous experiments has given us the following functions:

Sunny Mo-Th

$$Ed = -0{,}2225 * Tdv + 3{,}8899 \qquad (12)$$
$$R^2 = 0{,}8935$$

Sunny Fr-Su

$$Ed = -0{,}1899 * Tdv + 4{,}0289 \quad (13)$$
$$R^2 = 0{,}8852$$

Common Mo-Th

$$Ed = -0{,}2280 * Tdv + 4{,}1088 \quad (14)$$
$$R^2 = 0{,}8276$$

Common Fr-Su

$$Ed = -0{,}2359 * Tdv + 4{,}2648 \quad (15)$$
$$R^2 = 0{,}9281$$

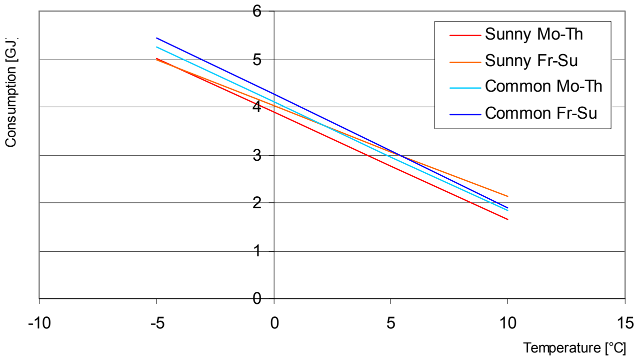

Fig. 19 Linearized consumption for common and sunny days considering day type

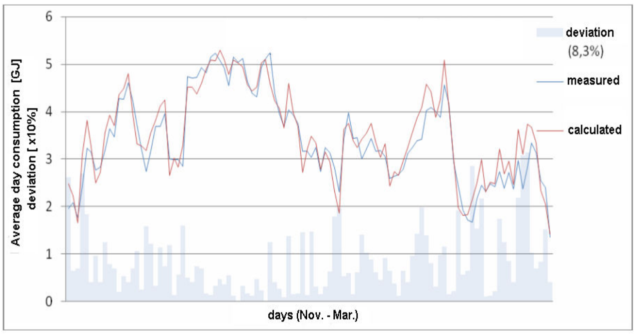

Fig. 20 Measured and calculated consumption

Even though this method uses all the examined precision that result should lead to the most exact, deviation of this method is one of the highest of all methods. The probable cause is too small number of samples in each group and thus inaccurate estimation of the function.

For example, the group Sunny Fri-Sun for the whole projection period contained only 24 samples. However some important facts can be seen from both experiments. As can be seen in Fig 17, the days with the same outside temperature have various energy needs. Especially with outside temperature fall the variation is more significant. Now, have a look to Fig. 19.:

The significance of the colder temperature days with sunny activity and lower energy needs is noticeable. A little bit confusing is line of sunny weekends and common weekdays. The effect of weekends day adds energy needs but sun intensity push these needs down, so final results are similar to common day – with lower needs, but compare to sunny day growth.

VII. Conclusion

In this research various factors that may affect the heat consumption were analyzed. Described procedures do not come with general, exact parameters of the process of heat dependences, but focused only to verify the expected relations, and thus give a basis and directing the development of intelligent prediction algorithms for power management.

Also it must be considered as an example for specific location; however modified procedure should be applicable widely.

This work confirmed validity of ideas about dividing days into specific groups. The following divisions were examined:

- Weekday and weekends (Friday considered as a weekend)
- Sunny and common days (With own calculation of sun intensity from outside temperature)
- Monday, Tuesday-Thursday, Friday and Saturday-Sunday individually
- Weekday (sunny), Weekday (common), Weekend (sunny) and Weekend (common)

Upon further examination of factors affecting consumption should be taken into account properties that have not been in this work due to the simplification considered. The following list shows some of them, and also sets targets for further research in this field.

- The dependences were calculated from the whole period, the real prediction can be used only to previous values, and it is therefore necessary to apply any of the methods of line identification. (Can be partially corrected by using the previous values of the heating season)
- Has been assumed only a linear dependence, it would be appropriate to apply more sophisticated functions.
- To achieve the above mentioned deviations would need to know the exact value of the ambient temperature the following day. The real prediction would therefore have to enter the forecast error.
- On the contrary, solar activity was considered indicative only and only in the form will be / will be a sunny day. Thus the introduction of more parameters describing the intensity could lead to further refinement.
- The experiment was conducted for only one inclined house, in one location and thus the necessary procedures to verify the larger group of objects and locations.
- Due to a large accumulation capacity of the houses to be appropriate in future experiments to look about relationships where the function will be adjusted depending on the nature of the previous day (day).

Well, this short research tried to show things to be considered. It pointed to significance of few factors from the large groups affecting consumption. It is important not to forget, that each step specifying problem with possible subsequence to precise regulation can fetch in significant savings. Presented improvement were sometimes just about 0.5% in identification process.

If we look for more factors affecting consumption we can surely get better percent, but as shown above, some steps need more attention. And of course, better problem description opens possibilities for better regulation and so on. And also we dare say the economy savings at the end of it.

Often few factors are considered, usually outside temperature as the base for weather compensation controls, day and night, and sometimes the day of the week (weekends or working day). Evidently, as mentioned several times above, effort to be more accurate is obviously suitable.

ACKNOWLEDGMENT

The work was performed with financial support of research project NPVII-2C06007, by the Ministry of Education of the Czech Republic.

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