# The influence of user behaviour on energy use in old dwellings: case-study analysis of a social housing neighbourhood

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## ABSTRACT

Taking user behaviour into account to predict the real energy use and possible savings in houses, remains a challenge of huge importance for the Belgian social housing sector, which owns large buildings stocks in urgent need of refurbishment. Within this context, a case-study analysis was carried out on 36 (nearly) identical social houses from a single neighbourhood, dating from the sixties. Information on user behaviour, indoor air quality and thermal comfort was gathered both through in-situ measurements and through surveys of the inhabitants. Furthermore, air tightness and heat flux measurements aimed at increasing the accurate knowledge of the buildings' characteristics and data on real energy use were gathered.

This paper presents some findings from this case study, focusing on the energy use for heating. The huge differences in energy use observed between households on the one hand and between theoretic EPBD-calculations and real measurements on the other hand are investigated. The findings from the measurements and the surveys are implemented in an improved multi-zone quasi-steady state calculation code reaching much better correlations with the real energy figures. This illustrates the influence of some behavioural parameters and the usefulness of both sources of information: surveys and measurements. Remaining causes of discrepancies are further reported.


## 1. Introduction

Divergences due to user behaviour between real and predicted energy use in dwellings as well as some basic principles such as the rebound-effect have been raised many times in literature (as in e.g. Hens 2009). Taking user behaviour into account to predict real energy use in simplified models however, remains a challenging task. Probabilistic approaches can deliver smooth fits between theory and practice when analysing energy use on larger building stock levels. The challenge is different, however, when predictions have to be made for individual building projects or even specific households. This is of great concern to many house owners and tenants in order to know the (often financial) effectiveness of their investments. This is all the more so crucial for the social housing sector, as social housing companies are on a tight investment budget for their often very old and poorly performing building stock, as well as for the tenants on a tight household budget. To estimate potential savings, current energy use first has to be quantified and understood before possible renovation measures and the 'renewed' energy figures can be considered.

The calculation method for local official energy labelling, as programmed in the Flemish EPBD-software, aims primarily at certifying dwellings with regards to their energy performance, rather than estimating their actual energy demand for a specific household. More advanced, dynamic calculation methods exist, yet they require a higher knowledge and expertise in order to be used correctly as well as more work and time, resulting in higher costs. Therefore, it would be valuable to see how close to reality predictions could get with simplified, yet more accurate methods while keeping essential similarities with the official calculation method and some of its advantages.

Within this aim, a case-study analysis was carried out on an old social housing neighbourhood. The raw data on this neighbourhood was gathered during a joint master thesis and is being reprocessed within the framework of a PhD-research. The case-study illustrates the large divergences in energy use between households and the even large overestimation of the heating demand by the official calculation method. Yet the goals lie further than in mere illustration: they lie in gaining additional insight and knowledge in the most influencing factors causing those divergences between the calculated and measured energy figures. Information on user behaviour and thermal performance was therefore gathered both through in-situ measurements as well as through a thorough survey of the inhabitants. Furthermore, measurements were conducted on the building level to increase the researcher's knowledge of the buildings' real characteristics. Additionally, energy use data was collected. The findings from analyses on this data served subsequently as an input to test possible increase in prediction accuracy in a more extended, yet simple and fast-calculating multi-zone model.

This paper presents the results from the analysis on the heating demand. It shows that better correlations can be found between the present calculations from the EPBD-methodology and real energy use with some basic modifications of the calculation method, looking mainly at multi-zoning and intermittency. Despite the better correlation, both the absolute as well as the relative gaps remain high.

## 2. Case-study & direct findings

### 2.1 The dwellings

The case-study consists of a neighbourhood of 36 (nearly) identical houses dating from the '60-ties. Over the years, some minor works were performed on the houses, though without any global or systematic approach. Therefore the changes and differences between the buildings are investigated through visual inspection and measurements.

### *2.1.1 Building typology*

The dwellings are all small single family houses based on the same design, composed of a ground floor with the 'day-area's', 3 bedrooms and a bathroom on the first floor, a small cellar and a closed attic (Fig.2). The building envelope was built out of brick cavity walls, wood window frames with single glazing and a tiled roof. No insulation whatsoever was placed, be it in the walls, floor, roof panes or on the attic floor. The only heating system originally installed was a gas furnace in the living room. The only 3 original differentiations between the dwellings arise from their positioning within the neighbourhood (Fig.1).

The houses being spread over both sides of 3 parallel streets, 2 main orientations occur (NE & SW). While orientation is a main concern within energetic design of houses, its effect remains minimal in this case as front and back facade show nearly the same window area and as the house zoning is almost symmetric. Moreover, the living space consists of a single open space reaching from front to back facade with windows on both sides.

The houses are spread in small groups separated by a garage on ground level, causing some to have neighbours on only one side and an unheated space adjacent to the ground floor on the other side and nothing on the first floor.

To require only 1 access to the street and 1 chimney construction every 2 houses, one out of two is mirrored thus placing circulation zones as well as living rooms against each other. While not taken into account in the energy labelling procedure as both sides are considered as zones on the same temperature, this is an optimal placement in practice as the most heated spaces touch each other. Nevertheless, some houses are uninhabited, causing increased heat losses through the adjacent dwellings.

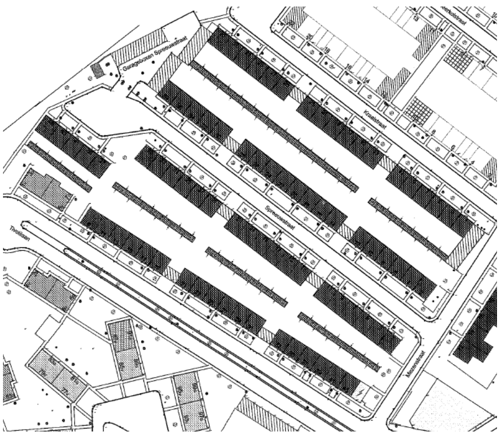

Fig.1. neighbourhood

### *2.1.2 Building changes*

Over their 50 year lifespan, some houses did undergo limited renovations of which the main ones are described hereunder. Some windows were replaced on individual basis, causing an unstructured mix of single and double glazing as well as of wood and PVC window frames. The amount of double glazing is very limited, with only 3 houses having double glazing in both living room windows.

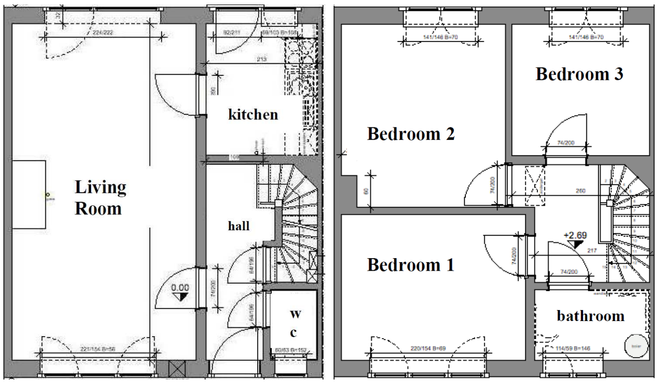


Fig.2. Plans: ground floor (left) and first floor (right)

The heating systems also remained mostly unchanged, with only one house (W27) being equipped with a central heating system with radiators. In most houses a small electric heater was installed in the bathroom and some inhabitants added an electric heater in their bedroom.

Nothing changed in the inside structure or organisation of the houses, except for the kitchen door being removed in almost every house, creating a single 'day/living area'.

### *2.1.3 Measured characteristics*

As the massive non insulated cavity walls constitute a large fraction of the building envelope, making up for a huge fraction of the transmission heat losses, correct information on their thermal properties is crucial for input in the calculation models. While all dwellings were built together, workmanship amongst others can cause variations in thermal performances from one wall to another. Furthermore, measurement conditions, sensor placement and analysis models can cause some additional deviations. Therefore, heat flux measurement were conducted on a sample of 4 walls of as many different dwellings, taking measurements at 2 different location on each wall. Fig.3 shows the results from those 8 measurements, each analysed with the simple average method, the average method with storage correction and the dynamic method from ISO 9869:1994(E) and compares them to measurements on a reference sample of non insulated cavity walls from a Belgian research project on cavity wall retrofitting (Delghust et al. 2010).

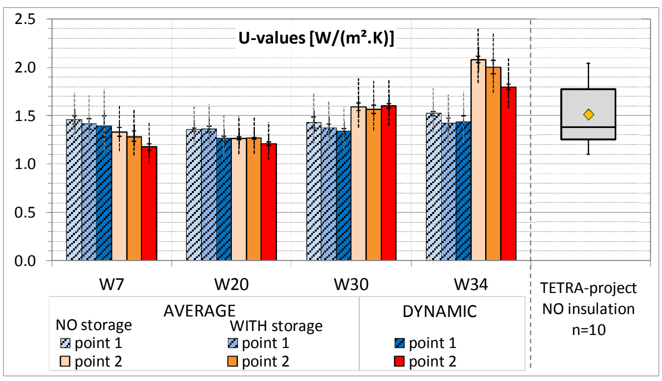


Fig.3. Heat flux measurements: U-values [W/(m².K)]

It shows a clear spread of results, of which most lie within each others' error margins. Those are constituted mainly from the error-estimation due to placement according to ISO 9869.

The part of the error bars between the horizontal cross-lines indicates the error estimation due to the calculation method itself. Nevertheless, one measurement on the wall of house W34 clearly shows a higher level of heat losses. This could partly be due to measurement inaccuracies, but local disruptions such as mortar bridges in the cavity and wall ties should not be dismissed. In both cases, the value of taking more than one measurement point is to be stressed.

The second set of field measurements on the buildings themselves was air tightness testing. The 24 measured houses showed very high levels of air leakage, reaching even higher than the default v50 value of 12m³/m² implemented in the Belgian official EPBD-method. This is in considerable contrast not only with the best practice values for low energy dwellings, but also with standard levels measured in Belgium for standard new builds. This is not uncommon, however, for old dwellings. Fig. 4 compares the air change rates at 50Pa pressure difference (n50-values [$h^{-1}$]) with reference data for Belgian single family houses. Those are results from a random sample of houses built in the late '80ties and early '90ties from the Senvivv-project, from a random sample of standard dwellings from the past 5 years (UGent) and from recent measurement data from private party consultants (BD), of which the explicit low-energy houses (LEH) are separated, as a representation of todays 'engaged' market segment, as discussed by Laverge et al. (2010). The spread in air tightness within the neighbourhood can be attributed to workmanship, some small dispersed renovations such as local window replacements and to the presence of a few semi-detached houses.

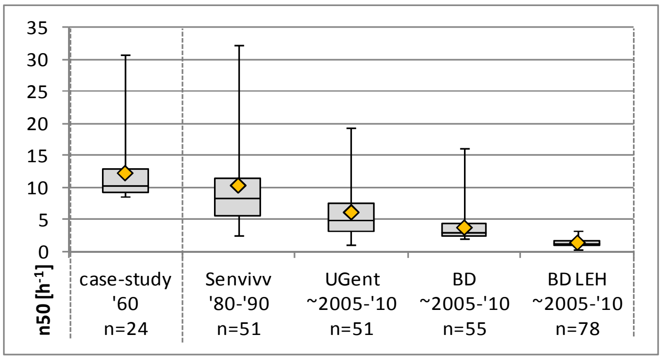


Fig. 4. air tightness measurements: n50-values [$h^{-1}$]

### *2.1.4 Reference energy use according to EPBD*

The heating demand calculations in this paper were not performed in the official EPBD-software, but in a separately developed calculation code, allowing automation and parameterisation as well as calculating the house both according to the official EPBD-method and in more detailed models (see 3.2). The dark dots in Fig.5 compare the real energy use derived from the gas consumption data with the energy use for heating according to the current Belgian EPBD-methodology, taking all available building related data into account, including also the measurement data. The model is thus composed of a single zone for the entire inhabited area (ground and first floor), with a fixed averaged set point temperature of 18°C, while the attic is implemented as an adjacent unconditioned zone and no heat losses are considered to the adjacent houses. With the lighter markers in Fig.5 the uninhabited adjacent houses are implemented as detailed unheated adjacent zones in the building model and no intentional ventilation heat losses are considered, as window opening times are considered minimal during the heating season (see 2.2.2). Taking into account the presence of unheated houses within the neighbourhood causes the adjacent houses to have larger heating demands and thus creates a larger spread within the sample. Considering no ventilation heat losses however, has a larger effect on the heat balance, causing all heating demand estimation to be lowered.

Apart from the estimated divergences due to the building characteristics and adjacent spaces, the huge gap and lack of correlation between predicted and real energy use are sources of concern. This can be vastly attributed to the varying user behaviour not being taken into account, even though the overestimation is valid for every household. Possible errors in the assumed building characteristics and other model properties should not be dismissed, as will be further discussed in paragraph 3.

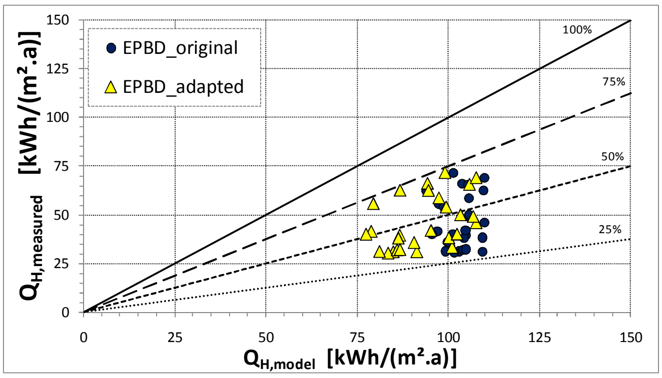


Fig.5. gross energy demand for heating: EPBD

## 2.2 The inhabitants

Data on the inhabitants, the household compositions and their interaction with the buildings was collected through surveys. Those surveys were taken only after the measurement period so as to prevent their influencing the measured behaviours. To cross-check the reliability of the answers, information on some points of special interest were collected through different ways at different points within the survey. With regards to the size of the survey, this paragraph compares only as illustrative, selecting some of the most influencing parameter from the perspective of the energy need for heating.

### *2.2.1 The inhabitants and their presence*

From the 36 analysed houses, 33 have both useable measurement data and surveys, corresponding to 97 inhabitants. To foresee applicability of the results from this case study onto other cases (of social houses or not), checking the representativeness of the inhabitants sample is crucial before analysing the survey results in more detail. This is especially necessary as the sample is quite small from a statistical point of view and consists purely of social housing. This was done by comparing the figures from the neighbourhood to Belgian data from the National Institute for Statistics (NIS). It is however important to note that the comparison data for Belgium is not specific for single family houses. Fig.6 compares the ages of the population, showing a higher representation of elder people and young children in this neighbourhood.

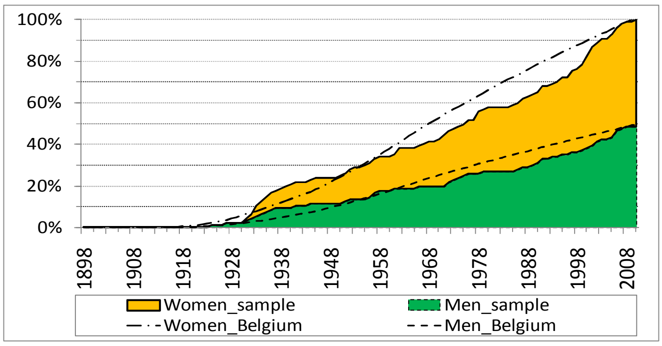


Fig.6. year of birth: cumulative distribution

The next comparison selected here focuses on the probability for a specific person to be present in a certain room of the house over the course of a day, as derived from the time schedules filled in by the inhabitants. It shows the first, though not actively defined link between the user and the building. While some clear and expected agreements can be seen between the samples' figures (Fig.8) and the Belgian data (Fig.7), especially when looking at night hours, a clear difference can be noticed when looking at day time values. The sensibly higher occupancy of the living room during daytime, can be explained both by the age distribution (more older, retired people) as well as through the somewhat higher level of unemployment found in social housing. The lower occupancy of the kitchen is as noticeable but less obvious to explain, though the absence of any eating zone in the kitchen might be one reason for its low occupancy. The probability of at least one person to be present in the house or to be present in the living room, is added in Fig.8 as this will define the possible need to heat the building for direct thermal comfort.

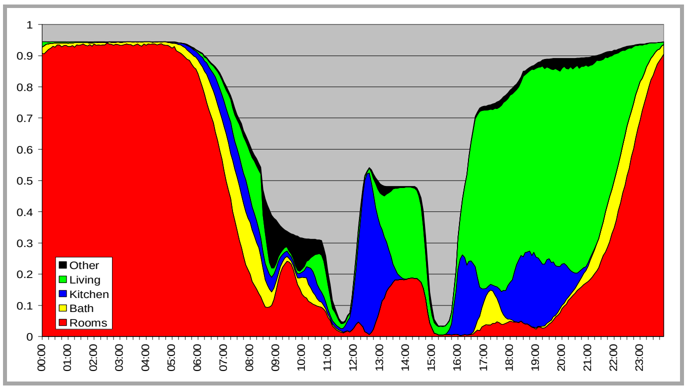


Fig.7. cumulated probability of presence: Belgian data (NIS)

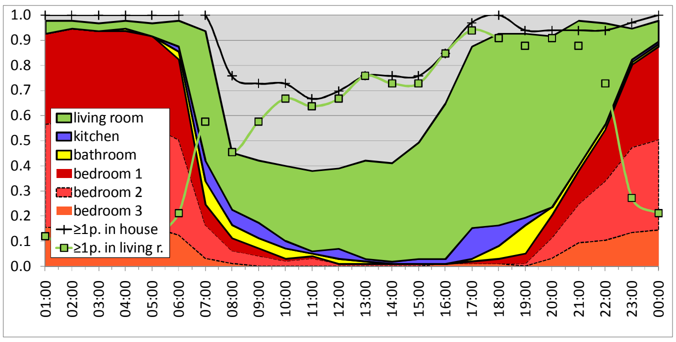


Fig.8. cumulated probability of presence: case-study

*2.2.2 Active user-building interaction*

Next to presence, the use of heating devices over the course of a winter day was investigated and translated into a similar, yet not cumulated, daily probability profile (Fig.9). These figures are of course coloured by the limited availability and spread of heat emission units, furthermore mainly electric ones, outside the living room. Nevertheless, further analyses of the surveys and measurement data show that also those people with heating devices in their bedrooms tend to use them only seldom and for a brief period of time, mainly before going to sleep on very cold days. This coincides with findings about heating use from a larger, regional Flemish study (VEA 2008).

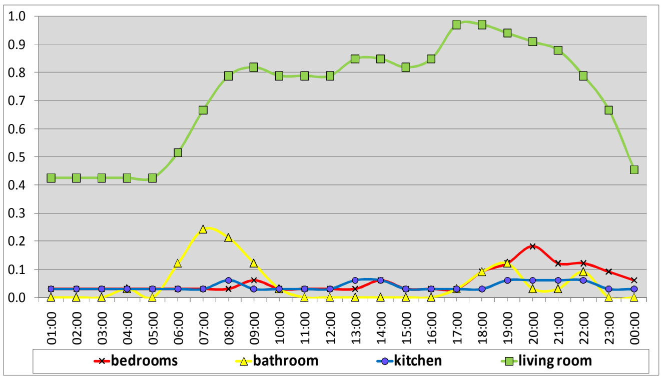


Fig.9. probability of heating: case-study (neighbourhood)

The opening of windows is yet another major factor of influence behaviour has on a buildings heat balance. It is the subject of Fig.10. The very low amount of open windows is most noticeable in the living room, which is the most heated and most actively used room, while the bedrooms are mainly ventilated outside presence time during the winter season.

Because of this low probability of opening windows in the heating area, it is left out of the energy calculation model, resulting in a sound simplification, as early cited in paragraph 2.1.4. This is further strengthened by the fact that "keeping the cold outside" is clearly indicated as the main reason in all rooms for keeping windows closed or *closing* any open windows, yet interestingly enough more so for the bedrooms (79% of the respondents) than for the heated living room (58%). This is followed by "preventing cold draft", showing no significant difference between living room (33%) and bedrooms (30%) and by "for security reasons" (especially on the ground floor on street side: 36%). In addition, only 3 out of the 33 households stated that they did not close any windows in case of weather precipitation.

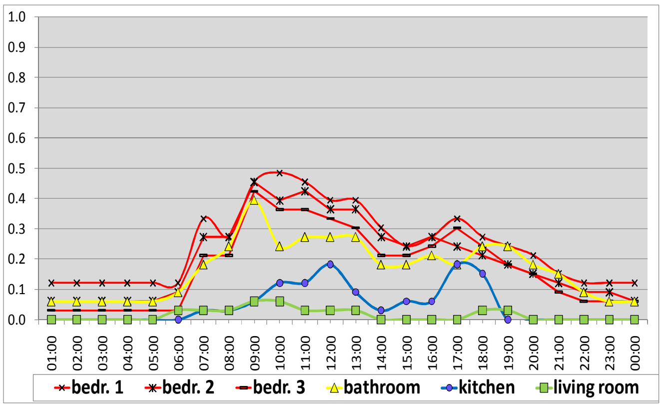


Fig.10. probability of an open window: case-study

## 2.3 The indoor measurements

Measurements of indoor air quality and thermal comfort took place for relatively brief periods of 7 to 10 days during the heating season. CO2-measurements were only taken in the living room, while temperature and relative humidity was measured (if possible) in every accessible room, including the basement. Although this would be a possible subject for a separate inquiry on indoor air quality and comfort, this data will only briefly be discussed here, solely from the perspective of the heating demand and thermal comfort.

As might be expected from the distribution of the heating appliances and their use profiles, the temperatures in the living room reach much higher values than in the other zones (see 3.3.2 and Fig.14). Their fluctuation over time is mainly caused by the heating intermittency patterns in contrast to the cold outdoor temperatures, while the fluctuations of the indoor temperatures in the other zones are more highly influenced by the dynamics of the outdoor climate in itself. From these dynamic profiles, averaged set point temperatures and daily heating periods have to be derived for subsequent use as inputs in the heating demand calculation model.

### *2.3.1 Set point temperatures*

As the analysed houses (except W27) have simple gas furnaces without thermostat, it might seem questionable to look for a 'set point' temperature. Nevertheless, from careful analyses of the temperature profiles, average equivalent set point temperatures can be deduced from the average point of stabilisation of the indoor temperature during occupancy. The low energy performance of the buildings allows very clear distinction of the real start and end of heating phases during the cold measurement period. The representativeness of those set point temperatures for use over the whole heating period can be questioned due to manual control of indoor climate conditioning being subject to different phenomena of adaptation through e.g. shifts in expectation. Some basic correlations exist such as from the work of van der Linden (2006), though they are mainly of probabilistic nature and often oriented towards use in office buildings and therefore risky to apply here as we are looking at individual households in a specific type of dwelling. As measurements were taken during the middle of the heating season, underestimated set points might be rendered for the start and end of the heating season due to these adaptation phenomena. On the other hand, during the middle of the winter, other causes of discomfort are more likely to occur, such as draft, radiation asymmetry etc. that might be compensated by a higher set point. In the absence of longer term measurements, making corrections on the measured values would be merely guesswork.

### *2.3.2 Heating periods*

One by one comparisons of the measured indoor temperature profiles with the assumed heating profiles from the surveys reveal the need for a critical approach to data collected from surveys. While some variations are fully normal and expected, especially as there are no clock thermostats, some discrepancies are quite recurrent. The most common ones consist of systematically later wake-up times and bed-times as well as less frequent use of the bathroom while, on the opposite, switching the bathroom heater back off is sometimes forgotten. The use of the electric heaters in the bedroom, while almost always of brief duration, also shows discrepancies. From the measurements and survey, this could probably be attributed on the one hand to the fluctuating outdoor temperature (lower use of electric heaters: only when it is really cold) and on the other hand from the secretive turning on of the heaters by the children in their bedroom. While the reason or origin of these discrepancies could only be investigated through more extended analyses on larger samples, it is important for this analysis to take the findings from the individual measurements into account when defining the heating profiles for the individual heating demand calculations. This might not always be feasible in a design phase by absence of measurement data on the preceding and, by definition, on the future condition. Nevertheless, it is performed in this analysis to narrow down the error margins and filter out a maximum number or error causes.

Fig.11 shows, for the living room, both the averaged measured temperature and the daily heating time fraction in comparison to the derived set point temperature. It shows how most people heat their living room less than 60% of the time, resulting in a considerably lower average temperature than the high set point temperature. Few have their gas furnace on almost all day long. Those reach good correspondence between both temperatures. While the average temperature in mid season might reach higher levels than the set point temperature, due to e.g. sunny afternoons, this was not noticed here due to the very cold period in which measurements took place and the low insulation level of the houses. Some houses where heating is assumed 24hours a day show slightly lower average temperatures than the set point temperature. This might be caused by temporary temperature drops due to very rare occasions of setback, lack of heating power, or brief opening of windows/doors. Of course, one has to bear in mind the possible error on the estimated set point temperature or its possible fluctuation over the course of the heating season and even the measurement period, as described in 2.3.1.

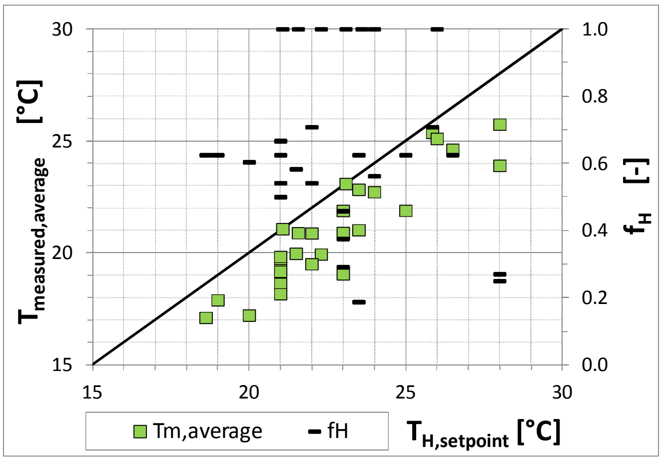


Fig.11. daily heating time fraction & average measured temperature vs. set point temperature (living room)

## 3. Personalised heating demand calculation

Findings from the cross-analyses of both the surveys and the measurements, as selectively illustrated above, were used to further refine the calculation models and personalise the input data to each households' profile. The results from these models are subsequently compared with the real energy use figures and measured temperatures.

### 3.1 Pre-considerations

While the goal is to see how close the simplified models' results will get to the real measured values, a perfect match can hardly be expected. Discrepancies will arises from inaccuracies on the measured values, on the input data for the model and on the simplified model itself.

In the surveys, the inhabitants were asked about important building and user related changes over the last years, to determine the length of the representative energy use period back in time. As very few changes occurred to the houses and a large portion of the households have lived there for a long time, for most dwellings, energy figures dating from yet 2004 are considered useable, with data of at least 2 years for the few other cases. Those energy use figures from yearly gas meter readings were further completed with several meter readings taken over winter/spring 2010-2011. This allowed to estimate the gross heating energy use for a normalised year through regression analyses based mainly on degree days principles, the gas meter readings and the survey inputs.

The second cause of errors arises from the input data. While thorough care is put in detailed analyses of the survey data together with the measurement readings, errors and fluctuations might occur both on the measured building properties as well as on the user related settings, as is described in previous paragraphs. Furthermore, some input values could not be measured as a result of which theoretic calculations had to be made and default values had to be taken as prescribed in the Belgian EPBD-regulation. This often occurs with varying consequences for building component characteristics such as e.g. the physical properties of old glazing and the efficiency of the old gas furnaces, for building zone characteristics such as infiltration rates of the attic, but also within conversion factors when e.g. converting air tightness measurements to infiltration rates and correcting thermal resistances of ground floors to heat losses through the ground. Nevertheless, most of these characteristics will show only minor variations from one building to another due to them being nearly identical. These inaccuracies might therefore be expected to cause mostly systematic errors with fewer consequences on the correlation factor between real and simulated values rather than on the difference in absolute values. This for one, is a major reason for testing the building model in practice on nearly identical buildings first.

The third cause of errors can be found in the calculation model itself, which bases are briefly described in next paragraph.

## 3.2 Model

### *3.2.1 Starting point*

While more advanced dynamic simulation software exist, it was decided for this project to first look at prediction through simplified quasi-steady state models. The reason lies in their being widely used in building practice and in their lower computational costs. Many countries base their energy labelling of buildings on simplified transmission heat loss calculations according to ISO 13789 and the quasi-steady state hourly or monthly methods from EN 13790. In Belgium, a monthly method is used in the governmental EPBD-software. While these were originally conceived as labelling tools, many architects and engineers use them in practice for their estimations on energy use and savings. This often leads to an overestimation of energy savings due to some inherent simplifications of the model and it neglecting some major user related factors. Nevertheless, using such type of simplified methods bares some major advantages such as ease of use, lower dependency on users' knowledge, experience and conscientiousness and, last but not least, lower work and calculation loads. These are all matters of great concern within practice in the building sector, especially when looking at small scale and relatively low budget projects such as in large parts of the housing sector.

In research projects, comparisons are often made on large theoretical, yet simplified samples between dynamic simulations and quasi-steady state simulations on the one hand to validate or correct the simplified methods or, on the other hand, on limited samples between dynamic simulations and their thorough and detailed real word case-studies. Another path was chosen here, making a direct comparison on a sample of nearly identical dwellings between limited measurements, completed with survey data and a simplified, yet more elaborated model than the official software. Therefore hope lies in directly identifying how close energy estimation can get to real energy use for this type of buildings, through a simplified, more pragmatic model and limited questioning and measurements. While this would logically yield lower level of agreements between both comparison datasets, it is more representative of what would be achievable on large scale in everyday practice within the nearer future.

### *3.2.2 Calculation model*

The model used, is based on ISO 13789 and the monthly method from ISO 13790, as is the Belgian EPBD-software. It goes further by being a multi-zone model (based on Annex B of ISO 13790), by implementing a simplified method for taking intermittent heating into account and, of course, by allowing an override of all input constants such as e.g. the set point temperature (instead of a fixed value of 18°C).

While some small corrections to the methods from the standards were developed for this code, discussing these would carry us beyond the scope of this paper. The implementation of intermittency-correction however, is of very high importance and is based on the formula from DIN 18599-2 stated in Eq.(1), giving a corrected equivalent set point-temperature due to heating switch-off:

$$\vartheta_{\mathrm{i,h}} = \max\begin{pmatrix} \vartheta_{\mathrm{i,h,soll}} - f_{\mathrm{NA}}\left(\vartheta_{\mathrm{i,h,soll}} - \vartheta_{\mathrm{e}}\right), \\ \vartheta_{\mathrm{i,h,soll}} - \Delta\,\vartheta_{\mathrm{i,NA}}\,\dfrac{t_{\mathrm{NA}}}{24\,\mathrm{h}} \end{pmatrix} \quad (1)$$

Where $\theta_{i,h,soll}$ is the internal set point temperature in the normal heating mode ; $\theta_e$ is the monthly average external temperature ; $\Delta\theta_{i,NA}$ is the permitted set-back of the internal temperature for reduced heating operation ; $t_{NA}$ is the daily reduced heating time, the boost time being part of the operating time ; $f_{NA}$ is the correction factor for reduced night-time heating operation according to Eq.(2):

$$f_{NA} = 0.26\,\frac{t_{NA}}{24\,\mathrm{h}}\exp\left(-\frac{\tau}{250\,\mathrm{h}}\right) \quad (2)$$

Where $\tau$ is the thermal time constant of the building zone (in hours).

The heating set point temperature and the switch-off time used in these formulas are here derived for every individual case from the survey and measured temperature data, as described in 2.3.1 and 2.3.2.

### 3.3 Results

#### *3.3.1 Heating energy use*

Fig.12 and Fig.13 compare the real measured energy use for heating with the results from the adapted model in a 1-, 2-, 3- and 8-zone configuration. While in the 1-zone model, the whole inhabited part of the house is considered as 1 zone (without the basement and the attic), the living room and kitchen are isolated together in the 2-zone model. The circulation area is further considered as a separate intermediate zone in the 3-zone model and for the 8-zone model the heat balance is calculated for all spaces separately. The adjacent houses were also further detailed into 2-zone-models to take into account temperature differences on the other side of the party walls, as discussed in 2.1.1. When combining spaces into one zone, it was found necessary to consider weighted average set point temperatures, resulting in better correlations between measured and calculated energy use. However, while this in itself is a necessary process in every but the 8-zone model, it causes them to show higher spreads in agreement between measured and calculated values. While the overestimation of the heating demand remains high in the 8-zone model, a better correlation can be found between both values. As only user behavioural parameters were changed in comparison to the simulations from Fig.5, one can conclude that their influence is taken into account in a large extent by using the adjusted heating profiles in a multi-zone model.

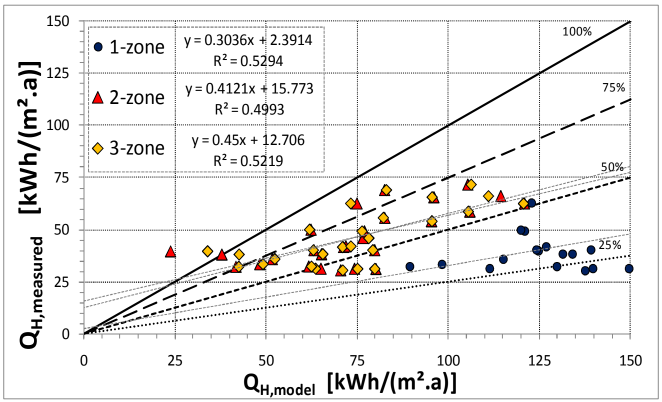


Fig.12. gross energy demand for heating: 1/2/3-zone models

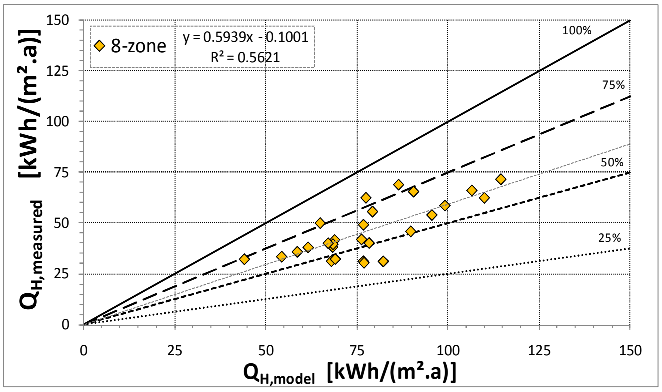


Fig.13. gross energy demand for heating: 8-zone model

One might be inclined to further use a correction factor to fit the calculated gas consumption to the measured one as is often done in building stock models. Nevertheless, it is impossible to conclude from this single case whether the remaining discrepancies are systematic only to this case or not and whether they are due to the calculation model or to the input parameters. While both will have their share in this matter, it is an important question to ask as there lies the area of further investigation. Unfortunately, this question cannot be answered by looking only at this data.

#### *3.3.2 Average indoor temperature*

To further investigate where the differences occur within the calculation, one can look at the temperature data, as it is a major intermediate step within the calculation of the heating demand and as measurement data of higher intelligence is available: directly measured temperatures in each zone. To make the comparison of the indoor temperatures valid, one has to start from the same boundary conditions. As the outdoor temperature is assumed to have the highest climatic influence on the indoor temperatures of such low isolated dwellings, it is taken as the point of reference. This is done for all houses individually by taking the 12 monthly values of both indoor and outdoor temperatures from the multi-zone calculation and interpolate (or extrapolate) these model-values of indoor temperatures for the models' outdoor temperatures to match the *average* measured outdoor temperature.

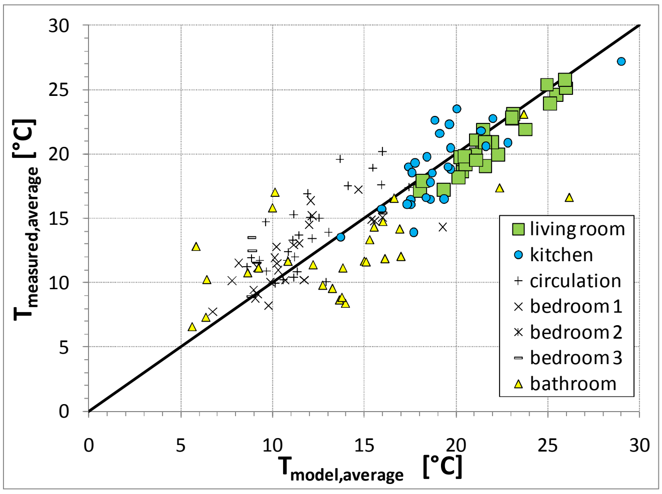


Fig.14. average temperatures: measured vs. 8-zone model

Fig.14 compares for each room the average temperature from the multi-zone model to the corresponding average measured temperature after the extrapolation. First of all, the high correlation between the temperatures of the heated zones appears, yet with a limited averaged overestimation 0.9°C. This is even more appreciable as this is the most, yet only intermittently heated zone. Part of this overestimation might be due to an underestimation of the boost heating period caused by the high thermal inertia and the high heat transfer coefficient of the building in combination with the relatively high set point temperatures. Nevertheless, considering this boost heating period as a part of the operation period coincides with the directives from DIN 18599-2 which is in line with the manually switching on of the heating system when entering the room. The resulting small overestimation of the average temperature will be one of the direct causes of the overestimated heating demand. Nevertheless, as it results from the total heat balance, looking at the other zones will give further information.

The underestimation of the temperatures in the bedrooms and the circulation area is the second most obvious point, as it appears almost systematically in every house, especially for the circulation hall. It is the more surprising as the (limited) ventilation heat losses due to window opening in these zones were neglected. If the cause is an overestimation of the heat losses from those rooms to the outdoor, through e.g. the attic, this would further explain the underestimation of the heating demand. If the cause lies in an underestimation of the heat gains from the adjacent heated living room, this would yield the opposite conclusion. Indications about the temperature in the attics might have been of valuable interest to analyse the heat balance of the first floor, yet no such measurement data are available.

The worst correlations lie in the bathroom and the kitchen. This can be explained by the high dependency of those rooms' heat balances on user behaviour, both on a time-basis as on bases of internal heat loads and punctual ventilation. Such irregular dynamic conditions reveal the inherent limitations of quasi-steady state models.

#### *3.3.3 Post-considerations*

Apart from the building envelope, the heating appliances are also of influence on the comparison, as it is the gross energy demand that was deduced from the gas meter readings and therefore compared to the net heating demand divided by the total efficiency of the heating system. The efficiency of the heating system was here derived from the default values from the EPBD-regulations and might thus also be one cause of the systematic overestimation of the energy demand in the model. Furthermore, some interaction exists between the heat balance of the house and the heating appliances' characteristics, such as their latency caused e.g. by the limited power of the heating production system and the thermal capacity of e.g. a water-based distribution system. Nevertheless, this is not taken directly into account within ISO 13790 or EN 18599-2 while the power of the heating system was taken into account in the, yet more complex intermittency modelling from the preceding EN 832. This should be a domain of further investigation when analysing possible rebound effects.

To further investigate the problem, complementary simulations in an hourly model and a dynamic model might be of interest. Nevertheless, reaching good agreement between dynamic simulations and real measured values are also a challenge, as is endorsed by the launch of the new IEA Annex 58 on the subject. Therefore, it is of the author's opinion that other case-studies on nearly-identical houses are equally essential, sampling both old and more recent, energy-efficient houses and extending the scope to non-social housings. Such future field measurement campaigns are already planned for winter 2011-2012 and the following years.

## 4. Conclusions

This paper illustrates both the huge influence of user behaviour on real heating demand as well as the complexity of taking user behaviour into account in energy calculations. The need of basing oneself both on some (at least limited) measurement data as well as on thorough surveys is to be stressed. Nevertheless, it is possible to take a large part of the behavioural compound in account and yield acceptable correlations between real and calculated values by a correct multi-zoning of the model and adapted figures on intermittency duration and heating set points. This, in turn, uncovers other difficulties such as defining the real characteristics of both HVAC and building envelope components. These problems should be tackled together with further investigation on some default correction factors and use factors on which the quasi-steady state methods are based and which were mainly derived for single zone models, often without intermittency and with lower set point temperatures than those measured in this case study.

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