ENERGY PERFORMANCE LABELS FOR DWELLINGS VERSUS REAL ENERGY CONSUMPTION

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ABSTRACT

The Flemish EPB calculation method, in accordance with the EU EPBD, determines an insulation label and an energy performance label as an assessment method for the theoretical energy performance of buildings. By monitoring 70 recently built dwellings, this research aims to check the extent to which these labels correspond to the real energy performance of standard up to energy neutral dwellings. Results show that the labels correspond reasonably, meaning that dwellings with a better label generally effectively have lower energy consumption. The calculated consumption for both heating and hot water, however, are in general an overestimation of the real energy consumption.

INTRODUCTION

In the EU, the obligations of the Kyoto-protocol regarding the reduction of energy use and CO_2 emissions of buildings resulted in the EU Energy Performance of Buildings Directive (EPBD, 2002). This directive imposes requirements to the EU Member States concerning the energy performance of buildings. Thus, each Member State had to develop a calculation method to determine the energy performance of buildings and had to formulate minimum requirements for new buildings and thorough renovations of buildings. In 2010, the directive was recasted, specifying that by 2021 all new buildings have to be Nearly Zero Energy Buildings (Recast EPBD, 2010).

In Belgium, having a federal political system with three regions, energy is a regional competence, so in Flanders, as one of the regions, the EPBD was converted into the EPB-legislation in 2006 (EPB = Energy Performance and Indoor Climate). Since 2006, requirements are imposed as a function of the destination of the building and the nature of the work. For new or thoroughly renovated dwellings, the EPB regulation formulates requirements considering both the energy performance and the indoor climate. The energy performance requirements concern requirements for the insulation of the different construction components, for the overall insulation level and for the overall energy performance level. The requirements concerning the indoor climate are specified by means of a risk on summery overheating and of ventilation requirements. On a regular basis the requirements are tightened, in anticipation to the target for Nearly Zero Energy Buildings by 2021.

Although the calculation methods are not intended to forecast the real energy consumption of these dwellings, the labels, as determined by the EPB regulation, should be representative for the real energy performance in order to be valuable as assessment method. In addition, the assumptions which were made to simplify the simulation and were determined based on the standards and technologies prior to 2006, should be valid for the whole range of energy performances, with special attention to very low, near zero energy performances.

The results of this paper are part of a larger research project in which the robustness of the performance of low energy dwellings is studied. Through monitoring and simulations, the sensitivity of low energy concepts is evaluated, with regard to their impact on both energy consumption and indoor comfort. The objectives of this research are to define guidelines to create robust, comfortable and really energy efficient dwellings.

In this paper the results on the energy performance are described. Section 2 presents the monitored dwellings and describes briefly the EPB calculation method and the way the registered data were processed. Then section 3 and 4 present and discuss the main results of the monitoring campaign and comparisons with the calculations. Finally, in section 5, conclusions are formulated.

METHODOLOGY

EPB calculation method

The energy performance is determined in terms of an insulation level (K-level) and an energy performance level (E-level) (EPB, 2010).

The K-level is a dimensionless indicator of the overall insulation level of the building. It is calculated based on the U-value of all construction elements, the compactness of the building (ratio of heated volume and overall heat loss area) and the heat loss through 2D and 3D component junctions. Well-insulated dwellings have a lower K-level. The current legal requirement is K40, corresponding to a mean U-value of 0.40W/m²K for a compactness of

1m. For passive houses, the K-level is typically around K10 to K20.

The energy performance level is the ratio of the characteristic yearly primary energy use of the building to a reference value based on the size (overall heat loss area and heated volume) and the ventilation flow of the building (EPB Bijlage V, 2010). The characteristic primary energy use is calculated on a steady-state one-zone monthly basis, based on the EN ISO 13790. For dwellings, this method takes into account the building envelope and systems for heating, cooling, domestic hot water, ventilation, pumps and fans, thermal solar systems and PV-installations. The current legal requirement is E70. Low energy houses have a lower E-level. Negative E-levels are possible for energy positive dwellings which produce more primary energy by PV solar panels than they consume for heating, cooling, domestic hot water and ventilation. Near-zero energy, the aim for new buildings by 2021, is represented by ±E0.

The method starts by calculating the net energy demand for heating, cooling and hot water of the dwelling. Through the system efficiency and the generation efficiency, the gross and final energy use is calculated. If present, the gains of a thermal solar system are subtracted of the final energy use. Also the final energy use for pumps and fans (if present) is calculated. Subsequently the monthly primary energy use for each fraction is determined using the primary energy conversion factor of the corresponding energy carrier (1 for natural gas and fuel, 2.5 for electricity). After subtracting the primary electricity produced by the PV solar system, if present, the characteristic yearly primary energy use is calculated.

Although the primary energy use makes it possible to compare different dwellings and applied technologies in an objective way, regardless of the energy carrier used, the final energy use is representative for what the occupants will consume. The results of gas and electricity consumption of the investigated dwellings will therefore be compared to these calculated values. To eliminate the influence of the considered weather data, the monthly mean outdoor temperature and the monthly mean direct solar irradiance of the Test Reference Year of Brussels, which are taken into account in the standard calculation, were corrected by the appropriate weather data for 2012.

Description of the dwellings

In the frame of this research, 70 dwellings were selected, distributed over the Flemish territory. These dwellings are almost all recently built, after or right before the implementation of the EPB legislation in 2006. Three houses were thoroughly renovated, in a way they have an energy performance comparable to new buildings.

A very wide range of dwellings was obtained, both in terms of energy performance as of applied materials and heating and ventilation systems.

With regard to typology, the selection consists of 45 detached, 24 semi detached and 2 attached houses. There are 44 massive constructions with brick cavity walls and 27 wood frame constructions. The 3 ventilation types, which are most frequently applied in Flanders, are represented: 14 dwellings have natural ventilation, 14 exhaust ventilation and 43 have balanced ventilation with heat recovery. With regard to the heating system, gas boilers, heat pumps, wood pellet boilers and local electrical heaters are represented.

Considering the energy performance, the dwellings vary from standard execution to very low energy, even energy positive, houses. Figure 1 shows the distribution of the selected dwellings according to insulation level (K-level) and energy performance level (E-level). Additionally the requirements since 2006 and the aim of near-zero energy are indicated.

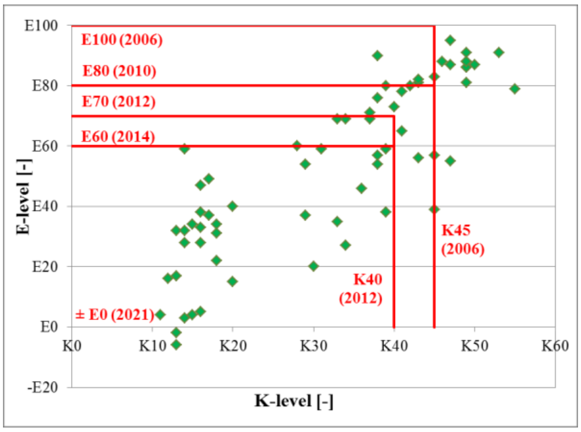

Figure 1 Distribution of the dwellings according to their insulation level (K) and energy performance level (E)

Monitoring campaign

The data of the real energy consumption were obtained with the help of the occupants, who noted down the energy meter values on a regular, mostly weekly, basis. In addition, the gains of the PV installations and the wood consumption were registered, if applicable. Since the occupants were not always able to register very consistently, due to holidays and obliviousness, the consumption, derived from the meter data, had to be linearly interpolated to obtain comparable weekly, monthly and yearly values.

For gas consumption, the trend of the results was fitted by a linear function using the method of least squares fitting. The consumption was supposed to be a function of the number of days for both domestic hot water and space heating, and of the number of degree-days, for space heating. As, for some dwellings, the standard use of degree-days 15/15 (heating till 15°C mean indoor temperature, when the mean daily outdoor temperature is below 15°C) appeared to be an overestimation of the heating period, the results were additionally fitted using degree-days 15/12 and 15/10. For each individual dwelling, the best fitting was then used, based on both the r²-value and the overall real and fitted gas consumption for the complete measuring period. Figure 2 shows an example for one of these dwellings. The value of the gas consumption between each measuring moment is displayed, both the real values as the fitted values using degree-days 15/15, 15/12 and 15/10. For this dwelling, the fitting with degree-days 15/15 gave the best result, with a r²-value of 0.97 and a deviation on the overall gas consumption of 0.2%.

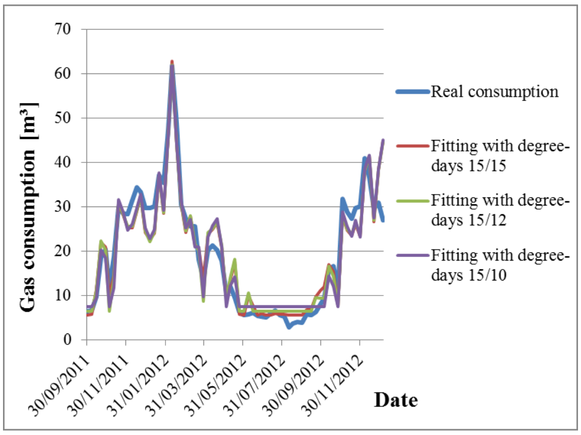

Figure 2 Example of comparison of the real gas consumption vs the results of the fitting by linear regression using degree-days 15/15, respectively 15/12 and 15/10

R²-values range from 0.77 to 1.00 with a mean value of 0.95, where for only two dwellings the r²-value is below 0.90. Considering the overall real and fitted gas consumption, the deviation ranges from -12% to 6%, with a mean value of -0.01%. In only 5 cases, the deviation exceeds 3%. It is therefore safe to conclude that interpolations with the calculated fitting functions are representative for the real gas consumption, not taking into account unusual situations like holidays.

Since the registration of the energy consumptions was insufficiently detailed or regular, no exact values between specific moments (e.g. first and last day of a month) could be derived. The monthly and yearly results, as presented below, are therefore an interpolation based on the linear regressions, discussed before. When monthly results are shown for dwellings with incomplete energy registration (18 of the 30 cases with gas boilers), only the values for the registered months are included, knowing that the error on these interpolations is rather small. For the yearly results, the energy consumption is extrapolated for the missing months and then totaled. Therefore the error on the yearly results of these 18 dwellings might be larger.

For dwellings with an electrical heating, the data of electricity consumption were analysed. First, an estimation of the domestic electricity use was made according to (Hens and Verdonck, 1997). This model is derived from weekly measurements of domestic electricity consumption in 26 dwellings and calculates a yearly domestic electricity consumption, based on the presence of the main electric equipment, like dishwasher, fridge, computer,… and depending on the size of the dwelling and the number of occupants and their age. However, the domestic electricity consumption is not constant throughout the year, but more dependent on the seasons. In winter, people stay more inside, days are darker, so lighting is used more often. In summer, people cook less on their stove,… Therefore, in this research a sinusoidal trend was assumed for the distribution of the yearly domestic electricity use, opposite to the trend of the solar irradiance throughout the year. After subtracting the thus calculated domestic electricity use from the measured total electricity consumption, the 'technical' electricity use remained, meaning the electricity consumption for heating, hot water, fans and pumps (if applicable). These data were then fitted by a linear function using the method of least squares fitting, in the same way as the gas consumption, assuming a term as a function of the number of days and a term as a function of number of degree-days 15/15, 15/12 or 15/10. R²-values for these fittings range from 0.79 to 0.99 with a mean value of 0.90. Considering the overall real and fitted electricity consumption, the deviation ranges from -17% to 14%, with a mean value of -2%. In only 3 cases, the deviation exceeds 3%. The interpolations of these fittings are therefore also presumed to be representative for the real electricity consumption.

RESULTS

Figures 3 and 4 display the total gas consumption for 2012 as a function of the insulation level (K-level) and as a function of the energy performance level (E-level) (blue dots). Since the size of the dwelling has an important influence on energy use for space heating, the gas consumption is considered per square meter gross heated floor area. Additionally, the total calculated final energy use for heating and hot water of these dwellings, according to the EPB method, adjusted to the weather data of 2012, is shown (red dots). The full line indicates the trend of the measurements, whereas the dotted line represents the trend of the calculated final energy.

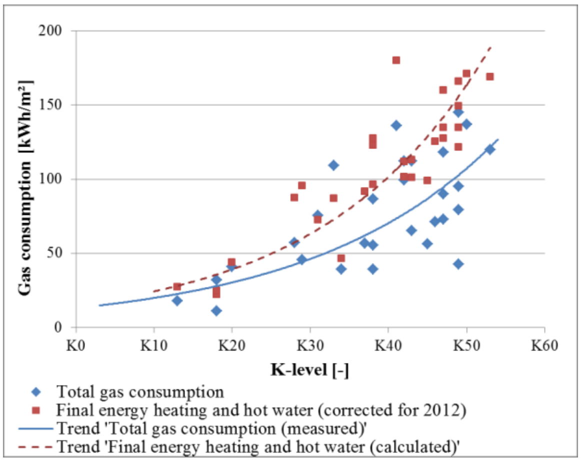

Figure 3 Total gas consumption per square meter for 2012 as a function of K-level.

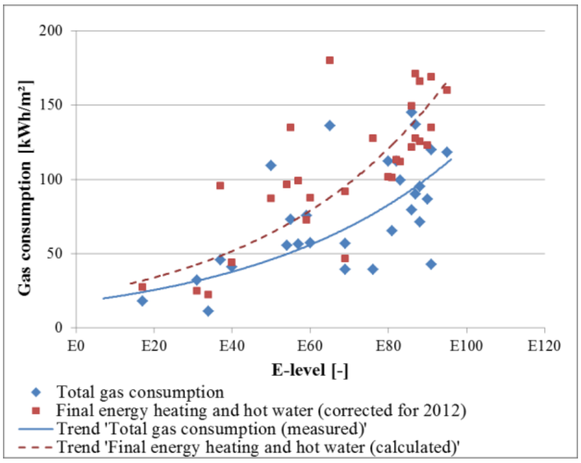

Figure 4 Total gas consumption per square meter for 2012 as a function of E-level.

Figure 5 shows the total gas consumption for 2012 per square meter gross floor area and per occupant of the dwelling, as a function of K-level and as a function of the type of ventilation system.

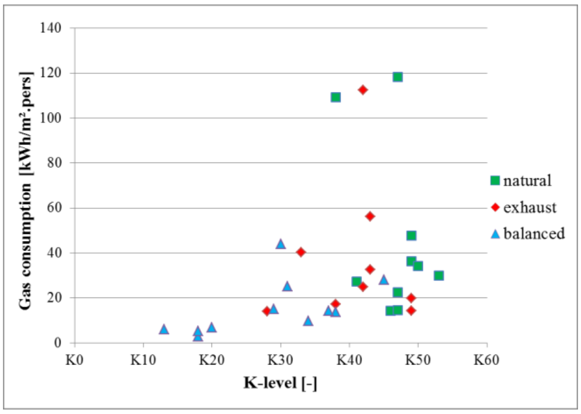

Figure 5 Total gas consumption per square meter and per occupant as a function of K-level and type of ventilation.

Figures 6 and 7 show the monthly deviation between measured gas consumption and calculated final energy for heating and hot water by the EPB method, taken into account the weather data of 2012. A positive deviation expresses an overestimation by the EPB calculation, meaning that in reality less gas was consumed than estimated. In both figures, lines connect the monthly values for each dwelling. Dwellings with a thermal solar system for domestic hot water are represented by a dotted line, whereas full lines represent dwellings without a thermal solar system. In figure 6 the ratio is taken relative to the calculated final energy, so positive deviations can be maximum 100%, where negative deviations can be larger, when the real gas consumption is 1.5 or 2 times larger than the calculated final energy. In figure 7 the absolute monthly deviations are shown per square meter gross heated floor area.

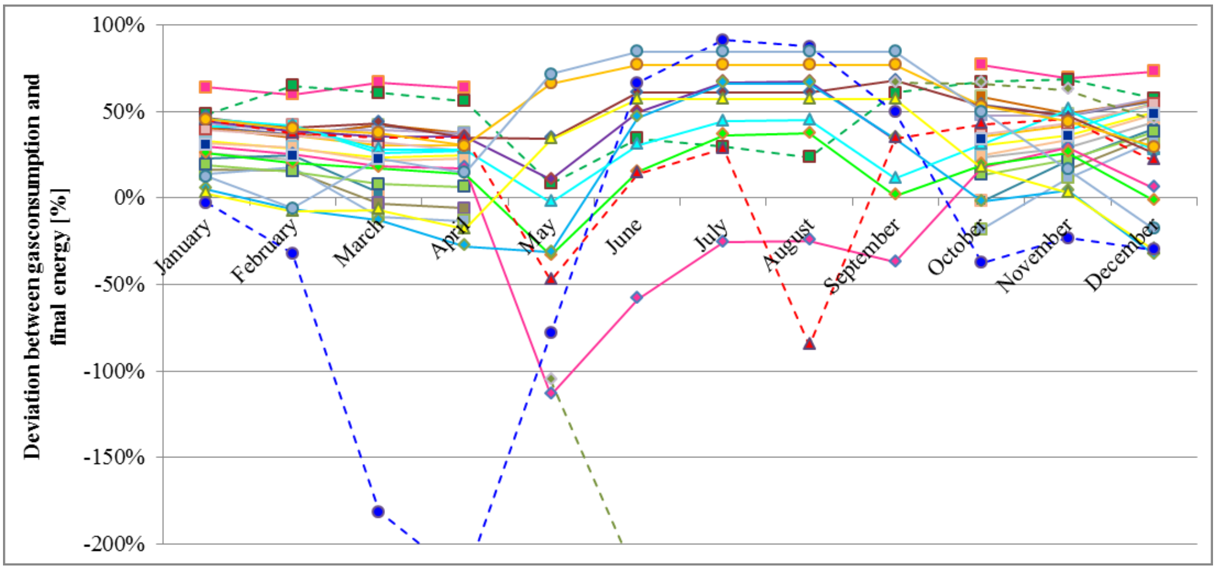

Figure 6 Monthly deviation between measured gas consumption and calculated final energy for heating and hot water. Deviation relative to calculated final energy

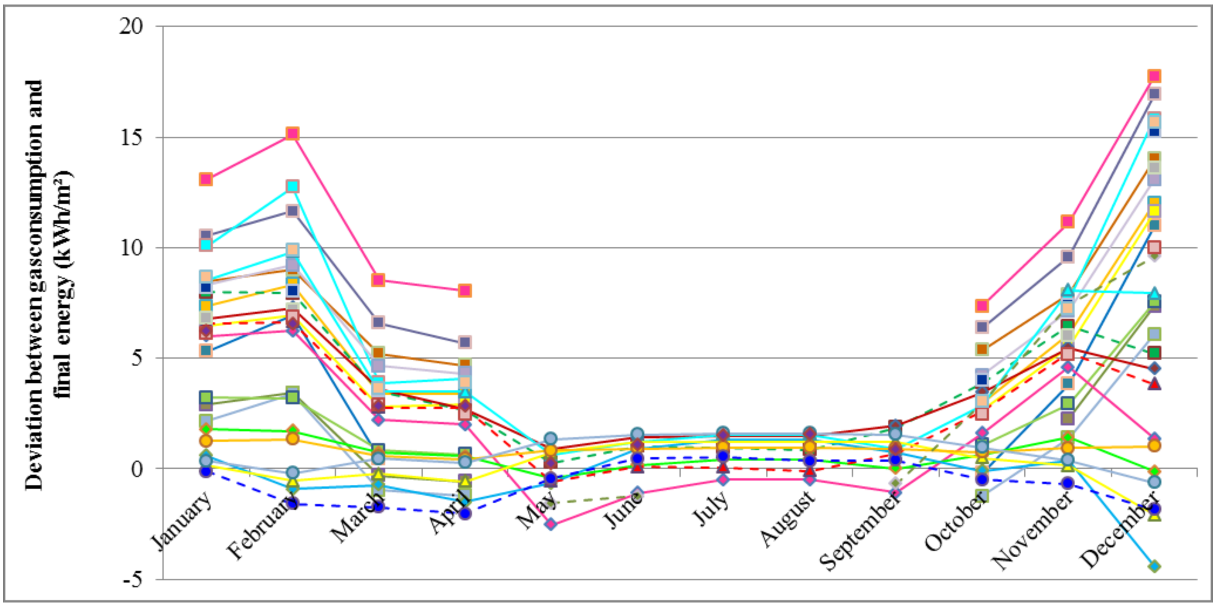

Figure 7 Monthly deviation between measured gas consumption and calculated final energy for heating and hot water. Absolute deviation per square meter gross heated floor area

In five of the 70 dwellings, more detailed measurements were executed in the frame of another research. Through calorimeters, the individual gross energy use for heating and domestic hot water was measured. Figure 8 shows the monthly results for hot water. The values of the measured energy use are indicated by the diamonds and the full line, where the squares and dotted lines represent the values as calculated by the EPB.

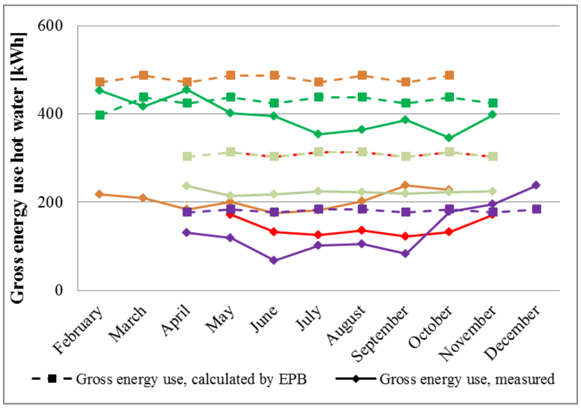

Figure 8 Detailed results on the gross energy use for domestic hot water for 5 dwellings

Figure 9 presents the mean relative deviation between the gas consumption of 2012 and the final energy for heating and hot water as a function of K-level. The mean deviation for each dwelling is the average of the monthly deviations, taking into account only the registered months. Distinction was made between dwellings with or without a thermal solar system for the production of hot water. The full line indicates the general trend of the deviations for the dwellings without a thermal solar system. Due to the limited amount of dwellings with a thermal solar system, the trend was not deemed to be representative and was thus not presented.

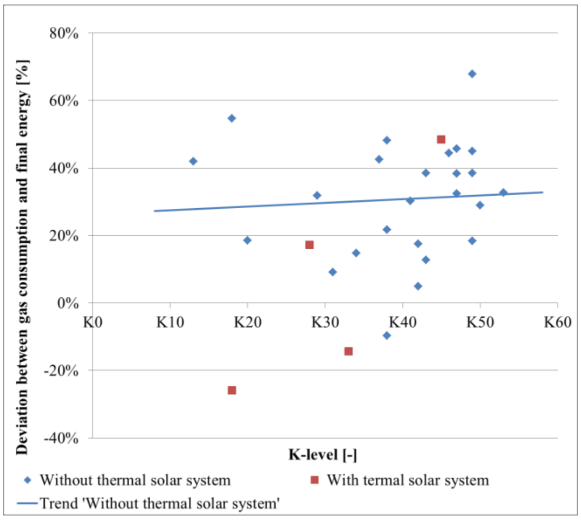

Figure 9 Mean deviation between measured gas consumption and calculated final energy for heating and hot water as a function of K-level and the presence of a thermal solar system. (positive deviation: calculation overestimates real consumption, negative deviation: calculation underestimates real consumption)

For dwellings with electrical heating (heat pumps, local electrical heaters, air-heating), figures 10 and 11 show the total electricity consumption for heating, hot water, pumps and fans for 2012 per square meter gross floor area, as a function of the insulation level (K-level) and as a function of the energy performance level (E-level). The full line indicates the trend of the measurements.

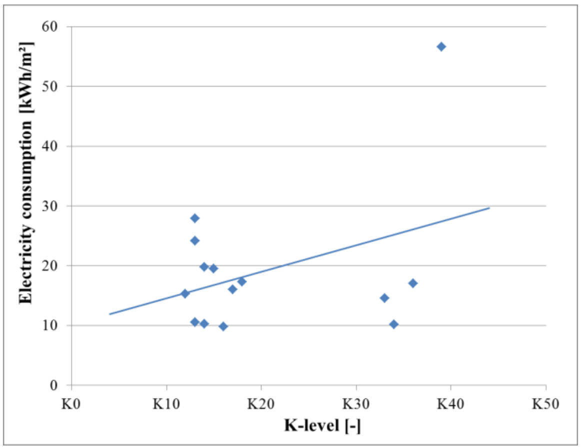

Figure 10 Total electricity consumption per square meter for 2012 for heating, hot water and ventilation as a function of K-level.

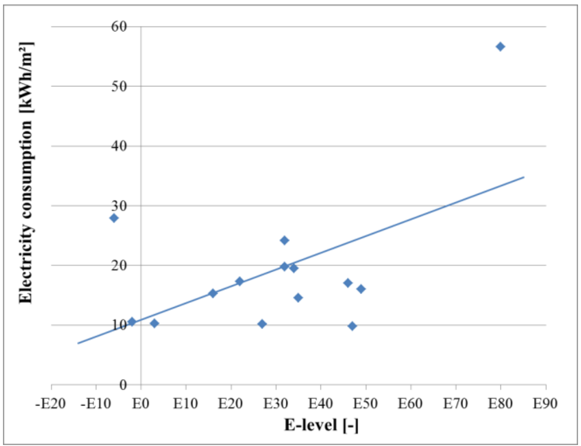

Figure 11 Total electricity consumption per square meter for 2012 for heating, hot water and ventilation

DISCUSSIONS

As figure 1 shows, there is in general a linear correlation between insulation level and energy performance level. However, figure 1 also clearly shows that a similar insulation level can result in a diversity of energy performance levels with a difference between minimum and maximum E-level per K-level up to 40 – 60 E-points. This is due to the fact that the energy performance not only depends on the insulation performance, but also on the applied systems for ventilation, heating and hot water and on the presence of thermal solar collectors and photovoltaic panels,

The results of the gas consumption as presented in figures 3 and 4, show that in general the K-level and E-level are adequate labels. The overall trend, as indicated by the full trend line, suggests lower energy consumption for dwellings with lower K-level, meaning a better insulation level. The trend is presented as an exponential function, however not with the intention to suggest correctness of this relation, but rather to represent the general trend.

The wide range of the results around the trend line indicates however, that large differences are possible for dwellings with similar insulation or energy performance levels. This means that not only the overall insulation level is of influence on the real gas consumption. Firstly, also the building size is relevant. In these figures, the influence of this parameter was limited by representing the results per square meter gross heated floor area. In addition, as part of the gas consumption originates from the production of domestic hot water, also the number of occupants of the dwelling has an influence. Therefore, the results in figure 5 were presented per square meter gross heated floor area and per occupant. Still, large differences in gas consumption between dwellings with similar K-level exist. Caution is needed for the conclusion considering two of the three points at the top of the figure. They concern dwellings that are only occupied by one person. It shows that, especially for these dwellings with higher K-level, the energy use for space heating is a substantial part of the overall gas consumption and is only limitedly influenced by the number of occupants.

In figure 5, distinction has been made between the applied types of ventilation system. For dwellings with a balanced ventilation system, the incoming air is preheated by heat recovered from the exhaust air. For dwellings with a natural or exhaust ventilation system, the air directly enters the rooms, where it has to be heated entirely to room temperature by the heating system, thus resulting in a higher energy consumption. As shown in figure 5, this difference cannot really be detected in the results. In the zone between insulation level K28 and K45, the three different types are present, but without a distinct difference in gas consumption. There are even dwellings with higher K-level and a natural or exhaust ventilation system, which have a lower specific gas consumption. It is not to be concluded that the heat recovery will not have any effect, although the real efficiency might be lower than the theoretical value presented by the manufacturers. This can be due to various reasons like insufficient airtightness of the building envelope and the ductwork and unbalanced airflows, which results in more uncontrolled in- and exfiltration (Staepels, 2002). In addition, it is likely that other effects diminish the gains from the balanced ventilation system. For instance, in dwellings with natural or exhaust ventilation systems, the occupants have more control on the amount of incoming air by closing or opening the window grills, thus effecting (usually minimizing) the energy consumption due to ventilation losses. In general, user behaviour will have a very large impact on the gas consumption, resulting in the differences as shown in figures 3, 4 and 5. A first analysis of the impact of user behaviour within this research project is further discussed in (Van Gelder et al., 2013).

In figures 3 and 4, also the results and trend (dotted line) of the final energy use for heating and hot water, as calculated by the EPB method and corrected for the weather data of 2012, are shown. This line lies higher than the full line, indicating that the EPB calculation method generally makes an overestimation of the final energy use for heating and hot water. This general conclusion is represented in more detail through the monthly deviations in figures 6 and 7.

These figures confirm that for most dwellings the real gas consumption is lower than the simulated final energy use. However, there are also dwellings with negative deviations, where during some months the real gas consumption is sometimes significantly higher than calculated. One of these dwellings accords to the point at the top of figure 5, a dwelling with three occupants. It can be concluded that the user behaviour of these occupants result in a high energy use. The other dwellings with high negative relative deviations in figure 6, are dwellings with a thermal solar system (see later).

For the positive deviations, it can be noticed that during summer period the relative deviations are larger than during winter months. Since in summer the gas consumption is mainly due to production of domestic hot water, it can be deduced that the overestimation primarily assigned to that aspect. This is confirmed through the results of complementary research in five dwellings as presented in figure 8. For each of these dwellings during the measuring period, the gross energy use for hot water was lower than calculated, even up to 50% lower (similar to a positive 50% deviation in figures 6 and 9). In addition, results of this research showed smaller real gross energy use for heating than calculated, even after taking into account the appropriate weather data. This is confirmed by the results presented in figure 7, which show that in winter the absolute deviations are even larger than in summer. The deviations on the energy use for hot water are increased by the deviations on the energy use for heating.

The full and dotted lines in figure 3 indicate that the differences between the real gas consumption and the calculated final energy use are larger in absolute value for dwellings with higher K-levels. The relative differences are presented in figure 9. The linear trend line here shows that the relative deviation is rather independent of the K-level. The calculated final energy use for heating and hot water by gas boilers is approximately 30% overestimated with respect to the real gas consumption, independent of the insulation level.

Figure 9 also shows three dwellings with negative mean deviations. One, without a thermal solar system, concerns the dwelling with high gas consumption as already pointed out earlier. The two others are dwellings with a thermal solar system. Although there are also two dwellings with thermal solar system and a positive mean deviation, detailed results show for three of these dwellings lower deviations in summer (more negative or smaller positive) than in winter. The fourth dwelling has a large negative deviation in the spring. This means that the gains of the thermal solar system in reality are not as high as calculated in the EPB method. In winter, this effect is limited due to the relative smaller part of the energy demand for hot water compared to the total energy demand and the smaller gains of the solar system.

In extension to these results for dwellings with gas boilers, figures 10 and 11 show results for dwellings with electrical heating, by heat pumps, local electrical heaters or air-heating. Here also, the linear trend line is no relativeness to the relation between the electricity consumption per square meter gross heated floor area and the K-level or E-level, but merely indicates the overall trend of this relation, indicating that dwellings with lower K-level, respectively lower E-level will generally have lower energy consumption for heating, hot water, pumps and fans.

As it is impossible, in the Belgian climate, to create low energy dwellings without consuming energy for domestic hot water and fans, Near-Zero Energy or E0-level can only be obtained by adding the gains of energy production through renewable energy sources like PV solar systems. These gains are not included in the values presented in figure 11, resulting in considerable electricity consumptions for dwellings with very low or even negative E-levels.

CONCLUSION

In the frame of the EU EPBD, the Flemish Government developed a calculation method for the energy performance of buildings, determining an insulation label and an energy performance label.

By monitoring the real energy consumption of recently built dwellings representing a wide range of energy performance labels, the correctness of the calculation method and the validity of the labels are investigated.

In general, it can be concluded that both the insulation label (K-level) and the energy performance label (E-level) are reasonably representative for the energy performance of the dwellings. Dwellings with a lower K and E-level, will generally consume less energy for heating, hot water, pumps and fans. However, large differences are possible between energy consumption of dwellings with comparable labels. This can be due to objective differences such as the number of occupants, the ventilation system, the presence of a thermal solar system,… but will also be strongly determined by the user behaviour of the occupants. This is further investigated within the research project and a first analysis is discussed in (Van Gelder et al, 2013).

Comparing the measured energy consumption with the calculated final energy use shows that the EPB calculation in most cases makes an overestimation, especially in the part of the energy consumption for the production of hot water. The relative deviation between real and calculated gas consumption is rather independent of the K-level. The overestimation amounts approximately 30% of the calculated final energy use for heating and domestic hot water, for dwellings with no thermal solar system.

For dwellings with a thermal solar system, the EPB calculation overestimates the gains of the solar system, resulting in underestimation of the real energy consumption of these dwellings.

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