THREE COMPLEMENTORY METHODS TO DETERMINE HEAT LOSSES OF DWELLINGS

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ABSTRACT

A methodology is presented that entails three ways to determine the heat losses of a dwelling in the heating season, each using a different set of data. The first method gives an indication of the theoretical 'energetic' quality of a dwelling, the second and third provide an indication of the actual 'energetic' quality of the dwelling. The third method includes effects of user behaviour.

The methodology was applied to the private dwellings of (former) colleagues. It appeared that the three ways of calculating the heat losses provide comparable values for a variety of dwellings, showing the validity of the approach.

INTRODUCTION

On paper, houses in The Netherlands are becoming more and more energy-efficient, an effect, often attributed to the introduction of the EPC (Energy Performance Coefficient) in 1995 and subsequent introductions of more stringent target values thereof.

The question arises to what extent dwellings actually perform as expected. A study by ECN and RIGO (Menkveld, et.al. 2010) tried to answer this question with user surveys in which the observed energy demand for heating (space heating and Domestic Hot Water DHW) was related to a number of dwelling characteristics, in particular the EPC, the type of installation and characteristics of the occupants.

The analysis was hampered by a number of problems. First, the occupants had measured the total energy demand for heating, and it appeared to be difficult to accurately separate the energy demand for space heating and that for DHW without additional metering.

Secondly, user behaviour such as maintaining a high indoor temperature in the heating season has a large effect on the energy consumption. In fact, (Menkveld, et.al., 2010) lists an earlier study (RIGO, 2009) in which it was concluded that: "The spread in the natural gas consumption of individual dwellings in the same project appeared so large, due to the behaviour of the occupants, that no statistically relevant correlation was found between energy performance and natural gas consumption."

Thirdly and finally, annual energy consumption depends on the mildness of the winter, in particular on the average ambient temperature and the number of sunshine hours in the heating season.

The ECN/RIGO study tried to solve the problems by including a large number of dwellings (939) in their analysis in an attempt to average out individual differences. Still, the study acknowledged the difficulty in identifying a relationship between the EPC and the 'energetic' quality of the dwelling due to the large number of parameters affecting energy consumption, such as size and type of the dwelling, type of installation, number and age of inhabitants etc. The fact remains that on the level of individual dwellings, no method is available to assess their 'energetic' quality.

In the current study, a method is proposed for assessing the 'energetic' quality of an individual dwelling that can potentially solve the three problems mentioned above. It can thus provide insight into the quality of a dwelling and the effect of energy saving measures thereon. In that respect, the methodology may be of good use for quality control or when analysing the energy performance of energy ambitious housing projects, either newly built or renovated.

THREE VALUES FOR HEAT LOSSES

The methodology entails three complementary ways to determine the heat losses of a dwelling in the heating season, each using a different set of data. The heat losses are expressed in W/K or, when related to the floor area of the dwelling, in W/m2K. The different sets of data yield three values for the heat losses:

1. the theoretical or expected heat losses,
2. the measured heat losses, using the 'energy signature' method and
3. the overall heat losses derived from the energy balance in the heating season.

The first two are a measure of the 'energetic' quality of a dwelling (expected and measured respectively). Obviously, the lower the heat losses, the higher the energetic quality of the dwelling. The third method includes effects of user behaviour, such as the level of indoor temperature maintained in the heating season. Comparing the first value with the second shows whether there is any difference between the theoretical quality of the dwelling (as designed) and its actual quality, which can be used for quality control of building projects. By comparing the third value with the second, effects of user behaviour on energy consumption (for space heating) can be assessed.

To test the validity of the approach, the methodology was applied to the private dwellings of a number of colleagues, all working in the group Energy Technology in the Built Environment (ETBE) and one former colleague. It should be noted that as such, the participants were biased towards the knowledgeable.

The theoretical or expected heat losses

Calculation of the theoretical losses is partly based on the Passive House Planning Package PHPP (Feist 2004), but in far more simplified and less elaborate form. Theoretical losses include transmission, infiltration and ventilation losses.

Transmission or conduction losses are calculated for the floor, roof, walls, doors, windows and window frames by multiplying the U value [W/m^{2}K] and the area [m^2]. For the floor, a correction factor of 1/(1+U) is introduced to correct for the higher temperature under the floor compared to the ambient temperature.

Heat losses due to a mechanical ventilation system are calculated from the volume of the dwelling and an assumed value for the number of air changes per hour (ach). The Dutch building code prescribes a value of about 0.5 ach. Demand-controlled ventilation, if present, is assumed to reduce this value by 50%. Heat losses are further reduced by a factor representing the efficiency of the heat recovery in the ventilation system (0% if none is present). Values for the efficiency in practice range from 60%-80% (Schuitema, 2002), considerably lower than manufacturer's specifications, which are measured in labs under ideal conditions (such as identical inlet and outlet flows).

Uncontrolled air changes, due to crevices and other openings in the building envelope are called infiltration. Notorious sources of infiltration are ducts for electrical wiring as well as junctions between walls and windows. Unless specific attention was paid to minimise infiltration, a reasonable value is around 0.4 ach, corresponding to an n_{50} (air changes per hour at a pressure difference of 50 Pa) of about eight. When a mechanical (generally exhaust) ventilation system is present, the (extra) losses due to infiltration can be omitted because it is hard to distinguish between air entering the dwelling through the ventilation openings and air through other openings.

An overview of the calculation is shown in Figure 1 below.

ventilation/infiltration losses						
Volime dwelling [m3]	450	[m3]				
infiltration fold	0.4	ach				
infiltration flow rate		**0.050**	[m^3/s]			
qv10		**2.36**	dm^3/sm^2			
ventilation fold	0	ach				
demand controlled ventilation y/n	n					
ventilation flow rate		**0**	m^3/hr			
		0.000	[m^3/s]			
efficiency heat recovery	0%					
Cp air	1230	[J/m^{3}K]				
infiltration+ventilation losses					**61.5**	W/K
transmission losses	A	R_c	U [3]	weight	A*U*weight	
	[m^2]	[m^{2}K/W]	[W/m^{2}K]		W/K	opm.
floor area (m^2)	45	1	**0.85**	**0.54**	**20.7**	
roof area (m^2)	50	2.5	**0.37**	1	**18.7**	
area of outside walls (m^2) opaque+windows	60.5					
doors	4		1.7	1	**6.8**	
glazed are (m^2)	34		2	1	**68.0**	
window frame (25% of window area) (m^2)	**8.5**		1.7	1	**14.2**	
opaque outside wall (m^2)	**22.5**	1.0	0.85	1	**19.2**	
total heat loss area (m^2)	**155.5**				**147.7**	W/K
ventilation/infiltration+transmission losses					***209***	

Figure 1 Excel sheet determining the theoretical or expected heat losses of a dwelling. Grey shaded cells are input cells.

Most input parameters are subject to some degree of uncertainty, especially those for infiltration and ventilation rates. The thermal insulation of walls is also often a matter of educated guessing, in particular with older dwellings. To assess the effect of these uncertainties, all input parameters were varied between plausible limits and the effect on the resulting heat losses was recorded. The (relative) uncertainty in the final result is calculated by taking the square root of the sum of the squared individual uncertainties. It lies in the order of 15-20%. It should be noted that the use of more sophisticated software tools such as TRNSYS or PHPP would not help to obtain more accurate results when accurate input parameters are unavailable.

The measured heat losses using the 'energy signature'

'Energy signature' methods have been in use for some time, see e.g. (Hammarsten, 1987). It entails plotting energy consumption data versus the ambient temperature.

For the sake of simplicity, let us assume that the heating demand of a dwelling (for both space heating and DHW) is provided for by a gas-fired boiler, and that gas consumption data are periodically recorded. It is not necessary for the time interval between recordings to be always the same, but for the moment we assume that it is and that it is one week.

The weekly gas consumption data are converted into a heating demand by assuming a certain efficiency of the boiler (e.g. 90% in case of a condensing boiler). The data are then plotted versus the average ambient temperature in each week to establish the so-called 'energy signature'.

In summertime, there is little or no heating demand for space heating, only for DHW, so the data points will be more or less on a horizontal line for ambient temperatures of typically 15ºC or higher, as illustrated in Figure 2 below.

In wintertime however, the heating demand for space heating will increase with falling ambient temperatures, and the slope of the line through the data points (in W/K) is a measure of the heat losses.

An advantage of the method is that the result (the slope) is independent of a number of user behaviour effects such as the indoor temperature in the heating season. The reason is that a (constantly) higher indoor temperature will shift the whole line to the right relative to an identical dwelling at a lower indoor temperature, but the slope of the line will remain unchanged.

The slope is also independent of the amount of internal gains - from electrical appliances and people - as long as the gains are the same for all ambient temperatures. Strictly speaking this is not the case because in particular lighting will produce more internal gains in the dark winter months than in spring and autumn.

A user behaviour effect that does affect the slope is related to the amount of ventilation, e.g. by leaving doors and windows open. This will cause additional heat losses, proportional to the temperature difference between indoor and outdoor, and it will result in an increased slope of the line in the energy signature.

Finally, the slope is independent of the climate. Cold and mild winters will yield different datasets but they will produce the same slope in the graph. This is illustrated in Figure 2 below, which shows the energy signature of the dwelling of the author with data from 2005 to 2011.

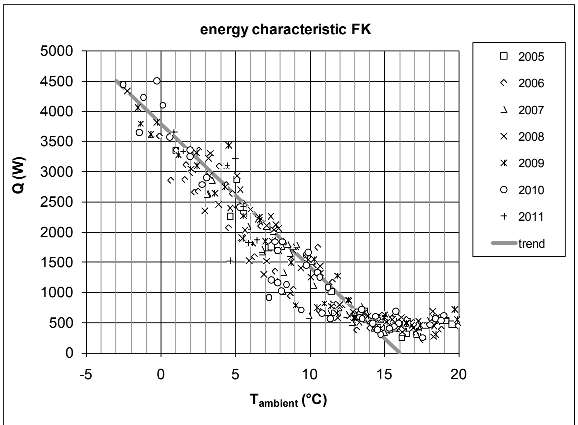

Figure 2 Illustration of an energy signature. Note that different years yield different data but they produce the same slope in the graph. The heat released by the soapstone fireplace is also taken into account by converting the weekly wood consumption into heat assuming an efficiency of 70% (educated guess).

As mentioned before, the horizontal part of the energy signature (in Figure 2 at ambient temperatures of 14°C or higher) shows the energy demand in summertime due to the need for DHW. Note however, that the net heating demand for DHW is actually lower. The reason is that the gas consumption for preparation of DHW should have been converted into heat using the efficiency of the boiler for DHW. This value is generally lower than that for space heating (typically 60% rather than 90%).

Dwellings with a heating system other than a gas fired boiler, e.g. a district heating system or a heat pump can also be analysed in this way. However, in the case of a heat pump, the parameter needed to convert electricity consumption into heat - the COP or Coefficient Of Performance – depends on the type of heat pump, the size of the heat source etc. and is generally unknown. Since the COP can vary widely, the heat delivered by the heat pump is unknown and will have to be separately measured using a heat flow meter.

Correction for solar gains

A prerequisite for the 'energy signature' method to yield the correct result is that internal gains (from people, appliances etc.) and solar gains be the same all year round, i.e. the same for all ambient temperatures. Only in that case, different gains will shift the line parallel to the y-axis, producing the same slope. While the prerequisite may hold for internal gains, it generally does not for solar gains because in spring and autumn these are larger than in wintertime (in summertime the magnitude of the solar gains is irrelevant because there is no heating demand for space heating).

Consequently the 'energy signature' method can only be used in case solar gains are of relatively small importance in the energy balance of a dwelling. As a rule of thumb, the glazed fraction of the south façade should not exceed 30%. When this is not the case, solar gains in spring and autumn tend to cause a scatter of data points at temperatures around 10°C (grey circle in Figure 3 below), depending on the number of sunshine hours in that particular week. This makes the slope difficult to determine accurately.

A method is proposed to correct for the disturbing effect of solar gains, making use of the fact that the third method (see below) produces the energy balance of the dwelling, in particular yielding an estimation of the solar gains in the heating period. Taking the number of 'sunshine hours' in each week (or other period) from the KNMI database on internet (KNMI, 2011) and assuming that the solar gains in a particular period are proportional to the number of sunshine hours recorded in that period, a correction for the solar contribution can be made[1]. As an illustration, Figure 3 below shows the energy signature without correction while Figure 4 shows the graph with the corrected data.

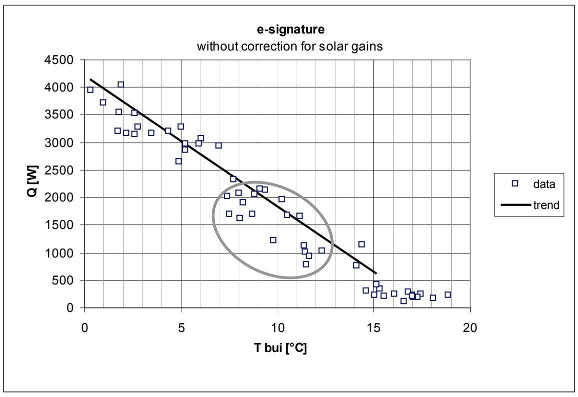

Figure 3 The energy signature without a correction for solar gains. The correction will mainly affect the data in the grey circle.

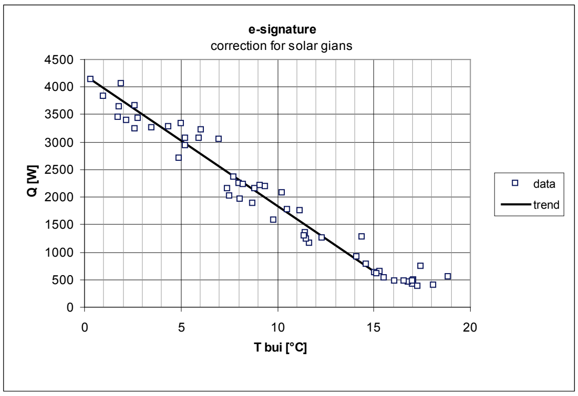

Figure 4 The energy signature of the same dwelling with a correction for solar gains.

The correction affects all data points in the graph, but in particular it decreases, as expected, the scatter of data points at temperatures around 10°C, making an estimation of the slope easier and more reliable.

It should be noted that the heating demand for DHW is compromised by the correction method due to the high solar gains in summer time, so the uncorrected chart should be used to find the heating demand for DHW (remember to correct for the boiler efficiency for DHW).

Uncertainty in the result

The most likely slope in the energy signature is determined visually because this allows for omitting data-points that seem less reliable. However, even after the solar correction procedure is applied, data points remain scattered. When the scatter is high, determination of the correct line is difficult and prone to misinterpretation of the reliability of some of the data points. To assess the uncertainty in the result, an educated guess is made of the possible variations of the slope as illustrated in Figure 5.

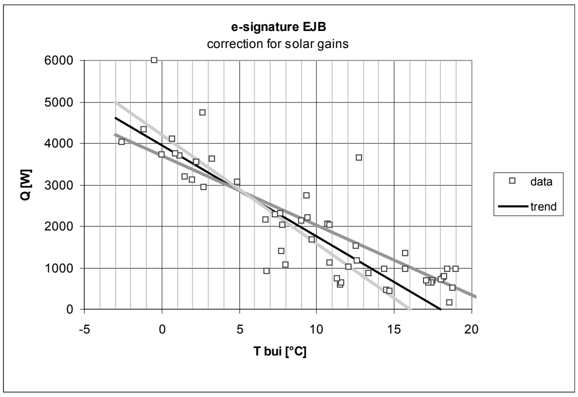

Figure 5 Determining the most likely slope in the energy signature (thin black line) and educated guess of variation therein (thicker grey lines).

Ideally, the heat losses derived from the energy signature should be identical or at least similar to the 'theoretical' heat losses. Differences between the two may appear because the thermal insulation of walls or windows is not what it is thought to be, for instance due to negligent construction or aging of materials.

The overall heat losses from the energy balance

The third way to determine the overall heat losses is based on the energy balance of the dwelling *in the heating season*. As with the first method, it uses some (simplified) elements of the PHPP tool (Feist, 2004).

Heat gains from the central heating system, solar gains and internal gains are estimated and the sum of these gains equals the overall heat losses.

The length of the heating season is estimated by entering the first and last months of active heating (default values are October and April respectively).

The gas consumption for space heating is calculated by subtracting from the total annual gas consumption the gas consumption for DHW [2] and cooking [3]. The latter two are scaled down from the annual consumption with a factor proportional to the length

[1] The solar contribution in each measuring period equals N_p/N_a*Q_{solar}, with N_p the number of sunshine hours in the period, N_a*the number of sunshine hours in the heating season (a constant value is assumed of 1880 for The Netherlands) and Q_{solar} the estimated solar contribution to the energy balance.

[2] The summer data from the energy signature can help to obtain a more accurate value of gas consumption for DHW.

[3] Default is an annual consumption of 60 m^3 of natural gas

of the heating season. With an estimation of the efficiency of the boiler for space heating, the contribution of the active heating system to the energy balance can be calculated.

Solar gains are estimated by multiplying, for each orientation, the glazed area of the dwelling with the solar irradiation in the heating period, the g-value of the glazing and an estimation of the solar access (100% in case of absence of sun shading, other buildings etc.). The solar irradiation in the heating season is calculated from monthly values (taken from the PHPP tool), and taking all months between the first and last months of active heating. It is assumed that the utilisation of solar gains in the heating season is 100%.

The internal gains are mainly due to heat from electrical appliances and people. The first is calculated assuming that all electricity in a household is converted into heat, with the exception of the electricity consumption by the washing machine, tumble dryer and dishwasher. The heat from these appliances is mostly lost to the environment through the sewer or through evaporation. Their contribution is calculated by estimating the number of cycles per week for each appliance and multiplying it with a (user defined or default) value of the electrical energy consumed per cycle. Internal gains from people are estimated by multiplying the number of people in a household, an estimated number of hours per year present (default 50% of 8760 hours) and a power of 100W per person. Children can be entered as contributing an amount of 0.5 or 0.7 times that of an adult.

Since all contributions to internal gains are annual numbers, their contribution to the energy balance in the heating season is scaled down with a factor proportional to the length of the heating season.

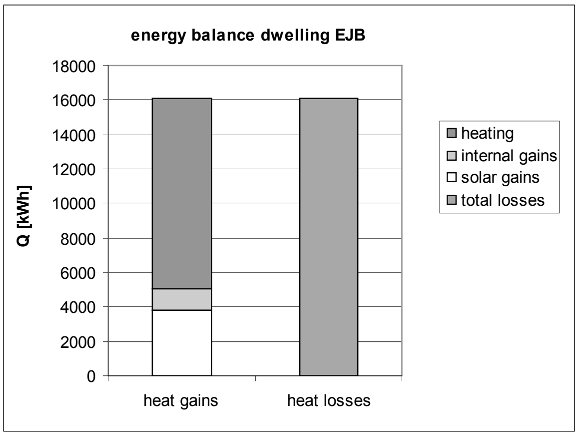

Figure 6 Annual energy balance of a dwelling. The solar contribution can be used to correct the energy signature method for the disturbing effect of solar gains in that method.

Over the length of the heating season the heat losses should equal the total of heat gains, shown graphically in Figure 6.

An illustration of the excel sheet that was used to determine the overall heat losses of the dwelling is shown in Figure 7 below.

energy balance method			**field types**	100	input required			
				100	input option			
details dwelling				100	from other sheet			
row house, built 1970				**100**	calculated			
				100	data (do not change)			
first month heating season		Oct		***100***	final result			
last month heating season		Apr						
length of heating season			**7**	months				
av indoor temp		19		°C				
av ambient temp in heating season		5.2		°C				
energy consumption	**annual**		**heating season**					
natural gas	1400			m^3/a				
for DHW		200	**117**	m^3/a				
for cooking		60	**35**	m^3/a				
for space heating			**1248**	m^3/a				
type of boiler	HR							
efficiency boiler for space heating			**90%**					
net heating demand heating season			**11010**	kWh/a				
solar irradiation								
g-value glazing		0.7						
					solar access			
glazed area South	17	m^2 x	**1054**	MJ/m^2 x	70%	=	**12543**	MJ/a
glazed area West	0	m^2 x	**689**	MJ/m^2 x	70%	=	**0**	MJ/a
glazed area North	17	m^2 x	**418**	MJ/m^2 x	100%	=	**7106**	MJ/a
glazed area East	0	m^2 x	**566**	MJ/m^2 x	70%	=	**0**	MJ/a
total glazed area	34	m^2					**19649**	MJ/a
solar gains in heating season:			**3821**	kWh/a				
internal gains								
electricity consumption	1600	kWh/a						
minus: dish washer	3	times/week x	1.39	kWh/cycle =	**217**	kWh/a		
washing machine	2	times/week x	1.1	kWh/cycle =	**114**	kWh/a		
tumble dryer	0	times/week x	2.85	kWh/cycle =	**0**	kWh/a		
minus: total					**331**	kWh/a		
internal gains in heating season:			**740**	kWh/a				
number of people in household	2							
% of time at home (av over 24hr)	50%							
internal gains from people in heating season:			**511**	kWh/a				
heat losses = total of heat gains in heating season:			**16082**	kWh/a				
average losses in heating season			***228***	W/K				

Figure 7 Excel sheet determining the overall heat losses of a dwelling. Grey shaded cells are input cells. Bordered cells also require input but their value is less critical so the default number can be maintained when no accurate data is available.

Finally, the heat losses are divided by the average temperature difference between indoor (default 19ºC) and outdoor. The latter is calculated automatically from averaging the monthly outdoor temperatures (again taken from the PHPP tool) between the first and last months of heating.

Uncertainty in the result

As in the first method, the accuracy of the heat losses calculated is assessed by varying the input parameters between plausible limits and recording the effect of each variation on the heat losses.

As noted in the introduction, user behaviour can have a strong effect on energy consumption. A trend worth noting is an increasing electricity consumption of about 2% per year (EuroStat 2011), mainly due to the presence of an ever-increasing number of electrical appliances in households. However, in terms of the energy balance, this only means that an increasing share of the space heating is accounted for by internal gains, i.e. the dissipation of electrical energy. Since it will result in a corresponding decrease of heat from the central heating system, the sum of all gains will remain the same and therefore, so will the total heat losses calculated from them.

Other effects of user behaviour are related to the average indoor temperature and the amount of ventilation or infiltration, e.g. by leaving doors and windows open. Both these effects will increase the gas consumption for space heating and thus the total heat losses computed. In that respect the method differs from the 'energy signature' method, which is insensitive to the indoor temperature set point.

Finally, the combination of the second and third method allow a useful cross check. The energy signature method shows the temperature where the sloping line and horizontal line meet. This is the ambient temperature below which the heating system is needed to keep the dwelling heated ($T_{threshold}$). At this temperature, the internal gains plus the solar gains balance the heat losses due to the temperature difference between indoor and outdoor. This yields the equation:

internal + solar gains = $(T_{indoor} – T_{threshold}) * \text{slope}$

If T_{indoor} is well known, the value of the internal plus solar gains calculated in the energy balance method can be checked. Conversely, when the gains are well known, the average indoor temperature can be checked. The latter check is carried out for the dwellings in this study and the results are compared to the reported indoor temperature in Figure 8.

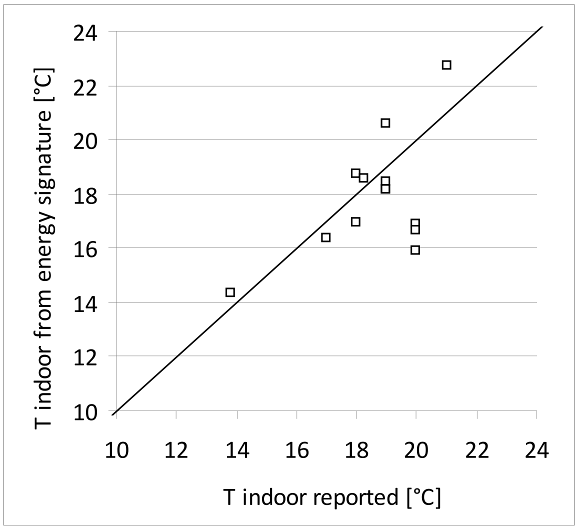

Figure 8 Indoor temperatures from the energy signature vs. the reported indoor temperatures for the dwellings studied.

The results agree reasonably well except for a few cases where the reported indoor temperature is the (default) value of 20°C. Possibly, it did not occur to the test subjects that this number could be changed.

RESULTS

The methodology of determining three values for the heat losses was applied to the 13 dwellings of (former) colleagues. The results are shown in Figure 9. The numbers are shown in W/K per m^2 of floor area and the uncertainty in each value is shown in the graph with an error bar.

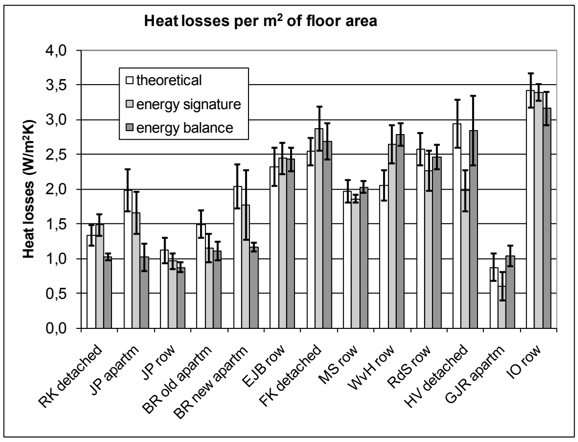

Figure 9 Heat losses in W/m²K determined with the three methods for the dwellings of 13 colleagues.

It appears that heat losses for most dwellings are in the range of 1-3 W/m²K, which corresponds to 65-200 kWh/m²a [4]. Low values for heat losses are typically found in centrally located apartments (e.g. GJR's apartment) and 'new' dwellings, such as JP's row house built in 2009. However, when compared to the Passive House standard of 15 kWh/m²a, there appears to be considerable room for improvement. Suggestions for improving the energy efficiency of the dwellings are outside the scope of this study, although the methodology is a very suitable tool for determining weak points in the energy balance and assessing the effect of energy saving measures. Also interesting but again outside the scope of this study, is a detailed analysis to correlate the characteristics of the dwellings and occupants and the heat losses calculated.

At first glance, the three types of heat losses agree fairly well. Looking first at the theoretical heat losses (white bars) and energy signature heat losses (light grey bars), it appears that they are comparable, showing that in most cases the quality of the dwelling is as expected on theoretical grounds. Of course the reason for the agreement may be that the calculation of the theoretical value is based on realistic estimations of actual U-values etc. rather than the U-values 'promised' by the building contractor.

There are two cases where the theoretical value and energy signature value disagree (i.e. lie outside the

[4] Based on a 6 month heating season with a constant temperature difference of 15 °C between indoor and outdoor.

range indicated by the error bars). One is the row house of WvH. When confronted with this finding, the owner remarked that his dwelling is in a continuous process of renovation and that some of the theoretical U-values entered in the calculation may not correspond to the period of recorded gas consumption.

The other disagreement is with HV's detached dwelling. This case is a special one as the owner heats only the ground floor of his dwelling to 17-18°C and a single room on the second floor to about 21°C. The dwelling, which was built in 1885 and partly renovated in 2000, is rather poorly insulated so it cools down rather strongly when the heating is switched off, which is at night and during office hours. Since the energy signature method relates gas consumption to heat losses assuming an equable and constant temperature difference between indoor and outdoor, it cannot be expected to catch the detailed and dynamic thermal behaviour of the dwelling and to accurately assess the quality of the dwelling.

When comparing the annual heat losses (dark grey bars) to the other two, the value is either comparable or lower. The effect is most pronounced in the case of the 5 dwellings on the left of Figure 9. These dwellings belong to or have belonged to only 3 different people. All three indicate that they consider themselves energy conscious to the point of austere.

This touches the point of the selected population. All occupants work or have worked at the group of Energy Technology in the Built Environment ETBE of our institute, so one might expect them to be energy conscious. In addition, one may expect them to possess the expertise necessary for minimizing their energy consumption. With that in mind, annual heat losses - which include some effects of user behaviour - were not expected to be higher than the other two types of losses in the first place. This may be quite different for less energy conscious people.

Another possible explanation for the lower values of the third method is the occurrence of mild winters in the last few years, which is when annual gas consumptions were being recorded.

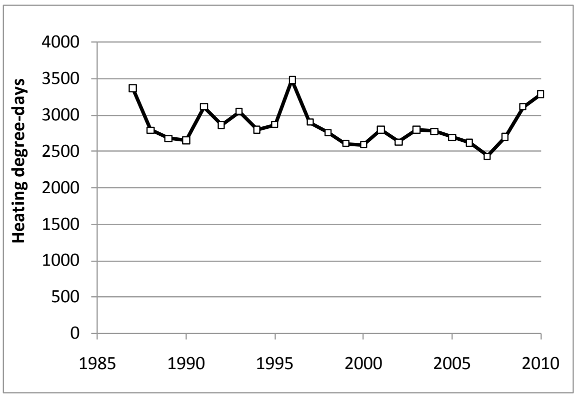

Figure 10 Number of heating degree-days in The Netherlands, averaged over 6 weather stations.

Figure 10 shows the number of heating degree-days in the Netherlands between 1985 and 2010, indicating the severity of the winters. If anything, the winters of 2009 and 2010 were more severe than the average winter in the period 1985-2010, so this is unlikely to have been the cause for the lower losses calculated with the energy balance method.

A naturally arising question is which of the three methods presented can be expected to provide the most accurate value for the heat losses and therefore, for the 'energetic quality' of the dwelling. This question is hard to answer. For one thing, the three methods yield different parameters (e.g. calculated vs. measured values) so two values may differ and still both be correct. In fact the essence of the paper is that conclusions can be drawn from the differences between the results obtained by the three methods.

Secondly, all three methods suffer to some degree from lack of accurate input data and/or inherent uncertainties. Judging from the size of the error bars in Figure 9, there does not seem to be a method that yields results with superior accuracy compared to the other two.

Future work

The logical next step is the collection of data from a number of less knowledge-biased households. This may face the problem that people with less knowledge of energy savings and who are less energy-conscious, generally are not the ones to bother themselves with periodic recordings of energy data, as is required for the energy signature method. The problem may be solved by introducing an automatic data collection system, using some sort of smart metering.

The dwellings studied are rather common ones, with conventional installations. In case of high energy-ambitious dwellings, installations tend to grow more complex, including e.g. a solar collector for DHW and space heating or a shower heat exchanger. Their effects on each of the three ways of calculating heat losses will have to be separately assessed. In most cases it will imply that the contribution of such systems will have to be separately monitored and included in the analysis in order for the methodology to produce correct results.

Another possible field of application of the methodology comprises non-residential buildings, in particular office buildings. The methodology can be used to help to identify the cause of energy consumptions that are higher than expected, as is quite often the case in these buildings.

A large share of the energy consumption of office buildings is due to cooling, which is not investigated in the present study. However, the energy signature method lends itself well for the assessment of the cooling demand. This entails including the energy demand for cooling in the graph and analysing the part of the graph of increasing (cooling) demand with increasing ambient temperatures. As was done in the present study, a correction for solar gains may have to be carried out. Still, the analysis is expected to be more difficult than that of the heating demand because the temperature of the building will vary more widely in summertime than in wintertime so the effect of the thermal mass cannot be excluded.

CONCLUSIONS

The methodology of comparing three types of heat losses is a rather simple one, not taking into account detailed effects such as dynamic thermal behaviour or different temperate regimes within a building. Still, the results show that the three types of heat losses are comparable for a variety of dwellings.

Uncertainties in the heat losses obtained remain but they are not solely due to shortcomings in the procedure or methodology but also due to lack of accurate input data e.g. for infiltration rate and U-values of walls and windows. Therefore, more sophisticated simulation software tools such as TRNSYS are not expected to yield more accurate results.

The energy signature method has improved by adding the procedure to correct for solar gains. Still, it is recommended that data be collected over a period of at least one-half of a heating season in order to be able to draw the correct line through the data points with some reliability.

The effect of user behaviour, in particular the level of indoor temperature in the heating season, on heat losses, by comparing values from the second and third methods, could be assessed only to a limited degree due to the population selected that did not appear to include any energy wasting occupants.

In potential however, the methodology proposed appears to be a useful tool to provide insight into the 'energetic' quality of a dwelling and to assess some effects of user behaviour on energy consumption.

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