The influence of behaviour on the effectiveness of more stringent standards

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Abstract
In order to restrict the effect of greenhouse gas emissions on climate change, the emissions need to be reduced with 50% in 2030 compared to 1990. In order to meet this target in the built environment, a severe reduction of energy use is required. Energy saving measures can be implemented in new as well as in existing dwellings. To determine the effectiveness of standards for new dwellings, it is important to know whether implementation of more stringent standards leads to corresponding energy savings. Or are life style changes needed to further decrease domestic energy consumption? To answer these questions, the energy consumption of over 200 houses was measured on a monthly base for one year. The households had to fill in extensive questionnaires dealing with various kinds of behaviour. The technical characteristics of the dwellings were obtained through real estate managers. Finally, the acceptance of advanced technological options was investigated by means of interviews. It turns out that the behaviour of the households strongly influences energy consumption. Nevertheless, the analysis shows that stricter norms do lead to corresponding energy savings. Therefore it can be concluded that setting stricter standards for new dwellings is an effective energy conservation measure. Measurements show that recently built well insulated detached dwellings use about the same amount of energy as an average existing dwelling. Because of consumer preferences, there is a tendency to build more detached houses. This means that the energy saving resulting from more stringent standards will be partly counteracted by the construction of larger dwellings.

Introduction
In order to restrict the effect of greenhouse gas emissions on climate change, the emissions need to be reduced with 50% in 2030 compared to 1990. This reduction target is set for direct and indirect greenhouse gas emissions. In the Dutch household sector, direct greenhouse gas emissions are mainly due to the combustion of natural gas. The so-called indirect emissions result from electricity use. In the period 1980 - 1990, the most important policy instrument was the setting of minimum standards for individual components of a new dwelling, e.g. minimum R_C-values for wall, floor and loft insulation and a maximum U-value for glazing. For existing dwellings, massive subsidy schemes were implemented. In 1995, the Energy Performance Standard (EPN) was implemented. This standard enables calculation of the integral energy performance of a new dwelling and consists of a standardised method for the calculation of an energy performance coefficient (EPC). The EPC is a theoretical value for the primary energy use, taking into account the size and type of the dwelling and the energy conservation measures. The EPN focuses on the integral energy performance and not on the quality of individual components. The reason behind this was to minimise costs and to maximise energy saving potential.

The carbon dioxide emissions have decreased since 1990, but in the period 1990-2000 the reduction in the household sector was only 5%. Therefore, substantial additional effort is required in order to meet the CO_2-emission reduction target for 2030. The amount of CO_2 exhausted in the built environment depends on two developments: the number of dwellings and the energy use per dwelling. The number of dwellings has increased by 14% since 1990 and is expected to further increase until 2030. This paper focuses on options as well as the potential to reduce the direct CO_2-emissions through limitation of energy consumption of new dwellings.

HISTORICAL DATA ON ENERGY CONSUMPTION PER DWELLING

The energy used by most Dutch households can be split up in electricity and natural gas. In the Netherlands, about 90% of the dwellings uses natural gas as energy carrier for space heating and hot water production. The remaining 10% of the dwellings is connected to a district-heating grid. Oil is hardly used anymore (<0.5% of total energy consumption). In Figure 1 and 2 the development of the average use of natural gas and electricity per household is shown. The average gas use per household has declined from about 3 300 m^3 (or 104 GJp) in 1980 to approximately 1 600 m^3 (or 51 GJp) in 2000. This decline is a consequence of improved insulation, the construction of more efficient new dwellings and the use of more efficient boilers (mainly condensing boilers). Some life style changes contributed to the decrease in energy consumption: the decrease of household size and of time spent at home. At the same time, other life style changes had the opposite effect: higher thermostat settings, heating of more rooms and higher shower frequency and shower duration have dimmed the decrease in energy use per household.

The amount of gas used per household strongly depends on the type of dwelling. The average energy consumption of a detached dwelling is more than twice as high as the average energy consumption of an apartment (see Figure 1). Despite the strong decrease of the specific energy consumption of detached houses in the period 1980 - 2000, the amount of natural gas used in a detached house is in 2000 still higher than the amount of natural gas used in 1980 in apartments.

The average use of electricity declined between 1980 and 1988, to rise after that. In 1998 the average use was approximately at the level of 1980. The increase is a consequence of higher penetration of appliances like dishwasher, tumble dryer, microwave, computer etc. The electricity used for space heating and heating of tap water declined strongly because of the more efficient pumps in central heating systems and because of the replacement of electric boilers by gas boilers.

STANDARDS FOR NEW DWELLINGS: THE EPN

As stated before, to make new dwellings more energy efficient at minimum costs, the Dutch Government introduced in 1995 the Energy Performance Norm (EPN). This standard concerns energy use for heating (space heating and the heating of water), cooling and the generation of electricity

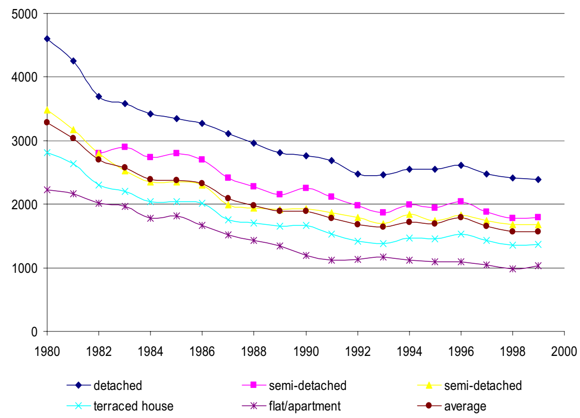

Figure 1. *Average natural gas consumption per dwelling.*

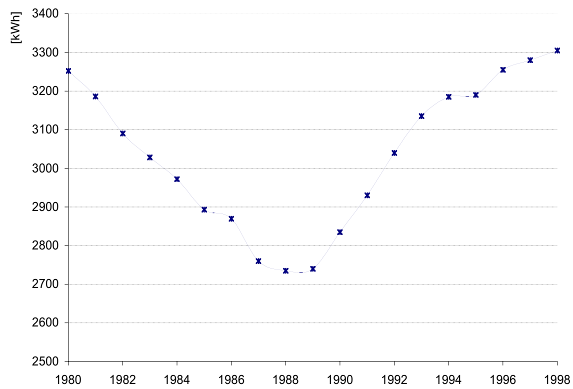

Figure 2. *Electricity consumption per household.*

by photovoltaic cells. The energy use of domestic appliances is not affected by the norm.

The EPN not only consists of a standardised method for the calculation of the EPC, but also indicates the maximum allowed EPC. The lower the EPN, the more stringent the norm is. The EPC is the ratio between a 'theoretical amount of primary energy use' and a 'reference use[1]'. The 'theoretical amount of primary energy use' differs from dwelling to dwelling and depends on characteristics like floor, wall and roof area, area of windows, orientation of the building and the quality of energy conservation measures. Specific life style aspects are not taken into account in the calculations. In order to be able to calculate the energy use of a dwelling, default values are used for lifestyle aspects. These default values are based on the average composition and behaviour of households (e.g. thermostat setting, demand for warm water, ventilation and heating behaviour etc). In reality, behaviour and composition of households vary. These deviations

1. The reference use is not a constant value (per square meter), but depends on the building design (floor area and shell area). Therefore, for a given EPC-value, the 'theoretic energy use' differs from building to building. The formula to calculate the EPC is as follows:

$$EPC = \frac{Q_{theoretic}}{Q_{reference}} = \frac{Qtheoretic}{65 \bullet A_{shell} + 330 \bullet A_{floor}}$$

, where A_{shell} stands for area of the building shell and A_{floor} for floor area. $Q_{reference}$ stands for reference energy use, $Q_{theoretic}$ stands for the total energy used for space heating, heating of tap water, cooling and lightning.

with regard to the default value may cause variations in energy use of dwellings, even while the dwellings are equal from a technical point of view.

In 1995, when the EPN was introduced, the value of the EPN was 1.4. The EPN became 1.2 in 1988 and 1.0 in 2000. In 2006 the EPN will probably be reduced to 0.8. Theoretically, one could therefore expect that a new dwelling built according to the EPN 2000 standard will be over 40% more efficient than a dwelling that complies with the EPN 1995 standard.

In an earlier research project, in which the energy consumption of about 200 dwellings built after 1995 was analysed, it was found that energy consumption in identical dwellings varied significantly. For that reason, it was not possible to draw any conclusion on the effectiveness of the EPN as a measure to reduce CO_2-emissions in the residential sector. Therefore, it was decided to launch another project in which not only the actual consumption was taken into account, but also the variation in energy consumption resulting from differences in life style characteristics. Assuming it is feasible to correct the actual (measured) energy consumption for life style differences, an indication of the effectiveness of the EPN can be obtained.

RESEARCH QUESTIONS

Since 1995 the EPN became stricter in several steps. For policy makers it is important to know whether this has led to corresponding energy savings. The research question therefore is formulated as follows:

- Does implementation of more stringent standards lead to corresponding energy savings, or are the theoretical savings in reality dominated by variances in lifestyle aspects?
- And are consequently life style changes needed to further decrease domestic energy consumption?

To answer these questions there must be insight into the extent that technical aspects cause variances in energy use, and into the extent that these variances are caused by behavioural/life style factors. In order to get insight in the factors that determine energy use, data have been collected from several sources. The methodology used for data collection and analysis is described in the next section. The subsequent section gives an overview of the information gathered and of the results of the data analysis. In the final section the most relevant outcomes are discussed and the research questions are answered.

Methodological approach

As stated before, a first attempt to derive the impact of the EPN failed because of the large variation in the actual energy consumption of new dwellings. Therefore, it was required to perform research on the impacts of life style on the height of the actual energy consumption. By correcting the actual energy consumption for these differences in life style, information about the impact of the EPN on energy consumption can be obtained. First, a list of variables that are likely to influence the actual energy consumption was compiled. This list includes life style related variables, such as household size, age of the household members, income, thermostat setting, number of rooms heated, as well as technical characteristics such as insulation quality of windows, wall, roof and floor, dwelling size and efficiency of the boiler. Information about the life style related variables was collected by means of questionnaires directed towards the households. Research projects in the past have shown that if is difficult for consumers to answer very specific technical questions (i.e. the U-value of their glazing or the R_C-value of the wall insulation). Therefore, all technical data were obtained through other sources such as project brochures, technical descriptions provided by the real estate developers and building constructors and evaluation studies conducted by the Dutch national energy agency SenterNovem.

DESIGN OF THE DATA COLLECTION

Approximately 76% of the average gas consumption in existing dwellings can be ascribed to space heating. The remaining 24% can be ascribed to the heating of tap water (about 22%) and to cooking (about 2%). The share of gas used for space heating is slowly decreasing as a result of improved insulation and more efficient boilers. For new dwellings, the share of space heating in the total gas consumption could be a lot lower than 76%. This implies that not only the factors that influence the demand for space heating have to be taken into account, but also the factors that influence the demand for warm tap water (and cooking). This is even more important since there are indications that energy consumption for hot water (showering, bathing) is more influenced by life style factors than the energy demand for space heating.

When measuring the actual energy consumption, it is in most cases not possible to make a distinction between the consumption for space heating and for hot water production. A complicating factor in this was the fact that all of the very efficient dwellings that use natural gas as energy carrier for space heating were equipped with solar thermal water heaters (with varying capacity). Only during the heating season (wintertime, early spring and late autumn), these very efficient houses have a demand for space heating. By analysing the energy consumption during the period that no space heating was required, one can obtain the energy demand for hot water production (and cooking). The demand for space heating could be obtained by subtracting the energy consumption resulting from hot water production (and cooking) from the total actual energy consumption during the heating season. Due to the fact that the production of solar thermal water heaters depends on the season, a correction has been made for decrease in production during the heating season. To simulate the energy production of solar thermal water heaters very detailed model calculations were performed, which included the actual weather conditions. These calculations were performed for solar water heaters with varying capacity and the model results were calibrated with the measurements of actual energy consumption during the period that no space heating was required.

In order to be able to derive a function for the development of energy demand for warm tap water, sufficient monitoring data has to be available. First, it was tried to obtain this information on e.g. a daily or weekly base from the energy service company, since part of the dwellings were equipped with electronic meters that can be read on dis-

Table 1. Average natural gas consumption and family size per project.

project	EPC (1994)	floor surface [m2]	Natural gas consumption [GJp/year]	[m^3/year]	Std. dev.	Min	Max	Family size [pers.]	Std. dev.
Almere	0.75	151	20	632	178	299	912	2.7	0.9
Amersfoort	0.85	99	24	756	164	370	1071	1.8	0.8
Den Helder	1.19	156	41	1297	354	422	1939	3.4	1.1
Heerlen	0.93	155	33	1046	430	540	2199*	2.5	0.7
Soest	1.26	133	35	1105	321	587	1619	2.8	1.2
Veenendaal	1.12	99	26	813	209	475	1126	3.3	1.1

* Household size is 6 persons

tance. This was for juridical reasons not feasible. Therefore, the only option was to ask the households to record their energy consumption. It was expected that a very high requested frequency of monitoring (e.g. weekly) would lead to a large number of people dropping out of the survey. On the other hand, sufficient data had to be available in order to be able to derive the required relationships. Therefore, the households were asked to monitor their energy consumption on a monthly basis for a twelve-month period.

To collect data about the behavioural factors, the households had to fill in two extensive questionnaires. One was about lifestyle characteristics like family size, the composition of the family and behaviour related to the use of warm water. The other one – filled in during the heating season- was about heating and ventilation behaviour. During the monthly monitoring of the energy consumption, the households were also asked to report changes in behaviour (e.g. change in frequency of being at home) or in household characteristics (e.g. increase or decrease in family size).

RANDOM SAMPLE SURVEY

In order to be able to determine the impact of the EPN, the sample has to consist of dwellings with varying efficiency. In order to be able to analyse and explain the fluctuations in energy consumption in identical dwellings, the sample has to consist of projects with a minimum number of identical houses. The data collected concern dwellings with an EPC ranging from 1.3 to 0.7. Only projects were selected where at least twenty technically equal dwellings were present. In total 700 households have been approached, of which 200 were willing to participate in this research. During the project about 20 households dropped out. All the households approached live in a single-family home (detached / semi-detached house / terraced house), because it was not feasible to construct an appropriate sample for apartments.

DATA ANALYSIS

A Multivariate Regression Analysis (MRA) was used to analyse the data. By means of an MRA it is possible to determine the (statistical significant) impact of individual variables on the spread in energy consumption. By doing this, a simple model can be built that determines and explains the energy consumption. After assessment of the impact of the individual variables, it is possible to construct a reference consumption that corresponds to a dwelling that is occupied with a hypothetical family with an 'average' behaviour.

Results

RESULTS OF QUESTIONNAIRES

Almost all participating households completely filled in the questionnaires. However, results are not applicable for the Netherlands in general, since the sample consisted of households living in a specific type of dwelling (almost all were owner occupied). In this section, some of the most relevant results on household behaviour and characteristics are discussed.

Family size and actual energy consumption

The average size of a household might be an important factor for the amount of energy used by the household. In Table 1, the average family size and the actual natural gas consumption is given. The average household size varies strongly between the projects, ranging from 1.8 to 3.4 persons per household. Consequently it is impossible to compare the energy use of the different locations without correcting for household size. The average household size of all locations (2,8 persons/household) is higher than the Dutch average (2,3 persons/household). Single households are underrepresented in the sample. The consequence of the high average household size is that the real energy use of the sample is probably higher than the theoretical energy use.

It is also clear from the table that there can be a large spread in actual energy consumption between identical dwellings. In Heerlen and Den Helder the difference between the minimum and maximum actual consumption was about a factor of four. For other projects the difference between the minimum and maximum value found was about a factor of three. These results explain why in previous research it was not feasible to assess the impact of the EPN by only analysing yearly measurements of actual energy consumption.

Behaviour for showering and bathing

The frequency and duration of a shower or bad session influences the energy use for heating tap water. The showering frequency (once or twice a day) is higher than the bathing frequency. There are no numbers known for the Dutch average frequency. The duration of showering is not asked for, as people in general cannot estimate this very well.

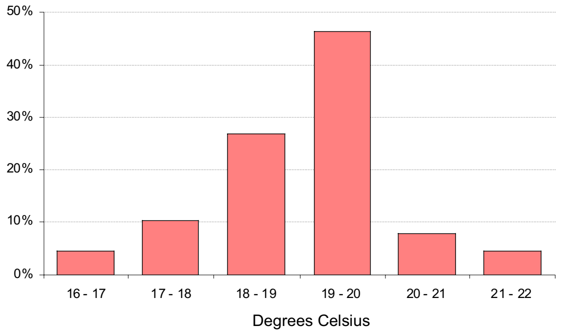

Figure 3. *Distribution of average temperature setting.*

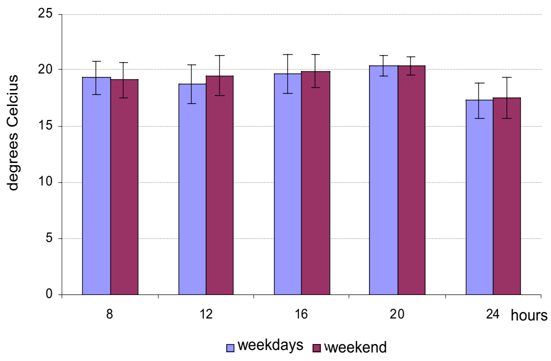

Figure 4. *Average temperature setting for weekends and weekdays.*

Thermostat setting

Most of the households adjust the 'thermostat' at a temperature between 18ºC en 20ºC (Figure 3). Only 12% of the households adjust a temperature higher than 20ºC. Two types of thermostats can be used: manual or programmable. Where the setting of a manual thermostat can take place only at the moment itself, the setting of a programmable thermostat can be programmed for a longer period. More than half of the households in the sample (56%) has a programmable thermostat. Figure 4 shows the average temperature setting during the week and weekend in case of a programmable 'thermostat'. For manual thermostats such detailed information could not be gathered. Figure 4 shows that the temperature is almost the same for weekends and weekdays.

More than 50% of the households with a manual thermostat change the temperature by absence of a few hours. Of the households with a programmable thermostat only 28% changes the temperature by absence. In case of a programmable thermostat there seems to be a barrier to change settings.

Frequency and number of rooms heated

The kitchen and living room are frequently or daily heated by most of the residents. Because of the good insulation of the buildings, heating of rooms on the first floor is not necessary. The bathroom is the most frequently heated room on the first floor. About 40% of the bedrooms is frequently heated.

Length and frequency of ventilation

The living room, bedrooms and bathroom are frequently or daily ventilated by only 20% of the households. Ventilation of the kitchen and other rooms takes place less frequently. The most frequently ventilated room in a dwelling is the bedroom: 86% of the residents ventilate this room at least once a week. In the living room and bathroom the thermostat is not switched down during ventilation.

RESULTS COLLECTION OF TECHNICAL DATA

The dwellings selected for this research have significantly deviating characteristics. The EPC of the dwellings ranges from 0.7[2] to 1.3. Most of the dwellings are connected to the natural gas grid (most of these dwellings use a condensing boiler for heating), the remaining houses are connected to a local or a more extensive heat grid. Also four dwellings heated by an electrical heat pump were monitored. Due to their deviating characteristics, these houses were not taken into account in the MRA but were analysed separately. The sample includes detached houses, semi detached houses and terraced houses. For houses that are not connected to the natural gas grid, only electric cooking is possible. Of the dwellings connected to the natural gas grid, 47% uses natural gas for cooking. The households were asked whether they changed the construction of their dwellings, e.g. by mounting a dormer (window) or building a conservatory, since these kinds of changes might influence the energy consumption. It turned out that almost no changes were made. In one case a sun lounge was added to the house.

RESULTS OF MONITORING OF ENERGY USE

The energy use has been monitored on a monthly base during one year. In Figure 5 the development of natural gas demand is shown for dwellings connected to the natural gas grid. In the period May till October the heat demand was almost constant. In this period there was no heat demand for space heating, all the heat was used for heating tap water (and in case of a connection to the gas grid sometimes also for cooking). In other words, in this specific year of monitoring the heating season ended in May and a new heating season started in October. The length of the heating season may differ from year to year. The year of monitoring had a relatively warm winter with hardly any frost. However, in April the temperatures were relatively low in the mornings.

Comparison of energy use in sample and Dutch average energy use

The energy use for space heating can only be calculated by subtracting the energy use for the heating of water and cooking from the total energy use. During the months July, Au-

2. This is already below the norm for 2006.

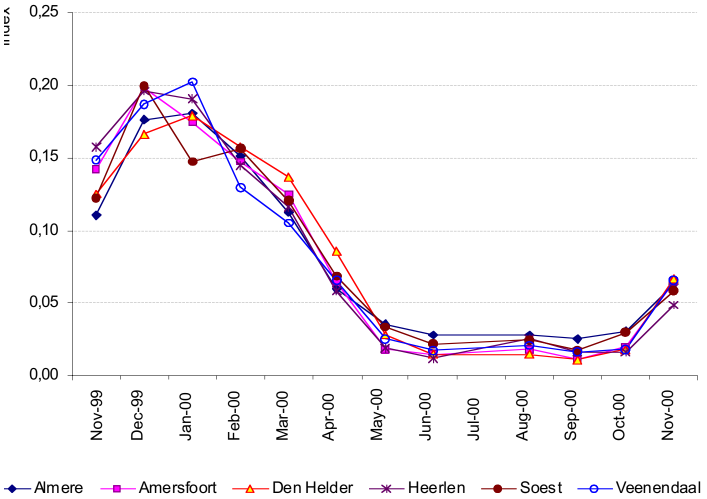

__Figure 5.__ Development of the average total natural gas consumption per dwelling for several projects. The index is defined as the monthly gas consumption relative to the total anual gas consumption of the dwelling.

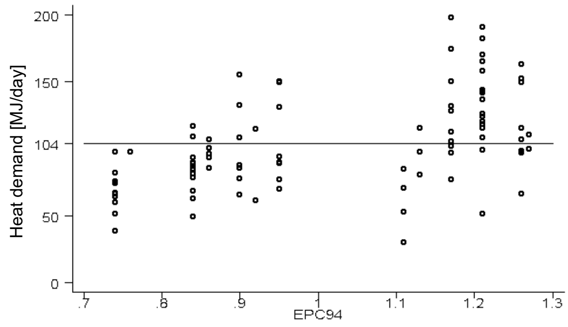

__Figure 6a.__ Average heat demand (for dwellings connected to the natural gas grid).

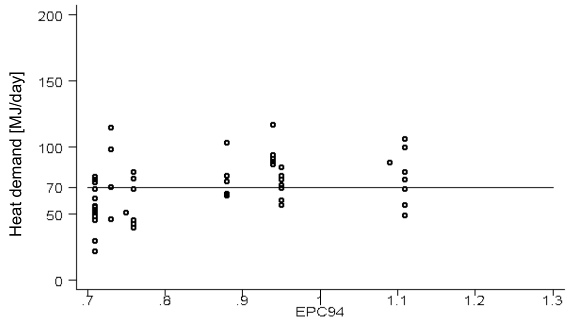

__Figure 6b.__ Average heat demand (for dwellings connected to the heat distribution grid).

gust and September, the energy demand is totally determined by the heat demand for warm water (and cooking). All the dwellings in the sample that are connected to the gas grid are equipped with a solar thermal water heater. The yield of this water heater is lower in wintertime than in summertime. Assumed that the use of warm water is constant all year round, more gas will be needed in wintertime than in summertime to foresee in the heat demand for warm tap water. To determine the gas used for the heating of warm tap water in the different months, the average yield of the solar thermal water heater must be calculated for the different months. As explained before, this was done by separate modelling. After correcting the heat demand for the yield of the solar thermal water heater, an average gas demand for the heating of tap water is obtained: 334 m^3 (or 11 GJ_p) per year. In case natural gas was used for cooking, the average use of gas was 84 m^3 (+/- 31 m^3) per year (or 3 GJ_p +/- 1 GJp per year).

Now the amount of natural gas for the heating of tap water and cooking is known, the natural gas use for space heating can be calculated. The average heat demand for space heating in dwellings was 66 MJ_p per day (or circa 59 MJ_{th} per day) in case of connection to the gas grid and 51 MJ_{th} per day in case of connection to a heat grid. Differences in size of dwelling and type of dwelling are likely to influence the heat demand for space heating.

It can be concluded that (for the given data accuracy) the sample is representative for an average Dutch household qua gas demand for cooking and warm water. As expected, the natural gas used for space heating is significantly lower for the sample than for a Dutch average household. This is a consequence of the lower EPC value of these dwellings.

Effect of EPN on energy demand

To get a first impression of the effect of more stringent norms, the heat demand for locations with different EPCs is shown in Figures 6a and 6b. The figures show that large variations in energy consumption exist. The average heat demand is 104 MJ per day for dwellings connected to the gas grid and 70 MJ per day for households connected to a heat distribution grid. The figures show that some of the households with an EPC lower than one have an energy use higher than average, whereas some of the households with an EPC higher than one have an energy use lower than average.

Figures 7a and 7b show the average energy use for different EPC-values. These figures show that a lower EPC does not necessarily lead to a lower gas/heat demand. But does this mean that more stringent norms don't lead to corresponding energy savings?

As a first check, a linear trendline has been fitted through the average energy use of the different projects (see Figure 8). It appears that the fitted line falls within the error margins[3] (except for Lent). The trendline crosses the 'origin'. Therefore it might be expected that more stringent norms lead to further reduction of the energy use and will drop to zero by EPC=0. Therefore, the expected energy use

3. Error margin is 1 Standard Deviation (SD).

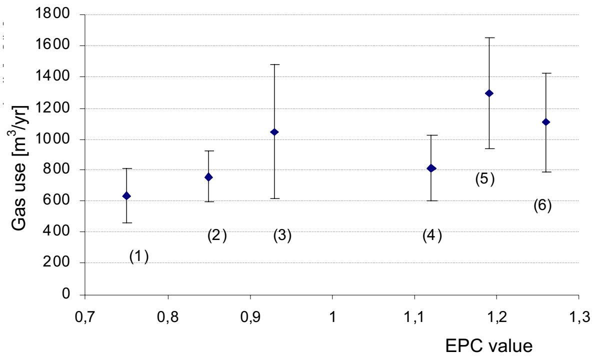

Figure 7a. *Natural gas use per location.*
1=Almere, 2=Amersfoort, 3=Heerlen, 4=Veenendaal, 5=Den Helder, 6=Soest

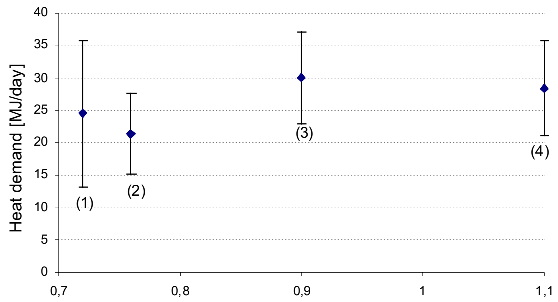

Figure 7b . H*eat demand per location. 1= Nieuwegein, 2=Tilburg, 3=Lent, 4=Den Haag.*

for EPC=0 derived from the analysis of the monitoring data equals the theoretical energy use for EPC=0.

A reliable estimation of the effect of more stringent norms, however, can only be made by analysing the effect of life style characteristics on the average actual energy consumption An MRA has been conducted, to make this analysis.

Result of MRA

In order to find out what aspects influence the average energy use and what aspects are responsible for deviations from this average energy use, an MRA has been carried out for both warm tap water and space heating. Life style aspects as well as technical aspects are analysed simultaneously.

For space heating, deviations from the average energy use are caused by temperature setting and self-monitoring. The setting of higher temperatures will cause a higher heat demand for space heating. As discussed before, thermostat setting is on its turn influenced by the presence of a 'programmable' thermostat. Self-monitoring means that the households periodically (on a monthly base or more frequent) have monitored their energy use. Self-monitoring leads to a lower heat demand for space heating. Self-monitoring did not have a significant effect on the heat demand for warm tap water. This means that people that are conscious of energy use adapt their behaviour related to space heating, but don't adapt their behaviour related to the heating of water – or only so little that there's no significant influence. Both thermostat setting and self-monitoring are life style characteristics that are not influenced by the EPN. More stringent norms will therefore hardly influence the variances in heat demand for space heating. As may be expected, the frequency of showering and bathing significantly influence the heat demand for warm water. This effect is a little stronger for showering than for bathing. Both show-

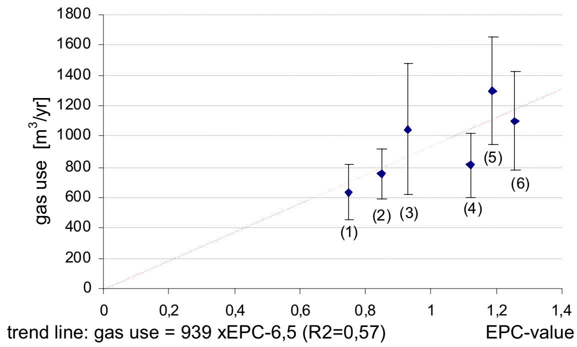

Figure 8. T*rend in natural gas use per location.*
1=Almere, 2=Amersfoort, 3=Heerlen, 4=Veenendaal, 5=Den Helder, 6=Soest

ering and bathing frequency are life style characteristics. More stringent norms will therefore hardly influence the variances in heat demand for space heating. From the MRA can thus be concluded that more stringent norms will hardly influence the variances in heat demand for space heating and the heating of tap water.

A final analysis has been conducted to determine the effectiveness of the EPN. This is done by comparing the theoretical (primary) energy consumption, which can be derived from the calculation of the EPC, with the actual energy consumption. In order to make a fair comparison, the actual (measured) energy consumption in the various projects has been corrected for differences in life style characteristics (e.g. thermostat setting), in household characteristics (e.g. age of the household members), and for annual climate fluctuations[4]. In this analysis the ratio has been calculated between theoretical energy use and (corrected) ac-

4. To correct for climate fluctuations the Heating-Degree Days (HDDs) of the year of monitoring have been compared to the average HDDs of the previous thirty years. The number of HDDs for a specific day is defined as the number of degrees Celsius of the mean daily temperature below the 18ºC treshold. If, for example, the mean daily temperature for a specific day is 12ºC, the number of HDDs for that day is 18-12 = 6. The 'heating degree correction' factor (G_t) equals the 'average number of HDDs' devided by the 'HDDs of the year of monitoring'. The corrected gas consumption can be calculated by the following formula:

$$GC_{corr} = GC_{uncorr} \bullet G_t \bullet 0{,}76$$

GC_{corr} and GC_{uncorr} stands for corrected and uncorrected gas consumption. G_t is the heating degree correction factor. The factor '0,76' indicates the amount of gas used for space heating (Spakman et al, 2003).

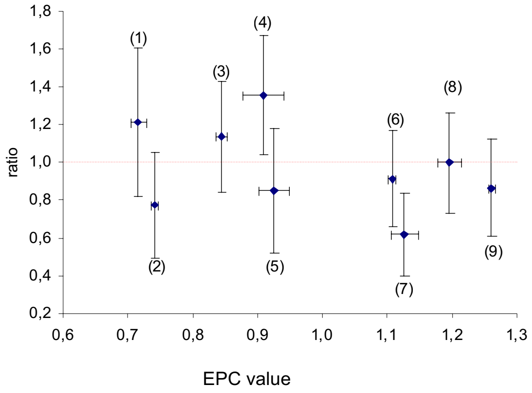

Figure 9. *Average energy use (temperature corrected). 1=Nieuwegein, 2= Almere, 3=Amersfoort, 4=Lent, 5= Heerlen, 6=Den Haag, 7= Veenendaal, 8=Den Helder, 9=Soest.*

tual energy use for a reference family. If this ratio is one, the corrected actual energy use for a reference family equals the theoretical energy use in the calculation of the EPC. The key factor now is to check whether the ratio between the corrected actual energy use and the theoretical energy use is constant for different EPC values. If this is more or less the case, then it can be concluded that, within the given EPC interval, no signs of a decreasing impact of the EPC are noticeable.

Figure 9 shows that for the dwellings with an EPC higher than one the average real energy use is lower than the theoretical energy use (the ratio is lower than one). For some of the projects with an EPC lower than one the real energy use is higher than the theoretical energy use (the ratio is higher than one). Because of the small number of projects with an EPC lower than one, it cannot be concluded that more stringent norms do not lead to corresponding energy savings. Furthermore, there are considerable differences in family sizes for the different locations. The energy use has not been corrected for this effect.

It has been analysed what variables lead to a ratio higher than one, or in other words, what variables cause an average energy use that is higher than the theoretical use. The variables that cause a ratio higher than one are the connection to a heat distribution grid, the use of glass with lower U-values and the presence of a programmable thermostat. Variables that lead to a lower ratio are self-monitoring and the size of the dwelling (the bigger the dwelling, the easier it is to fit the norm).

Variables that don't affect the ratio are the insulation of walls, roof and floor and the efficiency of a heat recovery system. That these variables don't affect the ratio means that the effect of these variables on the real energy use is the same as the effect of these variables on the theoretical energy use. In other words, the assumptions made in order to calculate the EPC, do very well represent the real effect of these technical measures. That the use of glass with lower U-values leads to a ratio higher than one may mean two things: or the estimation of the effect of lower U-values - used for the calculation of the theoretical energy use- was not correct. Or – which is probably the case- the difference between theoretical use and real use is the consequence of different definitions. In the calculations for the theoretical energy use, the U-value of the total window (glass and frame) is used. In the collection of technical data, only information about the glass has been gathered.

Discussion

The above analysis showed that lower EPC-values in general lead to a lower average energy use. Another result of the analysis is that the *averag*e energy use is mainly determined by technical aspects. Lifestyle aspects influence the average energy use in a lower extent, but they cause large variations in energy consumption within projects with identical dwellings. Once it is known that mainly technical aspects determine the average energy use, it is not surprising that more stringent norms lead to corresponding savings. After all, the technical aspects are taken into account in the calculation of the theoretical energy use.

Looking at the different techniques used in the different projects, it can be concluded that common techniques (high Rc-values, heat recovery of ventilation air, and solar water heating boilers) lead to the lowest heat demand. Dwellings with more experimental technologies performed worse than dwellings with a good insulation. So, no experimental or advanced technologies are needed to reduce energy use. Another reason to use the more common technologies, is that these technologies are prefered by the residents.

Despite the fact that lower EPC-values in general lead to a lower average energy use, there are considerable deviations from this average use. These deviations are caused by differences in lifestyle aspects. The energy use of a household in a very energy efficient dwelling and with an energy-intensive lifestyle may exceed the energy use of a household in a less energy effecient dwelling, but with a more energy extensive lifestyle. Therefore the conclusion can be drawn that by influencing life style, considerable energy reduction is possible.

As discussed before, the share of heat used for warming tap water is increasing. Therefore lifestyle changes that influence the use of warm tap water are becoming more and more important. It is surprising that households conscious of energy use (e.g. the ones that frequently monitor their energy consumption) adapt their behaviour related to space heating, but do not adapt their showering/bathing behaviour. That's why it is expected that it will be harder to convince households to change their behaviour related to the use of warm tap water, than to change their behaviour related to space heating.

In order to change life styles effectively, it must be known what is the most effective behaviour in a specific dwelling. Interviews showed that most households did not adapt their heating and ventilation behaviour when they moved to their new dwelling. They just acted out of habit. Habits were only changed if the old behaviour caused unacceptable changes in comfort. This was hardly the case however. The acquired behaviour in less energy efficient dwellings might however not be the most optimal behaviour in these very well insulated dwellings. Specifically since the analysis show large variations in energy consumption as a result of differences in life style, a significant and very cost effective energy saving potential may exist. Therefore, it is recommended to conduct additional research in order to determine if - and if so what - life style changes lead to a more efficient energy behaviour in very efficient dwellings.

Based on the above, the answers to the research questions can be formulated as follows:

- The average energy use corresponds to the theoretical use and therefore setting of more stringent standards seems to be effective.
- As the deviations of the average energy uses are considerable, and as these are mainly caused by life style aspects, it is useful not only to set more stringent norms, but also to focus on changing life styles.

Although the average energy use corresponds to the theoretical use, the setting of more stringent norms does not necessarily cause lower energy use. This is a consequence of the way the reference energy use is calculated. In this calculation the size and type of the dwelling is taken into account. This means that two dwellings with the same EPN but with different size, may differ considerably in theoretical energy use. Therefore, setting of more stringent norms will only be effective if the size of dwellings does not increase.

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