An analysis and diagnosis method for the energy consumption in existing residential buildings on municipal level

L.L. Soethout, B.C. Honselaar, H.C. Peitsman
TNO Building and Construction Research
Department of Indoor Environment, Building Physics and Systems
P.O. Box 49,
2600 AA Delft,
The Netherlands.

Tel : + 31 15 2608518
Fax : + 31 15 2608432
E-mail: H.Peitsman@bouw.tno.nl

Abstract

Municipalities, energy suppliers and building corporations in the Netherlands and beyond show a growing interest in energy management on municipal level. This is stimulated by the government, requiring the formulation and implementation of a policy of energy reduction. This not only affects the energy used in municipal buildings, but in all buildings on the territory of the municipality, including industry and residential buildings. In order to come up with a plan for energy reduction, an analysis of the energy use on the municipal level has to be performed. Municipalities and energy suppliers have a lot of data available on the energy consumption, but lack the tools to structure and analyse these data.

This paper describes an approach for an *energy analysis tool*, offering more insight in the energy use of several energy target groups. One energy target group, the residential buildings, is focused on, since this group normally is responsible for the largest energy consumption in the municipality, and therefore has a high saving potential.

As a first approach, the annual energy consumption for the households in a few Dutch cities is analysed by finding relationships between the energy consumption and several additional facts about the buildings (like building type and year of building) and its inhabitants (like the number and the age). In this way, subgroups can be defined, in which all households have the same input parameters. Based on the average energy use and the spreading around this average in the subgroup, individual households can be classified as being a good representative of the subgroup or as being a high-end user.

After the analysis, a good insight can be obtained in what parameters are useful for creating energy target groups. This enables us to produce a method for the analysis of general energy consumption rates. This method will be integrated in a software package for the analysis and diagnosis of the energy use of residential buildings on a municipal level.

Introduction

In the past years, several measures have led to a reduction in energy use for domestic heating. Technical measures include the insulation of the roof, the ground floor and the facade walls, the replacement of single by double glazing, and the application of more efficient heating systems. Other measures have increased the energy consciousness of inhabitants, in order to change their behaviour into wasting less energy. Despite all effort, the energy use of individual households still shows a large spreading. So, improvement on the overall energy use is still possible.

This requires that the energy consumption of individual households is quantified and can be compared with representative figures. These figures can be determined on several levels of detail, dependent upon interest and the number and kind of data available.

In the Netherlands, *municipalities* play a growing role in managing the use of energy in the city area, including residential buildings. In order for them to define a policy of energy saving, they need relevant data on municipal level. *Energy suppliers* also need information about energy use on several levels of detail. They do not only appear as energy vendors, but take on a role as advisor as well, by informing their clients about the rational use of energy. A third interested group are the *building corporations*.

The research focuses on a so-called top-down approach with respect to the energy use of existing residential buildings in the whole city, providing a large energy saving and energy management potential. It will try to relate the energy consumption of individual households to a larger representative set of households. The level of detail depends on the purpose of the end user. Municipalities will be mainly interested in figures at municipal and district level. Energy suppliers and building corporations will want to make comparisons on a lower level as well, like an apartment building or a row of houses in one street.

As a first approach, the annual energy consumption for the households in a few Dutch cities is analysed by finding relationships between the energy consumption and several additional facts about the buildings (like year of building) and its inhabitants (like the number and the age). In this way, subgroups can be defined, in which all households have the same input parameters. Based on the average energy use and the spreading around this average in the subgroup, individual households can be classified as being a good representative of the subgroup or as being a high-end user. For an energy-saving programme, the latter group can be focused on in first instance.

The analysis offers a good insight in what parameters are useful for creating subgroups for the different levels of detail. This enables us to produce a method for the analysis of general energy consumption rates. This method will be integrated in a software package for analysis and diagnosis of the energy use of residential buildings on a municipal level.

Residential buildings

Residential buildings give the main contribution to the total energy consumption on the municipal territory. Likely, the largest energy savings can be obtained in this group. As an example, Table 1 shows the main target groups of the city of Schiedam and their energy consumption. The figures are for the year 1993, when Schiedam had 71080 inhabitants [1].

For a “first step” analysis of the energy consumption in residential buildings, relationships are needed between the actual energy use and relevant aspects of the houses and their inhabitants. For the research, we have used data from the municipality of Schiedam, since these data give

Nr	Target group	Gas consumption (m3)	Electricity consumption (kWh)	Total in natural gas equivalent (m3)	Gas equivalent per inhabitant	Number of connections
1	Agrarian sector	5095	75011	26848	0.4	6
2	Industry	21147099	77188108	43531650	612.4	223
3	Trade and commerce	8655399	39265799	20042481	282.0	1548
4	Business service industry	2566598	9850008	5423100	76.3	280
5	Education	951805	1535189	1397010	19.7	63
6	Health authorities	2488581	4795856	3879379	54.6	30
7	Sport/recreation	626673	2480676	1346069	18.9	69
8	Municipality buildings	967488	5525988	2570025	36.2	130
9	Remaining service industries	2338648	10603244	5413589	76.2	235
10	Housing	50470131	72919172	71616691	1007.6	31977
11	Public lighting		2073888	601428	8.5	
12	Traffic/transport			45633360	642.0	
13	Remaining	1538130	3428370	2532357	35.6	898
	Total	91755647	229741309	204013987	2870.4	35459

Table 1 Energy consumption of the city of Schiedam, divided in several energy target groups

the most detailed information, compared to data from other municipalities. For the same reason, we only focus on the *gas* consumption.

Gas is used for heating the house, for the supply of domestic hot water and for cooking, in order of importance. The amount of gas that is actually used for a house depends on a lot of parameters. These can be grouped into four categories:

- architectural and building physical aspects;
- heating and ventilation installation types;
- inhabitant behaviour;
- climate.

The influence of the latter category cannot be studied with the data of Schiedam alone, since the climate is the same for all buildings. Further, a lot of relevant parameters in above categories is not well known, especially with respect to the behaviour of the inhabitants. This will result in less accurate predictions of the actual gas consumption, *i.e.* a large spreading around the average value. As an example, where no additional data are used, consider the annual gas consumption of 1993 for houses in Schiedam, shown in Figure 1. It is based on all houses of Schiedam, of which the gas consumption could be coupled uniquely to an address. The yearly amount of gas varies from 0 m^3 to over 10,000 m^3 for individual households, whereas the average is 1326 m^3. The expectation is that the inaccuracy decreases when one or more parameters are used to get a better estimate of the individual gas consumption than the average value.

When an exact knowledge of all relevant parameters is not present, one tries to derive an approximate method of calculation. Such a method uses a simplified input to derive the exact parameters, combined with target values for unknown parameters and rules of the thumb. As an example, a Dutch prenorm for calculation of the energy consumption for the heating of dwellings [2] requires the following simplified input:

- year of build;
- type of building:
    - single-family house or multi-family house;

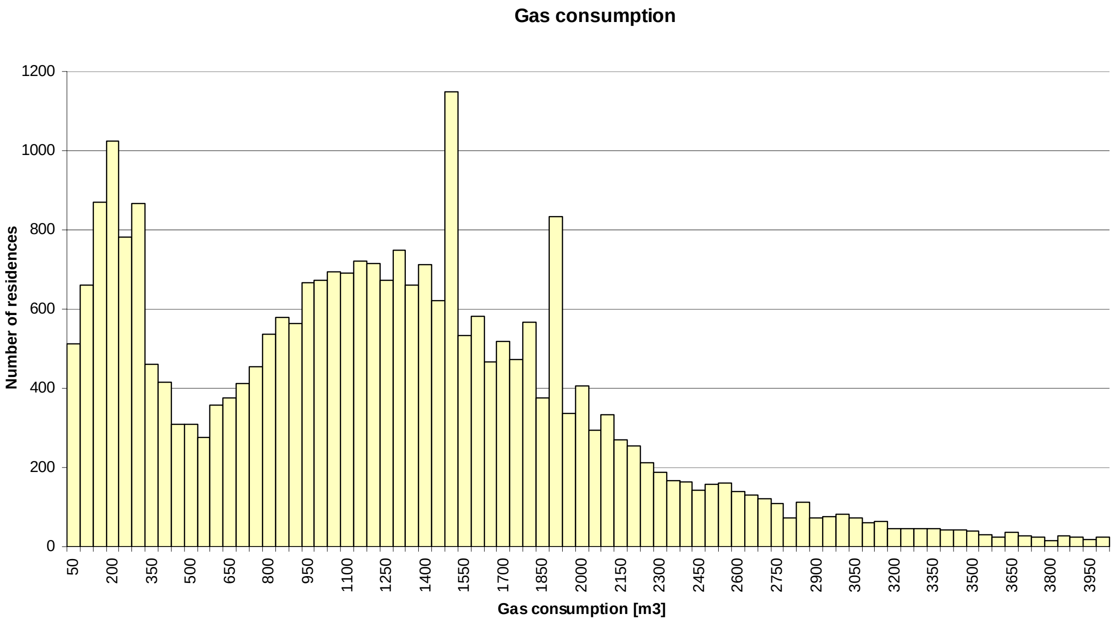

Figure 1 Gas consumption distribution for houses in the city of Schiedam

    - one of a row, corner, detached, ground floor, intermediate floor, roof floor;
- gross volume of the building;
- type of glazing;
- type of insulation;
- type of heating installation.

All other aspects, like the behaviour of the inhabitants, are approximated by target values. When the real energy consumption is more than 10% higher than the calculated value, the inhabitants are urged to have an energy advisor pinpoint possible causes.

The data available for the houses in Schiedam are partly comparable to above input. Three databases are available:

- gas consumption per address;
- building characteristics per address;
- inhabitant characteristics per address.

These databases can be coupled by combining data belonging to the same address. This leads to a set of 28,000 records, with the following information available:

- address: postal code, street name and street number;
- district;
- area;
- annual gas consumption;
- type of building: single-family house, multi-family house or apartment;
- position of building: one of a row, corner, semi-detached or detached;
- year of build;
- gross volume of building
- number of rooms;
- number of floors (for apartment);
- number of inhabitants;
- age of each inhabitant;

- rented house or house owned by the inhabitants.

It is clear that many of above parameters will have an influence on the gas consumption, but the exact relationship is not clear at first sight. The energy needed for heating of a building will increase with the volume of the building and probably with the number of rooms as well. The amount of heat loss depends on the area and the quality of the building shell, and therefore on the type of building, the position of the building and probably the year of build (as a measure for the insulation quality, provided that no renovation did take place). The amount of hot water use will depend on the number and age of the inhabitants. The number of inhabitants will also influence the energy use for heating.

Most of the relationships cannot be used directly to calculate the energy use and gas consumption, because important information is missing. For example, it is not possible to calculate the heat loss through transmission, since the exact construction of the walls is not known. The heat loss through ventilation is undetermined as well; it largely depends on the inhabitants behaviour with respect to opening doors and windows. The best we can do is deriving relationships through a statistical analysis of the available data, in order to find approximate relationships between the gas consumption and one or more of the input parameters. An extra complication in the analysis is that the input parameters are correlated as well. For example, the number of rooms will have an influence on the building volume; the number of inhabitants probably has an impact on the number of rooms.

Analysis of the annual gas consumption

When studying the data set of Schiedam, several records in the set appear to be unrealistic. Some houses have an exceptionally high gas consumption of over 10,000 m^3. Other have no gas consumption at all, which needs to be interpreted as an unknown gas consumption. Many houses (apartments only) have a low gas consumption between 0 and 500 m^3 (see also Figure 1), which indicates that gas is used only for the supply of hot water and for cooking. All these cases will not be included in the analysis.

Other houses have extreme building volumes, either below 50 m^3 or above 1000 m^3. These have been removed as well from the data set. Finally, 16300 records are left for inclusion in the analysis.

As mentioned above, the gas consumption versus the building volume is an increasing function. Therefore, the specific gas consumption, *i.e.* the gas consumption per unit building volume, might be a better quantity to use in the analysis.

Differentiation with respect to one aspect

In order to get a feeling for the relationships between the energy consumption and individual parameters, we divided the whole data set into subgroups according to such a parameter and compared their gas consumption. The results are shown in Table 2. It gives for each subgroup its size, *i.e.* the number of houses in the group, the averaged specific gas consumption, the spreading (standard deviation) and the relative spreading (standard deviation compared to the average) of individual houses around the average gas consumption.

One thing that is immediately clear from this table is that the accuracy does not much improve with respect to the total set when a subgroup is separated from the rest. This means that the spreading around the average does not decrease when variation with respect to a single parameter is suppressed. This can be explained by the fact that the other parameters in such a subgroup are still distributed in an unknown way over their possible values. This is also true for the unknown parameters, like the inhabitant behaviour.

Aspect	Subgroup	Number of houses	Building volume	Gas consumption [m^3 gas]	Specific gas consumption [m^3 gas / m^3]	Standard deviation [m^3 gas / m^3]	Relative accuracy
	Total	16313	255	1641	6.73	3.01	0.45
Property	Rented	12172	233	1491	6.72	3.03	0.45
	Owned	4141	319	2082	6.75	2.95	0.44
Building type	Single-family	5073	331	2090	6.54	2.95	0.45
	Multi-family	4861	241	1556	6.97	3.35	0.48
	Apartment	5934	206	1342	6.61	2.69	0.41
Building position	One of a row	12521	-	1553	6.61	3.01	0.45
	Corner	3011	-	1793	7.14	3.01	0.42
	Semi-detached	275	-	3203	7.28	2.51	0.35
	Detached	93	-	3556	8.91	3.94	0.44
Year of build	< 1945	6867	-	1793	7.25	3.41	0.47
	1945 - 1965	5995	-	1459	6.85	2.66	0.39
	1966 - 1975	1142	-	1726	5.15	2.23	0.43
	1976 - 1981	844	-	2028	6.31	2.27	0.36
	1982 - 1985	979	-	1322	5.35	2.39	0.45
	> 1985	486	-	1512	5.09	2.07	0.41
Number of inhabitants	1	5946	-	1449	6.77	3.13	0.46
	2	4478	-	1680	6.63	2.81	0.42
	3	2508	-	1749	6.75	2.96	0.44
	4	2025	-	1859	6.58	2.91	0.44
	5	562	-	1921	6.84	3.33	0.49
	6	160	-	2039	6.93	2.74	0.40

Table 2 Averaged specific gas consumption of houses grouped by various aspects

Still, some trends can be observed. Building volume is an important factor, which can explain for a large part the spreading in gas consumption between the groups. For example, whereas there is a large difference between the total gas consumption between houses owned by the inhabitants and rented houses, the specific gas consumption is nearly equal.

As building type is concerned, a single-family house has the lowest specific gas consumption. Multi-family houses and apartments use respectively 7% and 1% more gas. These percentages are not significant differences, when compared to the standard deviation. Specific gas consumption versus building position is as one would expect when the outer shell surface increases: a house in a row has the lowest gas consumption, followed by corner houses (8% more), semi-detached houses (10% more) and detached houses (35% more).

The year of build of a building is mainly related to the type of building, the insulation degree and the type of heating installation. Many multi-family buildings were built in the period from 1940 to 1950, whereas many apartments arose in the period between 1970 and 1980. Insulation of the building has been improved over the years, imposed by law: outer wall and roof insulation has been required since 1975, additional insulation of the ground floor and double glazing since 1981. Therefore, earlier periods have a higher specific gas consumption than the period since 1985, with amounts of respectively 42%, 35%, 1%, 24% and 5%, starting with the period before 1945. The period 1966-1975 has a remarkable low gas consumption, explained by the fact that many houses from this period have been renovated.

The number of inhabitants is the only parameter affecting the gas consumption for hot water supply and for cooking. Inhabitants also produce heat, reducing the amount of heating. Both have impact on the absolute gas consumption. On the other hand, the number of inhabitants is also correlated with the number of rooms, *i.e.* with the building volume. This suggests a constant specific gas consumption. Looking at the figures, the latter seems true indeed: the specific gas consumption does not show a strong dependence on the number of inhabitants.

Differentiation with respect to more aspects

Above technique of splitting the whole group of energy users into categories based on a single aspect only gives approximate relationships. This is due to the unknown arrangement of the categories with respect to the other aspects, *i.e.* due to the correlation between aspects.

Therefore, better results can be expected by a splitting based on all relevant aspects simultaneously. One way to realise this is to calculate the average gas consumption of each individual category and to derive relationships between these numbers, as was applied for the single-aspect case. A drawback of this method is the increased number of categories, which all have to be analysed and compared together.

A faster method, though less accurate, is the use of multiple regression. This requires a formula, reflecting the supposed relationship between the gas consumption and the parameters of importance. As a starting point, we take the observations of the single-parameter study. The *specific* gas consumption is affected by the building type, the building position and the year of build. The number of inhabitants contributes to the *total* gas consumption. The formula takes as base case the specific gas consumption of an apartment in a row, build in the period 1982-1985 and applies correction factors for houses with a different building type, building position or year of build. An extra term to the total gas consumption is added for each inhabitant. This leads to the following formula:

$$
\begin{aligned}
\boldsymbol{E} = \boldsymbol{E}_0 &\left(1+\boldsymbol{b}_{\text{corner}}\cdot \boldsymbol{a}_{\text{corner}}\right)\left(1+\boldsymbol{b}_{\text{semi-detached}}\cdot \boldsymbol{a}_{\text{semi-detached}}\right)\left(1+\boldsymbol{b}_{\text{detached}}\cdot \boldsymbol{a}_{\text{detached}}\right)\\
&*\left(1+\boldsymbol{b}_{\text{single-family}}\cdot \boldsymbol{a}_{\text{single-family}}\right)\left(1+\boldsymbol{b}_{\text{multi-family}}\cdot \boldsymbol{a}_{\text{multi-family}}\right)\\
&*\left(1+\boldsymbol{b}_{<1945}\cdot \boldsymbol{a}_{<1945}\right)\left(1+\boldsymbol{b}_{1945-1965}\cdot \boldsymbol{a}_{1945-1965}\right)\left(1+\boldsymbol{b}_{1966\text{-}1975}\cdot \boldsymbol{a}_{1966\text{-}1975}\right)\\
&*\left(1+\boldsymbol{b}_{1976-1981}\cdot \boldsymbol{a}_{1976-1981}\right)\left(1+\boldsymbol{b}_{\geq 1986}\cdot \boldsymbol{a}_{\geq 1986}\right)+\frac{\boldsymbol{n}_{\text{inhabitants}}}{\boldsymbol{V}}\cdot \boldsymbol{a}_{\text{inhabitants}}
\end{aligned}
$$

where

$\boldsymbol{E}$	=	**specific gas consumption**	**[m^3 gas / m^3]**
$\boldsymbol{E}_0$	=	**specific gas consumption of an appartment in a row**	**[m^3 gas / m^3]**
$\boldsymbol{b}_{\text{aspect}}$	=	**boolean value, indicating deviation from the standard case: 1 if the aspect is true, 0 otherwise; the aspects are building position, building type and year of build**	**[-]**
$\boldsymbol{a}_{\text{aspect}}$	=	**correction factor for the specified aspect**	**[-]**
$\boldsymbol{n}_{\text{inhabitants}}$	=	**number of inhabitants**	**[-]**
$\boldsymbol{V}$	=	**building volume**	**[m^3]**
$\boldsymbol{a}_{\text{inhabitants}}$	=	**correction factor for number of inhabitants**	**[m^3 gas]**

The correction factors a_{aspect} and $a_{\text{inhabitants}}$ have to be determined by finding the best fit of the formula to the data set by means of multiple regression. The correction factors have been identified with help of the statistical software package "*Statistical Analysis System*" (*SAS*), by means of a procedure built around the linear regression function *REG*. The results are shown in Table 3.

As can be seen from the table, a building position other than one of a row results in an increased gas consumption, as expected. As the building type is concerned, apartments use the most gas, multi-family houses use the least gas. This deviates from the results from the study with differentiation to one aspect, because of the strong correlation between building type and year of build. Multi-family houses were built mainly between 1940 and 1950, a period with a large extra gas consumption; therefore the net result is that multi-family houses use more energy than apartments. The year of build periods show an increase of gas consumption as the buildings are older. The period between 1966 and 1975 shows a smaller factor than expected, due to the influence of renovation; the period 1976-1981 shows a relatively high factor, due to the large part of single-family houses, in combination with the limited obligatory insulation measures. Finally, the number of inhabitants gives an extra gas consumption of around 100 m^3 gas per person.

Parameter	Value	
E_0	3.75	m^3 gas / m^3
a_{corner}	0.77	
$a_{\text{semi-detached}}$	0.95	
a_{detached}	1.75	
$a_{\text{single-family}}$	-0.15	
$a_{\text{multi-family}}$	-0.34	
$a_{<1945}$	2.84	
$a_{1945\text{-}1965}$	1.87	
$a_{1966\text{-}1975}$	0.65	
$a_{1976\text{-}1981}$	1.81	
$a_{\geq 1986}$	0.07	
$a_{\text{inhabitants}}$	101.31	m^3 gas

Table 3 Correction factors, calculated with multiple regression

For the determination of the accuracy of above formula, the estimated specific gas consumption, based on the formula, can be compared to the real specific gas consumption for each household in the data set:

$$\Delta E = E_{\text{real}} - E_{\text{estimated}}$$

The average value of ΔE gives an estimate how well the formula works for a set of households, the standard deviation is a measure for the spreading of individual real gas consumption around the estimated values. The relative accuracy can be found from the standard deviation of $\Delta E / E_{\text{estimated}}$. The results for the total set and for subgroups based on the building type are shown in Table 4.

It turns out that the average gas consumption of the whole group and of the subgroups based on the building type corresponds within 2% with the estimated value. The spreading of individual households around the predicted value for these households is still large, 32% for the whole set and around 40% for the subgroups. However, the accuracy has been improved when compared to the accuracy based on differentiation on one aspect (compare Table 4 and Table 2).

Subgroup	Number of houses	Averaged E_{real} [m^3 gas / m^3]	Averaged ΔE [m^3 gas / m^3]	Standard deviation [m^3 gas / m^3]	Relative accuracy
Total	16313	6.73	0.00	2.21	0.32
Single-family	5073	6.54	0.01	2.61	0.38
Multi-family	4861	6.97	-0.12	3.19	0.45
Apartment	5934	6.61	-0.10	2.67	0.40

Table 4 Averaged specific gas consumption compared with its estimated value

The same process can also be performed for other smaller subgroups, for example clusters of architecturally identical houses from the same street or area. The only unknown parameter in these cases is the inhabitants behaviour, including the number of inhabitants. A study of the inaccuracy in these cases can give a minimum value for the resolution that can be obtained, when certain parameters stay unknown. Results for six different clusters are presented in Table 5. Due to the smaller numbers in each cluster, the averaged real specific gas consumption deviates more from the estimated value than in Table 4. For many of the energy-efficient and renovated buildings the real consumption is lower than estimated. Cluster B is an exception. The spreading remains between 30 and 40%. Therefore, it can be concluded that the prediction of the gas consumption cannot be made more accurate than within 30 to 40% of the actual value, due to unknown parameters.

Cluster	Description	Number of houses	Averaged E_{real} [m^3 gas / m^3]	Averaged ΔE [m^3 gas / m^3]	Standard deviation [m^3 gas / m^3]	Relative accuracy
A	apartments in a row	127	5.46	0.37	1.72	0.34
B	single-family in a row; energy efficient	61	3.27	-1.41	0.80	0.17
C	multi-family in a row; energy efficient	38	4.50	0.20	1.43	0.33
D	apartments in a row; extra renovated	297	6.15	-0.65	2.23	0.33
E	apartments in a row; renovated	98	5.99	-0.73	2.60	0.39
F	apartments in a row	480	6.93	0.35	2.64	0.41

Table 5 Averaged specific gas consumption and its estimated value for six selected clusters of identical houses

High-end users

In order to investigate whether an approximated energy calculation based on regression can be used to discriminate between a correct use of energy and a excessive use of energy, we will focus on cluster A of the previous section. In Figure 2, the actual specific gas consumption in this cluster is plotted, together with the predicted value for each household. The inaccuracy is displayed as a band around the estimated gas consumption. The households are sorted according to the estimated gas consumption.

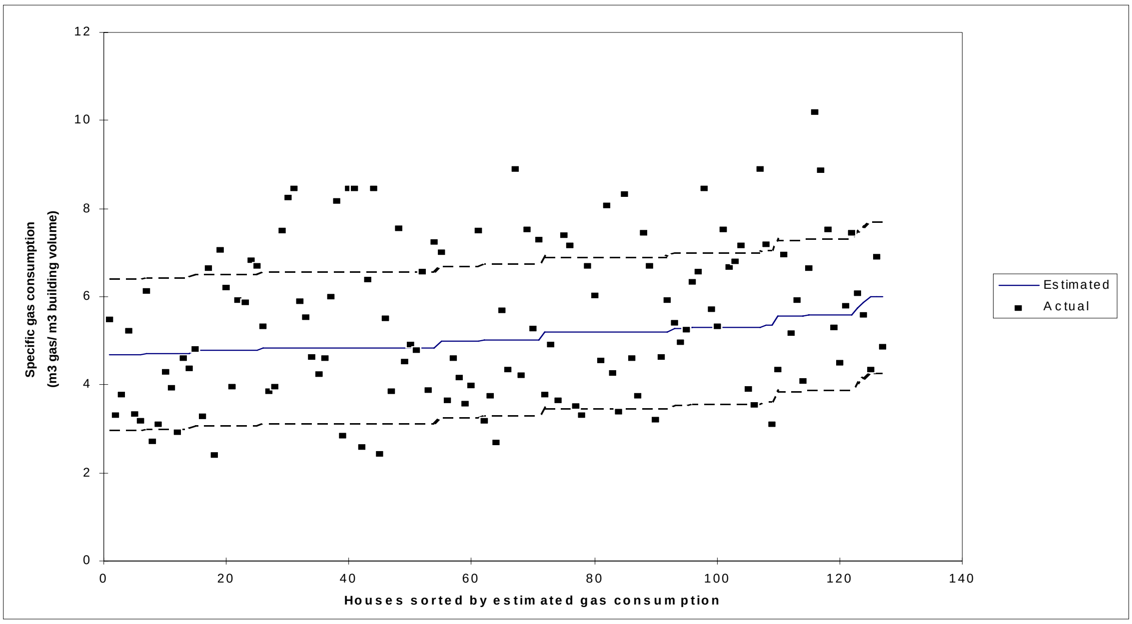

Figure 2 Specific gas consumption and its estimate for the houses in cluster A

As can be seen, several households lie outside the region, determined by the band around the estimated gas consumption. This region can be considered as a region where the gas consumption is normal. Above this region, the households potentially use more energy then necessary. This group of users needs a closer examination, in order to find the cause of the excessive energy use. Of course, the width of the band, taken twice the standard deviation of the energy difference between the actual and the estimated value, is arbitrary. On the other hand, the standard deviation is related to the spreading of individual households around the estimated value. With this approach, 32 of the 127 households might improve on their energy use; this is 25% of the cases.

Energy analysis software

The approach, sketched above, has formed the basis for the implementation of a software tool, supporting the analysis of the gas consumption of houses on a municipal level. It enables the user to define selections on the available houses in the municipality. The selections can then be statistically analysed to obtain general figures about the gas consumption of the selection. Houses with a marked deviation from the average gas consumption, as determined from similar houses, can be extracted from the selection for further investigation. Also, selections can be compared mutually.

Starting point is a database with gas consumption per household, related to the address of the house and other relevant information, like building type and number of inhabitants. This data set is allowed to be flexible, since the kind of data available will differ among municipalities. There is however a minimum set of data which must be available per house:

- gas consumption;
- building volume (analysis is based on specific gas consumption);
- unique address specification (like ZIP code, combined with house number).

This data might be supplemented with other information. This additional information can be divided in two categories, one based on the location of the house in the town (like information on district, area and street), the other based on characteristics of the house and its inhabitants. Information from the first category is mainly used to divide the municipal houses into smaller groups, whereas the parameters in the second category are used for the statistical analysis to estimate the gas consumption.

The software will allow the user to select groups of houses; after the formation of a group, the user can start the analysis of the gas consumption. Several grouping mechanisms are supported, dependent on the available information:

- clustering on location;
- clustering on characteristics;
- clustering on combinations of the previous methods.

An example of defining a cluster based on location is shown in Figure 3.

The statistical analysis is always performed on a cluster, defined by the user. The mechanics of this process is hidden from the user. The outcome can be presented on two levels: general and detailed. The general level shows overall results for the cluster as a whole:

- average gas consumption;
- spreading (standard deviation) around the average gas consumption;
- peak gas consumption;
- number of houses;
- average building volume;
- number of high-end gas users;
- average gas consumption of high-end gas users;

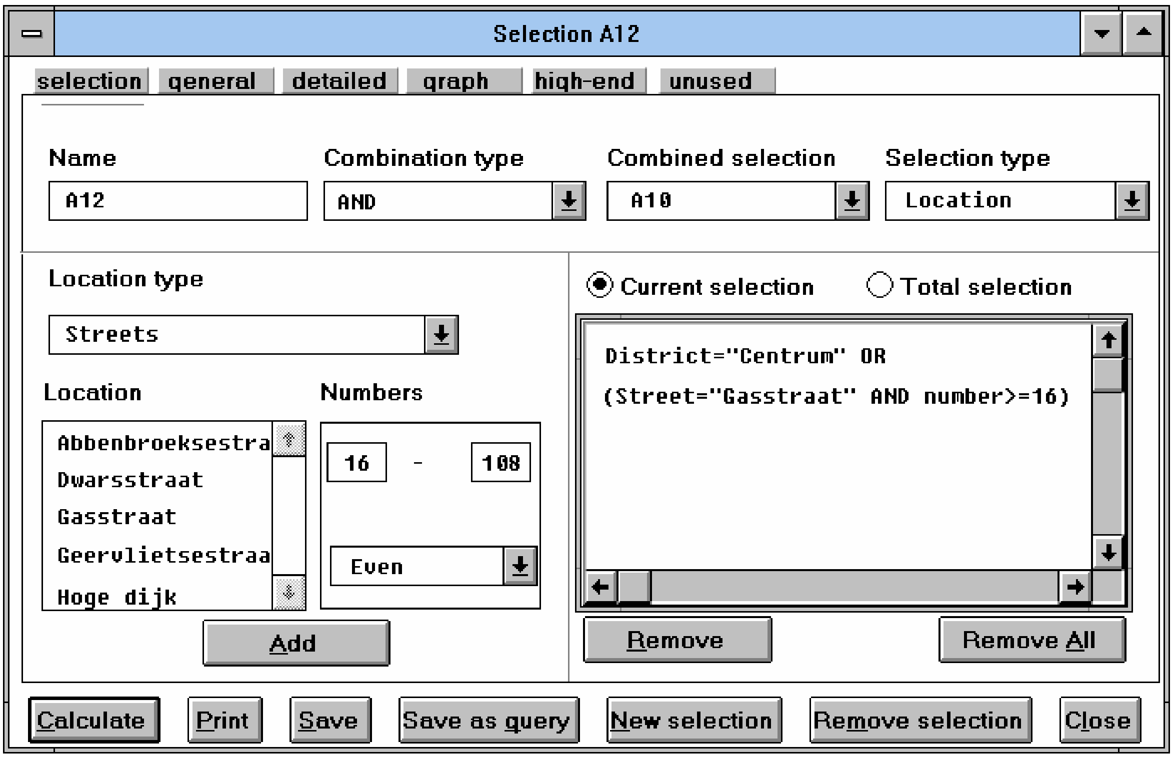

Figure 3 Selection of a cluster of houses

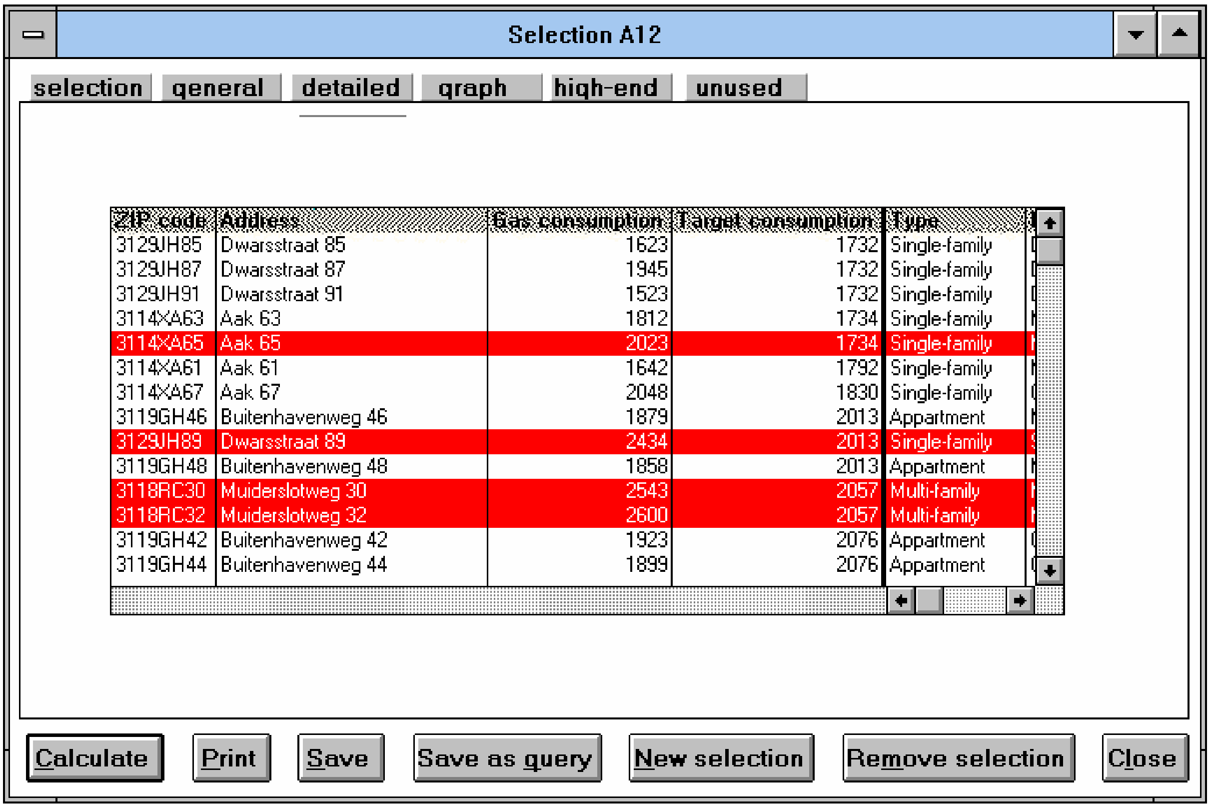

Figure 4 Detailed output of the gas consumption of a cluster

- amount of gas-saving potential (compared to the situation when all high-end gas users would be normal users).

The detailed level shows the results for individual houses in the cluster, either all of them or only the high-end users. The characteristics shown per house are:

- unique address code;
- street and house number (if available);
- gas consumption;
- target consumption (as determined through the statistics);
- building volume;
- other characteristics (if available and selected by the user).

An example of this output is shown in Figure 4. The high-end users, derived from the difference between the actual gas consumption and the calculated target consumption, are highlighted. A separate list of high-end users is also available. The municipality or the energy supplier can use this list as a starting point for an energy-saving programme.

The results can also be presented to the user in a graphical way, for example as a chart resembling the one in Figure 2.

To facilitate the comparison between different clusters, the user can make a selection from the available analysed clusters. The general results of this set of clusters is collected in one overview.

Above study has focused on the gas consumption, as a first step. For real use additional data are needed: data with respect to the climate, since another location and another time will change the climate conditions, and will therefore influence the energy needed for heating the houses; data concerned with the use of electricity. Besides, more data on the architectural condition of the houses and on the type and state of the heating installation will help to improve the accuracy of the energy use predictions.

Conclusions

This paper describes a first approach to structure the energy consumption of households on a municipal level. The goal is to discriminate between households of which the energy use is reasonable and households with a to high energy use. The latter group can then be focused on in order to come to a reduction in energy use on municipal level. The study has focused on the gas consumption.

It was found that a “first step” analysis of the specific gas consumption is a good way to eliminate to a great extent the variation in volume between individual houses. Splitting all houses into categories with respect to a single aspect (based on building type, building position, year of build or the number of inhabitants) can predict the gas consumption with an accuracy of 40 to 50%. Further differentiation, based on applying a combination of the aspects mentioned above, reduces the uncertainty to 30 to 40%. The latter was obtained with help of a regression technique. It is likely that a better resolution of the gas consumption will be difficult to obtain, due to the large uncertainty in the relation between the gas consumption and other relevant parameters, like the behaviour of the inhabitants. This is mainly caused by unknown facts like building insulation and inhabitant behaviour.

With this formula, the actual energy use of a household can be compared with the calculated energy use. A difference between the two of more than the standard deviation of the calculated result indicates a high-end user, where potentially energy can be saved. The inhabitants of these houses can be notified of their deviating energy use, as a method to end up with an overall reduced energy use.

A software tool, supporting the statistical analysis of the energy consumption on a municipal level, has been developed. It can be a help for municipalities, energy suppliers and building corporations to obtain a better insight in the energy use on several levels of detail.

References

[1] M. Jut. “Globale inventarisatie energiegebruik in Schiedam”, Openbaar Nutsbedrijf Schiedam (1993).

[2] “Energy consumption in buildings - Heating of dwellings - Simplified calculation method and target values”, Nederlandse Voornorm 5125, Nederlands Normalisatie-Instituut (1987).