Reducing the Performance Gap by Analysing Specific Combiantions of Occupant and Building Characteristics

van den Brom, Paula; Meijer, Arjen; Visscher, Henk

Publication date
2016

Document Version
Final published version

Published in
Proceedings of the 4th European Conference on Behaviour and Energy Efficiency

BEHAVE 2016
4th European Conference on Behaviour and Energy Efficiency
Coimbra, 8-9 September 2016

REDUCING THE PERFORMANCE GAP BY ANALYSING SPECIFIC COMBINATIONS OF OCCUPANT AND BUILDING CHARACTERISTICS

Paula van den Brom[1]*, Arjen Meijer[1] and Henk Visscher[1]

1: OTB – Research for the Built Environment
Faculty of Architecture and the Built Environment
Delft University of Technology
Julianalaan 134, 2628BL Delft, The Netherlands
e-mail: P.I.vandenBrom@tudelft.nl
web: http://www.bk.tudelft.nl

Keywords: Performance gap, Housing, Actual energy, Occupant characteristics, Method

Abstract

The energy saving policies of governments are not resulting in the energy saving they were aiming for[1]. Theoretical energy saving predictions are an important and frequently used tool for policy makers to develop energy saving policies and to set energy saving targets. Majcen et al. [2] showed a discrepancy between actual and theoretical energy consumption. The existence of the energy performance gap means that policy makers base their policies on assumptions that are not always right. It is expected that a significant part of the performance gap can be explained by the occupant behaviour, therefore a better insight in the influence of occupant behaviour on actual residential energy consumption is required. In this paper a method is introduced to analyse the influence of occupant behaviour on residential energy consumption, based on the principle that if occupant behaviour is studied also the building characteristics should be taken into account. In this paper a data analysis is executed with the use of a large building characteristics database (SHAERE - over 2 million cases), occupant data (Statistics Netherlands - entire Dutch population) and energy data (Statistics Netherlands – entire Dutch population). Although the results of the executed analysis are not conclusive, several important factors were found for further research. Firstly, the building and occupant cluster variables should be created with great care since they are one of the determining factors for correct function of the method. Secondly the quality of the dataset is of major importance for the final result. Finally, for further research it is advised to execute this method on other datasets, and compare the results in order to define which aspects are most important for applying this method.

1. INTRODUCTION

Reducing energy consumption has emerged as one of the major challenges of the current society. Around 40% of the total European energy use is consumed by buildings; from this 40% almost 25% is used by residential buildings *[3]*. . This is a significant part of the total energy consumption. Reducing the residential energy consumption is therefore seen as an effective mean to reduce the total energy consumption.
The European Union has set an energy saving goal of 20% by 2020 compared to the projected use of energy in 2020. In the EU energy summit of 2014 new energy efficiency targets for 2030 were set, energy saving of 27% or greater by 2030[4]. Research towards the pace of this energy saving shows us that if we continue in the current pace the targets will not be met [1, 2]. From this we can conclude that the energy saving policy of the government is not resulting in the energy saving they were aiming for.
Theoretical energy saving predictions are an important and frequently used tool for policy makers to develop energy saving policies and to set energy saving targets. However Majcen et al. [2]showed a discrepancy between actual and theoretical energy consumption. Buildings that were supposed to be very energy efficient (label A-B) consume more energy than expected and buildings with a “low” energy label (Label D-G) consume less energy as expected. This discrepancy between actual and theoretical energy consumption is also called the “energy performance gap”. The existence of the energy performance gap means that policy makers base their policies on wrong assumptions. This can partly explain why the energy saving measures does not result in the desired amount of energy savings.
To give policy makers better tools to base their energy saving policies on, a better understanding of the residential energy consumption is required. In previous years the main focus of residential energy research has been on the physical and technical quality of dwellings and the influence of the occupant has been underexposed. Although this is changing, as it is increasingly acknowledged that the occupant has a significant impact on residential energy consumption. Residential energy consumption is formed by energy consumption for heating, energy consumption for hot tap water and energy consumption for appliances. Previous research found that the building characteristics are much more correlated to energy consumption for heating than with electricity [5], understandable if you take into account that the amount of heating is determined by insulation rate, glazing type and heating installation. But in many cases people may forget that if the heating is not turned on, no energy will be consumed, the occupant is in charge of the heating system and therewith determines how much energy is used. Gram-Hanssen even claims that the influence of the energy related occupant behaviour is at least as important as the influence of the building characteristics [6]. Energy related occupant behaviour is in this context defined as: “All actions that the occupant takes in the house that have an influence on the energy consumption” [7] .
Although it is increasingly acknowledged that occupants influence residential energy consumption, research towards the explanation of the variance in energy consumption along dwellings with similar energy labels show only a small influence of the occupant on

residential energy consumption. However we know the occupant influences residential energy consumption, “buildings don’t use energy, people do” [8]. The problem with research towards occupant behaviour is that the data gathering method is often time consuming and intrusive for both the researcher and the residents. This is one of the reasons that previous studies towards the influence of the occupant behaviour on residential energy consumption are often conducted on relatively small datasets. However there is an increasing amount of information available about the residents and their dwelling. In this study we aim to develop a research method that enables researchers to study the influence of the occupant on residential energy consumption with the use of large and often more aggregated datasets. This research method will not make the need for detailed behaviour research disappear but the method is complementary to the traditional qualitative research and it aims to provide another insight in the effect of the occupant on the residential energy consumption.

2. LITERATURE REVIEW/FRAMEWORK

Since traditional research towards the influence of energy behaviour requires often time consuming and intrusive data gathering methods and because there is a need for more information about the influence of the occupant on residential energy consumption a new method is developed. This method is based on the assumption that we have large representative datasets available and it takes into account that those data sets primarily contain aggregated data.

In order to develop this method first a clear definition of energy related occupant behaviour should be given. In this paper we use the definition of energy related occupant behaviour as described by Martiskainen [7]: “All actions that the occupant takes in the house that have an influence on the energy consumption”. Several studies have already been focussing on the influence of occupant behaviour on residential energy consumption some of the results are described in table . These studies primarily focussed actual behaviour actions. Although the results from this type of research are highly relevant the drawback of this traditional research method is that it takes a lot of time and it is often experienced as intrusive by the tenants. This is also shown in the research of Guerra Santin [9] where a questionnaire was distributed among 7000 households with a response rate of 5%.

Table 1 studies towards the influence of occupant behaviour on residential energy consumption

Behaviour	Impact	Sample size
hours that the thermostat is set on the highest temperature can explain 10.3% of the variance in energy use for heating [10];	10,3%	OTB survey 313 usable cases
Number of hours radiator on in the living room explains 8.8% of the variance in energy consumption for heating [10]	8,8%	OTB survey 313 usable cases
Number of hours radiator on in the bathroom explains .9% of the variance for heating[10]	0,9%	OTB survey 313 usable cases
Households with a programmable thermostat were found to adjust the temperature in their dwellings less often than households with a manual thermostat, which results in more heating hours and therefore more energy use [11, 12].		Kwalitatieve woning registratie 15.000 dwellings [11] and questionnaire 146 usable cases
Set-point temperature in a house influences the energy consumption in a dwelling significantly [13];		Residential energy consumption survey, sample

		size varies per year but in general several thousand households
The total variance in energy consumption can be explained for 4 +/- 10% by ventilation habits [14];	4 +/- 10%	76 dwellings response rate 96,1%
Guerra-Santin and Itard [15]found a small positive correlation between energy use and number of hours with the grilles open, as well for houses with window open.	Small	OTB survey 313 usable cases
Households with children were found to ventilate less than households without children, and households with older occupants [15]. were found to ventilate more[11];		Kwalitatieve woning registratie 15.000 dwellings

Because this kind of data is time consuming to gather, researchers started to look at alternative methods to study the influence of occupant behaviour on residential energy consumption. The findings of previous research do not only show that occupant behaviour influences energy consumption but these findings also show that there is a relationship between occupant behaviour and behaviour characteristics e.g. Households with children were found to ventilate less than households without children and households with older occupants [15]. Therefor researchers have started to focus on the occupant characteristics apart from the actual occupant behaviour. In general there is for example assumed that older people behave differently than younger people, and families have a different lifestyle than single households. Based on the assumption that occupant characteristics are a determining factor for the energy related occupant behaviour the following results were found:

Table 2 studies towards the influence of occupant behaviour on residential energy consumption based on occupant characteristics

Findings	Impact	Data
a larger number of household members result in a higher energy consumption but it decreases the energy consumption per person [11-13, 15-20]		Kwalitatieve woning registratie 15.000 dwellings [11] and questionnaire 146 usable cases
Also the income is positively correlated to energy consumption. Vringer and Blok [20] found in their research that 1% increase in income results in 0,63% increase in energy consumption.	1% increase in income results in 0,63% increase in energy consumption.	Netherlands Household Expenditure survey of 1990, 2767 representatieve households in the Netherlands
Age is found to be the most determining indirect effect on heating and cooling energy use [9, 13, 19, 21].	high	Kwalitatieve woning registratie 15.000 dwellings [9]; Residential energy consumption survey, sample size varies per year but in general several thousand households[13] 4822 housing units form the US. [19]
Occupants between 40-50 years the highest comfort demands but also the highest average net income [18, 22].		27 homes [18] 240 homes [22]
Households with young children ventilate less and households with older children ventilate more[9].		Kwalitatieve woning registratie 15.000 dwellings [9]
The education level has only very limited impact on the residential energy consumption. Higher educated people set the temperature on the highest temperature	limited	Kwalitatieve woning registratie 15.000 dwellings [9]

for fewer hours than lower educated people [9].		

Although studying occupant characteristics instead of actual occupant behaviour is less time consuming, previous studies were only able to explain a limited amount of the performance gap and the variance in energy consumption for similar buildings with this method [23].But the more general studies towards the influence of occupant behaviour on residential energy consumption suggest that the actual impact is higher than we can prove yet [14, 24, 25].

In the basic household system of Hitchcock [26] is explained that the amount of energy used in a household is determined by both physical aspects of a building e.g. insulation rate, heating system, ventilation system etc. and the occupants who live in the house. The combination of those two aspects determines the residential energy consumption. The physical characteristics of a dwelling do not only influence residential energy consumption directly but those characteristics also influence energy related occupant behaviour. This can also be concluded from the studies that found a rebound effect and prebound effect [27, 28]. The rebound effect for energy consumption in dwellings can be defined as: the effect that people behave less energy efficient if they know that their dwelling is energy efficient. The prebound effect is the opposite; people behave more energy efficient when they know their dwelling is energy inefficient. Although the rebound effect is widely known by post occupancy energy research the majority of the existing studies focus on either occupant influence or building characteristics influence, rarely on both. The findings that residential energy consumption is not purely a sum of occupant influences and building characteristic influences can be one of the reasons why we can find that building characteristics have a significant influence on residential energy consumption but the results for the influence of occupant behaviour are only limited. This interaction between occupant and building characteristics is missing in the majority of the studies that focus on occupant characteristics and their relation with actual energy consumption.

We conclude from this that the influence of building characteristics and occupant behaviour cannot be seen independently from each other because they interact with each other, as is visualized in figure. However in traditional energy behaviour research those aspects are almost always studied separately. Therefore the method we set up should always takes in account both, building characteristics and occupant characteristics.

3. METHOD

Based on the findings in the literature study the following starting points are taken into account for the development of a method to determine the influence of the occupant on residential energy consumption:

- Make use of existing (aggregated) datasets
- Focus on occupant characteristics instead of actual occupant behaviour
- Take into account that occupant behaviour and building characteristics interact with each other.

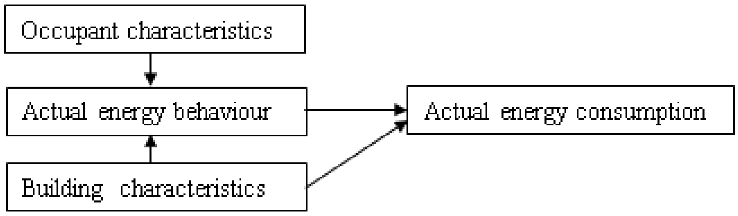

Figure 1 Method

3.1. Theoretical method description

This has resulted in the following method:
The first step is to carry out an inventory on what kind of data is available. The data needs to contain at least: actual energy consumption data, building characteristics data and occupant characteristics data.
The second step is to select the required data. If there is too many occupant or building characteristics information available, a selection has to be made, because it is impossible to study all physical building aspects and all occupant characteristics. This selection should be made based on finding in literature the characteristics that were found to have a significant influence on the residential energy consumption and a high effect size should be taken into account. When the data are selected, the data should be checked on possible failures and duplications.
The third step is to categorize the data and divide them into four variables: actual energy consumption (continuous), occupant characteristics (categorical), building characteristics (categorical) and a combined variable of occupant and building characteristics (categorical). The categorization of the data is required to reduce the number of groups e.g. the U-value of glazing, which is a continuous variable, should be divided in three types: single glazing double glazing, high performance double glazing and triple glazing. If all data is categorized the data can be grouped in the three groups.
Finally, when all data is grouped in the three categories, frequencies tables should be made. These will show which clusters are the most frequently occurring and therefore the most valuable to study. Note: If you have a more specific research question another consideration can be made of the selection of cases. The selection of cases is required because it is impossible to study all possible combinations.
When all those steps are executed a dataset with one continuous dependent variable (actual energy consumption) and three categorical independent variables are remained (occupant characteristics variable, building characteristics variable and a combination variable) and ready to use for statistical analysis that take both, occupant and building characteristics into account.

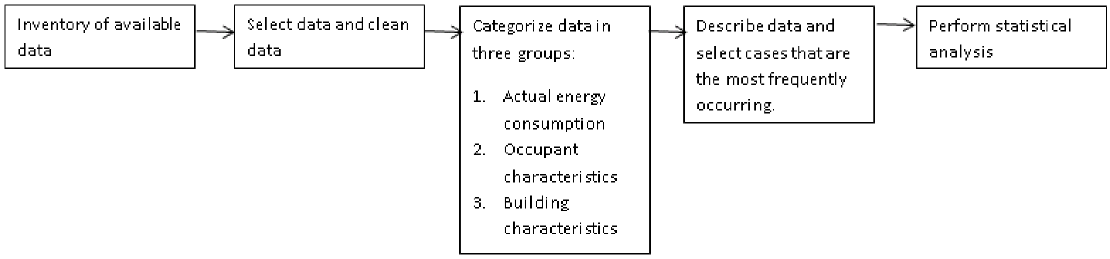

Figure 2 procedure

3.1. Method in practice

To validate this method it was used for a case study in the Netherlands. In the Netherlands several databases are available for this case study. We had access to four different data sets: The first database SHAERE contains information about the building characteristics of dwellings from social housing companies in the Netherlands. The social housing stock in the Netherlands contains 30% of the total housing stock; the SHAERE database contains 60% of the social housing stock in the Netherlands. The SHAERE database has been set up to monitor the progress in energy saving measures for the social housing sector and contains therefore a significant amount of building characteristics [29].
The second database that is use contains information about households; it has information about the number of family members, the household composition and the age of the youngest and oldest child. The third database contains annual energy consumption (gas and electricity) per address in the Netherlands. This database is also owned by Statistics Netherlands (CBS). Finally, the fourth database, also from Statistics Netherlands is used to combine the databases. This is required because due to privacy issues all data is encrypted. The household data is encrypted based on a specific person code and the energy consumption data and building characteristics data is encrypted on a specific object number. With the use of the fourth database all databases could be linked to each other. Based on the available data a selection of occupant characteristics and building characteristics was made as shown in table 3. After the selection the database was "cleaned". Only data of 2014 was used. Secondly all unrealistic data was removed from the database e.g. buildings with a construction year higher than 2014 and lower than 1130 were deleted. Since the energy database only contains gas and electricity data also all buildings that use district heating were removed from the dataset. Finally the databases were checked on duplicate cases.

Table 3 variables per cluster

Building characteristic	**Categories**	**Data source**
Heating installation	heat pump and , local heating and CR	SHAERE 2014 database
glazing type	Single double insulated glazing triple glazing	SHAERE 2014 database
Average R value building envelope	Not insulated/poorly insulated/good insulated/extra insulated	SHAERE 2014 database
ventilation	Natural/mechanical exhaust/balance	SHAERE 2014 database
Occupant characteristic		
Number of persons		GBAHuishoudensbus2014
Number of kids		GBAHuishoudensbus2014

Household type	Single, couple no kids not married, married couple no kids, couple with children, married couple with children, single parent	GBAHuishoudensbus2014
Age oldest child	0-4 5-12 13-18 18+	GBAHuishoudensbus2014
Age youngest child	0-4 5-12 13-18 18+	GBAHuishoudensbus2014
First time that reference person entered the system not as child	Less than 10 year / more than 10 years	GBAHuishoudensbus2014

When the database was cleaned the occupant and building characteristics aspects that were displayed as continuous numbers were categorized (e.g. U value windows, insulation rate). Additionally, some categorical variables were categorized in more general categories e.g the ventilation system was categorized in three categories instead of the original five. This is done in order to reduce the number of groups that will occur when all occupant characteristics variables and all building characteristics variables are combined into one variable. The energy consumption data was not categorized but because some of the heating systems use electricity and some of the use gas the energy consumption was converted to primary energy consumption. Since primary energy is a form of energy that is found in nature and has not been subject to any conversion or transformation process, appropriate heating values need to be taken into account when calculating its consumption. The assumed heating value for gas is 35.17 MJ/m3 (North Sea gas) and the efficiency of the electricity network is considered to be 0.39 [23].

$$Q_{total} = Q_{totalgas} \cdot 35.17 + Q_{totalel.} \cdot 3.6 \div 0.39$$
$$Q_{total} = primary\_energy[MJ]$$
$$Q_{totalgas} = gas[m^3]$$
$$Q_{totalel.} = electricity[kWh]$$

Finally, the occupant characteristic variable and the building characteristic variable were combined into one variable. When the occupant variable and the building characteristics variable were created some frequencies tables were generated. The cases with the highest frequency were selected to for analysis.

4. RESULTS CASE STUDY THE NETHERLANDS

In Figure 3 the influence of 9 different building groups on actual energy consumption are described. This shows us clearly that the cluster of building characteristics influences the actual energy consumption. The second graph (Figure 4) shows us the difference in actual energy consumption per occupant characteristic cluster. This graph shows less variance in energy consumption. It could be interpreted that the occupant characteristics has only a limited influence on the residential energy consumption. In the literature review it was mentioned that the occupant cannot be seen separately from the building characteristics, therefore a third graph was made. This graph shows that if we compare the different building types divided per occupant group a slightly more diversity is displayed. The anova method also proves these findings. The anova analysis for the building characteristics show a statistical difference with a measure of effect size of 4,80%, which may seem smaller than expected. A study performed by Filippidou et al. [30] on similar building characteristics data showed that the selected four building characteristics can only predict 4,6%. The influence of occupant clusters did, as expected, not show a significant difference in energy consumption per occupant characteristic cluster. For the third analysis a new variable was made that represents the combination of the occupant characteristic and the building cluster. This variable was also found to be statistically significant, however the measure of effect size only increase slightly 4,80-4,83%. The post hoc test shows us that the difference between some cases are significant but not for all.

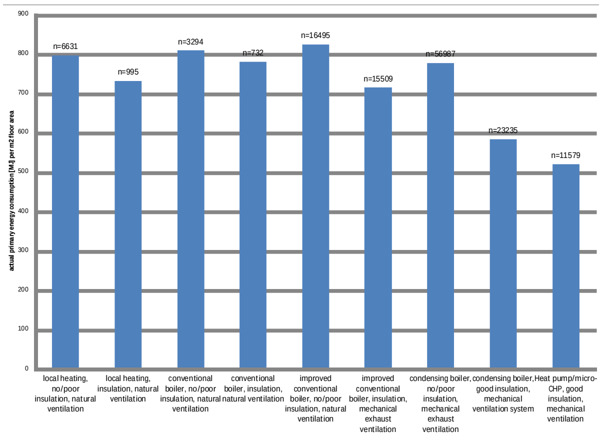

Figure 3 Primary energy consumption [MJ] per building cluster

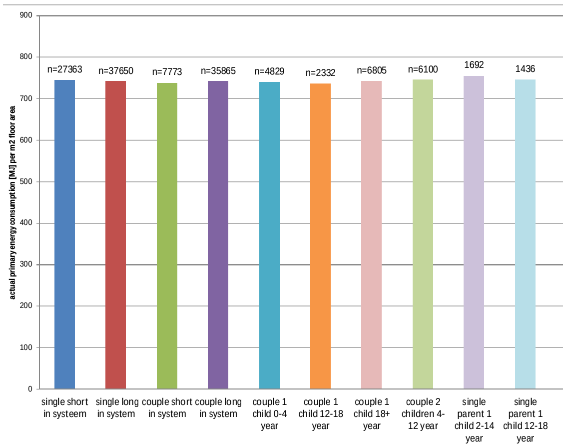

Figure 4 Primary energy consumption [MJ] per occupant characteristic cluster

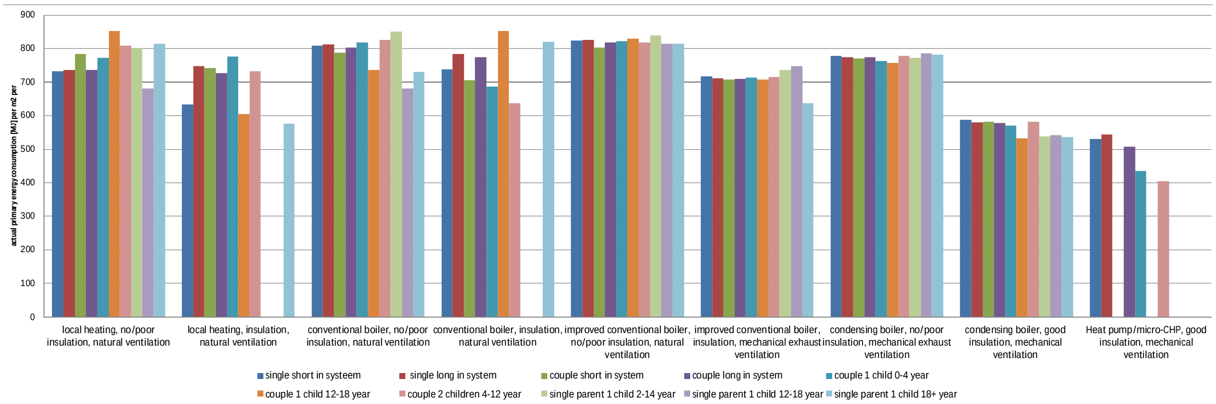

Figure 5 Primary energy consumption per combination building characteristics and occupant characteristics

5. DISCUSSION

Based on these findings several interpretations are possible: the occupant characteristic influence on residential energy consumption is very limited to zero; there is something wrong with the data as a 4,80% influence of building characteristics is also less than expected, if the variance between building characteristics is relatively small it is unlikely that the influence of occupant characteristics can be identified (as these are expected to be smaller than building characteristics based on previous research); the fact that we see at least an increase of the measure of effect size and that the combination is significant means that the occupant characteristics have an effect, but if you want to investigate the occupant behaviour you have to take the building characteristics into account. More research should be done to indicate which interpretation makes the most sense. First the clustering should be checked; whether this clustering was the most effective or if other more representative or more specific building and occupant clusters should have been made. There should also be indicated that the most important variables were taken into account, e.g. for the occupant behaviour we know from literature that income and age have a significant effect on residential energy consumption. Although the time a person is registered in the system as an adult shows us some insight in the age of the occupant, it may not be specific enough, and adding the actual age of the occupant could result in a larger effect on the energy consumption. At the time this paper was written those parameters were not available. Secondly and probably more important, the accuracy of the SHAERE database and Dutch statistics databases should be determined, since not only us but also other researchers found only limited effect of the building characteristics on residential energy consumption, and if this effect is limited it is expected that the combination of building and occupant characteristics will also be limited.

6. CONCLUSION AND FURTHER RESEARCH

The aim of this paper is the development of a method to study the influence of occupant on residential energy consumption with the use of large, aggregated and existing data and therewith to provide a better insight in the influence of occupant behaviour on residential energy consumption. The graphs show that the occupant characteristics influence the energy consumption more if the building characteristics were taken into account, but statistical analysis showed only a limited (almost negligible) effect. Because the results of the data analysis were not conclusive we did not prove the effectiveness of the method. We can also not discard this method since there can be other explanations for the results. Previous research that made use of the building characteristics data from SHAERE and energy consumption data form the Statistics Netherlands also showed a relatively small effect of the building characteristics on residential energy consumption. This could mean that the data is not representative. Another important aspect is that only a limited amount of occupant characteristics was available at the time of the research. It could be that in this analysis not the most determining occupant characteristics were taken into account, which explains the limited influence of the occupant on residential energy consumption. For further research it is advised to also apply this method on other databases and to investigate other occupant clustering methods. More research towards the effectiveness of this method is required, as is more research towards the accuracy of the used databases.

Further research towards the effectivity of this method should primarily focus on the importance of clustering methods and the representativeness of large databases.

REFERENCES

[1] Filippidou, F., N. Nieboer, and H. Visscher, *The pace of energy improvement in the Dutch non-profit housing sector*, in *World SB 14*. 2014: Barcelona.

[2] Majcen, D., L.C.M. Itard, and H. Visscher, *Theoretical vs. actual energy consumption of labelled dwellings in the Netherlands: Discrepancies and policy implications.* Energy Policy, 2013. **54**: p. 125-136.

[3] Eurostat, *Final energy consumption by sector*, tsdpc320, Editor. 2016: http://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tsdpc320.

[4] EuropeanUnion. *The 2020 climate and energy package*. 2015 08/05/2015 [cited 2015 13 May]; Available from: http://ec.europa.eu/clima/policies/package/index_en.htm.

[5] Majcen, D., L. Itard, and H. Visscher, *Energy labels in Dutch dwellings - their actual energy consumption and implications for reduction targets*, in *ECEEE 2013 Summber study - rethink, renew restart*. 2013.

[6] Gram-Hanssen, K., *Households' energy use - which is the more important: efficient technologies or user practices?*, in *World Renewable Energy Congress 2011*, EEE, Editor. 2011: Linkoping, Sweden.

[7] Martiskainen, M., *Chapter 4 Household energy consumption and behavioural change - the UK perspective*, in *Conference of the Sustainable Cosnumption Research Exchange (SCORE!) Network*, T.G.K. Ken, et al., Editors. 2008: Brussels, Belgium. p. 73-90.

[8] Janda, K.B., *Buildings don't use energy: people do.* Architectural Science Review, 2011. **54**(1): p. 15-22.

[9] Guerra Santin, O., *Actual energy consumption in dwellings; the effect of energy performance regulations and occupant behaviour*, in *OTB*. 2010, TU Delft: Delft. p. 237.

[10] Guerra Santin, O., *Behavioural Patterns and User Profiles related to energy consumption for heating.* Energy and buildings, 2011. **43**: p. 2662-2672.

[11] Guerra Santin, O., L. Itard, and H. Visscher, *The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock.* Energy and Buildings, 2009. **41**(11): p. 1223-1232.

[12] Jeeninga, H., M. Uyterlinde, and J. Uitzinger, *Energieverbruik van energiezuinige woningen; effecten van gedrag en besparingsmaatregelen op de spreiding in the hoogte van het reele energieverbruik*, E. &IVAM, Editor. 2001.

[13] O'Neill, B.C. and B.S. Chen, *Demographic Determinants of Household Energy Use in the United States.* Population and Development Review, 2002. **28**: p. 53-88.

[14] Palmborg, C., *Social Habits and energy consumption in single-family homes.* 1985.

[15] Guerra-Santin, O. and L. Itard, *Occupants' behaviour: determinants and effects on residential heating consumption.* Building Research & Information, 2010. **38**(3): p.

318-338.
[16] Chen, J., X. Wang, and K. Steemers, *A statistical analysis of a residential energy consumption survey study in Hangzhou, China.* Energy and Buildings, 2013. **66**(0): p. 193-202.
[17] Kaza, N., *Understanding the spectrum of residential energy consumption: A quantile regression approach.* Energy policy, 2010. **2010**(38): p. 6574-6585.
[18] Yohanis, Y.G., et al., *Real-life energy use in the UK: How occupancy and dwelling characteristics affect domestic electricity use.* Energy and buildings, 2007.
[19] Yun, G.Y. and K. Steemers, *Behavioural, physical and socio-economic factors in household cooling energy consumption.* Applied Energy, 2011. **88**(6): p. 2191-2200.
[20] Vringer, K. and K. Blok, *The direct and indirect energy requirements of households in the Netherlands.* Energy Policy, 1995. **23**(10): p. 893-910.
[21] Pettersen, T.D., *Variation of energy consumption in dwellings due to climate, building and inhabitants.* Energy and Buildings, 1994. **21**(3): p. 209-218.
[22] Yohanis, Y.G., *Domestic energy use and householders' energy behaviour.* Energy policy, 2011. **41**(2012).
[23] Majcen, D., *Predicting energy consumption and savings in the housing stock* **-** *A performance gap analysis in the Netherlands*, in *Architecture and the Built Environment*. 2016, Delft University of Technology: Delft. p. 224.
[24] Sonderegger, R.C., *Movers and Stayers: the resident's contribution to variation across houses in energy consumption for space heating.* Energy and buildings, 1978. **1977/78**(1): p. 313-324.
[25] Gram-Hanssen, K., *Efficient technologies or user behaviour, which is the more important when reducing households' energy consumption?* Energy efficiency, 2012. **2013**(6): p. 447-457.
[26] Hitchcock, G., *An integrated framework for energy use and behaviour in the domestic sector.* Energy and Buildings, 1993. **20**(2): p. 151-157.
[27] Sunikka-Blank, M. and R. Galvin, *Introducing the prebound effect: the gap between performance and actual energy consumption.* Building Research & Information, 2012. **40**(3): p. 260-273.
[28] Guerra Santin, O., *Occupant behaviour in energy efficient dwellings: evidence of a rebound effect.* Journal of Housing and the Built Environment, 2013. **28**(2): p. 311-327.
[29] Filippidou, F. and N.E.T. Nieboer, *Energetische verbeteringsmaatregelen in de sociale-huursector*. 2014, OTB-Onderzoek voor e gebouwde omgeving.
[30] Filippidou, F., et al., *Energie-efficientie van renovatie maatregelen in Amsterdamse corporatiewoningen*. 2015, OTB - Rsearch for the Built Environment, Faculty of Architecture and the Built Environment, Delft University of Technology: Delft. p. p. 94.