

Behavioural Climate Change Mitigation Options

Domain Report Housing

Report

Delft, April 2012

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Further information on this study can be obtained from the contact person, Jasper Faber.

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Preface

This is the final report on *Behavioural Climate Change Mitigation Options in the Housing Domain*. It is part of the study 'Behavioural climate change mitigation options and their appropriate inclusion in quantitative longer term policy scenarios' for the European Commission, DG Climate Action. The aim of the study is threefold:

1. To assess and demonstrate the GHG emission reduction potential of changes in behaviour and consumption patterns.
2. To analyse policy options for the further development of community policies and measures inducing changes in behaviour and consumption patterns. And
3. To identify the linkages with other technical and economic variables in such a way that it can be used in modelling and scenario development.

The study has focused on three domains: transport, food and housing.

This report is part of five reports which together constitute the final report of contract 070307/2010/576075/SER/A4. The other reports are:

1. The Main Final Report.
2. The Transport Domain Final Report.
3. The Food Domain Final Report.
4. A Technical Report on the appropriate inclusion of results of the analysis in model-based quantitative scenarios.

The study has been conducted by a consortium led by CE Delft comprising of Fraunhofer ISI and LEI.

Jasper Faber



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Summary

The EU's greenhouse gas (GHG) emission reduction policies and the goal to keep the global temperature increase below 2°C commits the EU and its Member States to reduce emissions by at least 20% below 1990 levels by 2020, and by 80-95% by 2050. A significant share of current emissions, in particular of those not covered by the EU Emissions Trading System (ETS) is related to housing and buildings.

In the first part of the housing domain report, an overview is established of behavioural GHG mitigation options in the housing sector (residential as well as non-residential buildings) which aim at reducing the demand of space heating energy. It is argued, that occupant behaviour bears an important potential for energy conservation. However, scientific literature on the effects of non-technical policy measures is scarce. Thus, a vast literature survey was conducted on the energy saving potential of changed behaviour with regard to heating and air conditioning. Studies on residential electricity use were out of scope of the current project, since the electricity sector is part of the ETS. From the number of possible behavioural change options, the selection process identified three behavioural change options in the housing domain that were then chosen to be finally analysed. Those are usually not covered by models. The assessment aimed at providing a complete synthesis of the available knowledge in this field. The three behavioural options are:

1. Reducing space heating temperature (=lowering room temperature).
2. Optimising thermostat settings (e.g. leaving room temperatures at the same level, reducing temperature at night/if absent). And
3. Optimising ventilation behaviour.

In a next step, regarding the behavioural options selected, their maximum as well as their realistic mitigation potentials could be calculated.

The assessment of the abatement potential of reducing space heating temperature by lowering the room temperature shows that the average theoretical reduction potential (2°C) in the EU-27 is about 18% (the 2°C goal as maximum reduction level is chosen in a way that it makes mitigation actions possible by at the same time keeping levels of comfort constant and not imposing significant side-effects). The maximum theoretical CO₂ abatement potential for the housing domain declines from 77 Mt in 2020 to 54 Mt in 2050 due to better energy efficiency standards in the housing sector. Non-behavioural constraints to the implementation of changed behaviour are for instance technical ones, like non-adjustable heating systems, but also personal needs of different resident groups (e.g. the elderly and children) or possible frost damages that suggest avoiding temperatures beneath a minimal room temperature of about 15°C.

The maximum realistic emission reduction potential is therefore the product of:

- The relative reduction potential per dwelling.
- The share of dwellings without the technical options to reduce the room temperature.
- The share of dwellings with people with special needs concerning temperature levels.
- The overall GHG emissions from space heating.

As for indirect effects, the same GHG abatement potential can be accounted for during the production phase of the energy. Possible rebound effects are too difficult to quantify and therefore left out; no monetary end-user costs occur when reducing in-home temperatures. No positive or negative side-effects are evident within a reasonable scope. Due to the above described



limitations, only 60% of the theoretical potential can be assumed for realisation. Therefore, the average realistic reduction potential (2°C) in the EU-27 is about 10%; the maximum realistic CO₂ abatement potential for reducing room temperatures declines from 45 Mt in 2020 to 32 Mt in 2050. In a similar vein, for optimising thermostat settings, it declines from 21 Mt in 2010 to 15 Mt in 2050. As the maximum realistic mitigation potential from optimal ventilation behaviour depends highly on the quality of the building stock, a reduction of the energy consumption by 25% of the ventilation losses is a reasonable assumption for the reduction potential.

The overall reduction potential for all measures sums up to 98 Mt in 2020 (2°C reduction; 75 Mt for a 1°C reduction). For 2050 this amount is slightly lower due to a more efficient building stock. Nevertheless the value is still 78 Mt for the 2°C and 62 Mt for the 1°C scenario.

A major part of the report focuses on barriers of behavioural change, consumer segments and policy instruments. First of all, what characterises the three options for reducing heating energy, is that this kind of behaviour is rather expressed by daily habits and routines. It manifests itself as sequences of small mitigation actions, and therefore is part of people's lifestyle. It is rather not driven by deliberative thoughts and decision making, as it would be the case when making an investment decision for high-cost technologies. Manifold barriers to domestic energy saving behaviour could be identified, and as a consequence categorised as psychological, knowledge-based, structural-physical, cultural, economic and institutional barriers. At the same time one should not neglect demographics and also unconscious behaviour as possible inhibiting factors. To the most important barriers towards residential energy saving belong limited cognition, as lack of knowledge and awareness about one's own energy consumption. Furthermore, hindering factors can be worldviews that tend to preclude pro-environmental attitudes, comparisons with other key people (that usually act as drivers) or the attribution of responsibility to others, sunk energy costs, plugged-in behavioural routines, the lack of direct energy consumption feedback or cultural barriers as e.g. people's needs for comfort. Those barriers are usually strongly correlated to some consumer segments characterised by certain demographic factors, e.g. low income and education, or gender differences.

Following this, we provided an in-depth assessment of policy instruments which could be used on a European level to induce changes in behaviour and consumption patterns, by also taking their diffusion patterns and barriers into account. Those instruments were explored and discussed that are able to promote user behavioural change towards optimising room temperatures, thermostat setting and ventilation behaviour. The analysis provided an evaluation of the instruments' effectiveness, pertaining to behavioural change and GHG emissions reduction. Possible regulative instruments are for instance mandatory heating energy billing at more frequent intervals and rendering the bills more informative at the same time. Financial incentives and subsidies can be subordinated to economic instruments. Direct governmental expenditures, e.g. in smart-metering infrastructure or procedural instruments like voluntary agreements with ESCO's, companies or schools can also be envisaged. Given that the main barriers to mitigation behaviour identified in this report are of psychological/social nature, the policy instruments to be thought most crucial in tackling behavioural change provide residents with communication and education activities. Those instruments come in diverse forms for various target groups, like information campaigns, networks and community programmes as well as demonstration of best practices and the creation of ICT-based tools.



As the assessment of barriers showed, the main barriers for consumers to reduce heating energy demand are psychological and knowledge-based ones. Thus, a policy package for the housing sector is eventually proposed in order to address those main barriers with a combination of effective policy instruments that may act in unison.

The following policies are proposed:

- various communication strategies, both for mass and individual target groups;
- obligations for energy providers to distribute truly informative and adequately frequent heating energy bills;
- direct governmental expenditures like national governments' public investments in infrastructure, e.g. smart-meters;
- *and as an option*: Financial incentives for reduced energy consumption or taxation of higher energy consumption.

The overall abatement potential identified for the selected options is equally addressed by the different policy instruments in the policy package. The ability of the policy package to address the potential can only be quantified roughly, as the barriers themselves are of a psychological nature. Even for fiscal instruments the effect on user behaviour has not been quantified in a way that allows describing detailed correlations. From several projects at least a share of 25-30% of the potential can be realistically addressed by the informational measures of the policy package.





1 Introduction

The EU's greenhouse gas (GHG) emission reduction policies and the goal to keep the global temperature increase below 2°C commits the EU and its Member States to reduce emissions by at least 20% below 1990 levels by 2020, and by 80-95% by 2050.

The current models for quantitative assessments of climate policies in the housing domain are implicitly or explicitly focused on technical mitigation measures and less on behavioural changes induced by policy instruments. However, it is known that there is a considerable potential to reduce emissions by changes in consumption patterns, especially in the area of heating energy demand, at low costs. Thus, if ambitious reduction targets are to be reached, shifts in consumption patterns of indoor heating energy may prove essential to complement technological developments. Therefore, it is crucial to assess the emission mitigation potential of residential behavioural changes, but also various kinds of barriers to these changes and eventually policy instruments to overcome the barriers.

To sum up, the aim of this report for the housing domain is to assess and demonstrate the GHG emission reduction potential of household changes in behaviour and consumption patterns. In this vein, it tries to properly assess and demonstrate the abatement potential of particular behavioural options with regards to space heating. A further target is the analysis of policy options for the further development of policy packages inducing changes in residential energy mitigation behaviour and consumption patterns. And finally, the presented results aim to identify the linkages with other technical and economic variables in such a way that they can be used in modelling and scenario development.

Chapter 2 provides an overview of behavioural options in the housing sector aiming to reduce the demand of residential space heating energy, and concludes with a selection of three behavioural options to be further analysed. Subsequently, **Chapter 3** deals with the abatement potential of the options chosen, providing insight into the theoretical and the realistic CO₂ mitigation potentials while also discussing possible indirect, rebound and side-effects as well as end-user costs. Next, **Chapter 4** on barriers, consumer segments and policy instruments delivers a broad overview of barriers inhibiting domestic curtailment behaviour with regard to the reduction of space heating energy, as cited from scientific studies. After referring to consumer segments and possible diffusion patterns, existing policy instruments with the ability to influence domestic energy saving behaviour are identified and evaluate, focusing on their ability to promote behavioural change. Finally, **Chapter 5** establishes a policy package on the basis of the most suitable policy instruments. The package's abatement potential and costs are eventually described when successfully addressing residential behavioural change.





2 Overview of behavioural options

2.1 Introduction

It is widely acknowledged in the literature that user behaviour significantly influences energy use in the housing sector (e.g. Guerra Santin et al., 2009; Branco et al., 2004; Jeeninga et al., 2001; IWU, 2003). Thus, also saving potentials that are possible from a technological point of view are contingent on user behaviour: “While there is a plethora of studies on the technical possibilities, i.e. the potential energy savings that new technologies allow, it is plain that energy consumption also depends on our attitudes, preferences, and income as well as relative prices.” (Kriström, 2008, p. 95). However, the extent to which variations in energy use are due to variations in user behaviour is still largely unknown (see Guerra Santin et al., 2009). Thus, also quantitative analyses of the potential of behavioural change measures can hardly be found in the literature. This is mirrored for example in the review by Abrahamse et al. (2005) which shows that hardly any study on behavioural change includes quantifications of the resulting effects or similarly, by results from the project BewareE which extensively reviews measures on reducing consumers’ energy consumption throughout Europe (Scharp, 2008; cp. also Gynther, Mikkonen and Smits, 2011, on results from the Behave project). Moreover, the majority of studies focus on residential electricity use which is out of scope of the current project. Furthermore, those studies that analyse behavioural change come to varying results (cp. Kriström, 2008) which is to be expected if the amount of literature is limited. Thus, in sum, the results from the literature and study review on the housing sector which will be presented in the following are less informative than expected.

2.2 Housing

In the residential sector energy is primarily used for space heating and cooling, water heating, lighting and electric appliances. If the focus of analyses is directed to non-electricity space and water heating are the main domains for achieving consumption patterns that are sustainable with regard to climate change. Cooling, e.g. using air-conditioning, is an additional domain, especially for the warmer parts of the EU, that is gaining importance also in relation of the hotter climate to be expected in consequence of climate change. Research has found that energy demand for space heating is positively related to the age of the occupants (older households consuming more energy), household size, income and ownership (more energy used in rented dwellings) (e.g. Jeeninga et al., 2001; Lenzen et al., 2006; Schuler et al., 2000; Guerra Santin et al., 2009). Energy use for heating has been estimated to vary by the factor of two depending on variations in user behaviour (cp. Guerra Santin et al., 2009). Similarly, studies assessing the energy demand by passive housing, show that depending on the user behaviour, energy demand may vary by the factor of four (Gintars and Friedrich, 2003).

From a theoretical point of view, behavioural measures with regards to mitigating energy use in households mainly comprise two areas: efficiency and curtailment behaviours (Gardner and Stern, 2002). The first one includes one-shot behaviours like the decision on and investment in equipment used, i.e. the energy source and the appliance for generating energy. The second refers to repetitive efforts, e.g. changes in everyday behaviour, i.e. the



operation of appliances, preferred room temperatures, usage patterns with regard to opening windows, etc. Some of these behavioural measures imply a change of routines without changing lifestyle (e.g. optimised operation of heating installations without reducing the room temperature), others imply greater changes (e.g. reduced room temperature). Efficiency behaviour is not the main focus of this study, for it mainly results in the investment into different technologies, but the curtailment behaviour remains unchanged.

The impact of efficiency behaviours on energy demand is often assumed to be higher than of curtailment behaviours (cp. Abrahamse et al., 2004). Furthermore it can be hypothesised that efficiency behaviours are more sustainable as they only once call for a certain behaviour (e.g. deciding on an investment) to achieve constant energy savings (not considering direct rebound effects). Curtailment behaviours usually do not require initial investments which may be a barrier to efficiency behaviours.

Up to now, first studies confirm that the behavioural potential for saving energy in the area under study is significant. For example, estimates of what is a comfortable room temperature greatly vary. A study by Schlomann et al. (2004) found values between 18 to 25°C to be evaluated as an acceptable temperature for the living room, for bedroom temperatures varied between 10 and 22°C. Ministry of the Environment (2008) provide data for an exemplary case, using data from a two-person-household which has an energy demand close to an average Finnish citizen. They come to the conclusion that lowering the room temperature - which is one of several behavioural measures analysed - by 2°C would reduce the CO₂ impact per person by 250 kg/a. These results imply that there may be a significant potential for saving energy by reducing room temperatures. With one exception, all of the studies included in the factsheets (see annex) further analyse the potential of changed behaviour with regard to heating thereby including the replacement of less efficient heating systems as well as curtailment behaviour in relation to space heating. Further results are to be expected to be published in the years to come, e.g. EU-funded projects like eSESH (Saving Energy in Social Housing with ICT; www.esesh.eu) and BECA (ICT for energy and water efficiency in social housing) have just started, however, not published results.

Thus, while heating is covered to some extent by the results of the literature review, studies on air-conditioning were even harder to identify. This may be due to the fact, that due to the actual climate, in Europe air-conditioning is just about gaining importance with saturation levels not reached up to now (cp. Bertoldi and Atanasiu, 2007; Moussaoui, n.d.). Some studies from the US which are also informative for the scope of this project with regard to heating include data on air-conditioning and were there also included into the factsheets (BC Hydro, 2007; Dietz et al., 2009; Gardner and Stern, 2008). However, behavioural changes in relation to air conditioning were finally removed due to poor data availability and lack of conceivable policy instruments (see Section 2.4). The final list of behavioural options identified is equally provided in that chapter.

Measures identified: Summary of factsheets

Overview - studies included in factsheets:

1. Abrahamse et al. (2007): The effect of tailored information, goal-setting and tailored feedback on household energy use, energy-related behaviours, and behavioural antecedents (plus further material from the same project).
2. BC Hydro (2007): Conservation Potential Review by the Canadian utility BC Hydro (plus further material from the same project).



3. Bohunovsky et al. 2010: Ausbau erneuerbarer Energien, Erhöhung der Energieeffizienz und Verhaltensänderungen im Energieverbrauch bis 2020 (plus further material from the same project - <http://www.energiemodell.at/projekte/e-co/>).
4. Öko-Institut (2000): Klimaschutz durch Minderung von Treibhausgasemissionen im Bereich Haushalte und Kleinverbrauch durch klimagerechtes Verhalten.
5. Bürger (2009): Identifikation, Quantifizierung und Systematisierung technischer und verhaltensbedingter Stromeinsparungspotenzial privater Haushalte (Project Transpose - www.uni-muenster.de/Transpose).
6. Dietz et al. (2009): Household actions can provide a behavioural wedge to rapidly reduce US carbon emissions.
7. Gardner and Stern (2008): The Short List The Most Effective Actions U.S. House-holds Can Take to Curb Climate Change.
8. Guerra Santin et al. (2009): The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock.
9. Huenecke et al. (2010): Sustainability of consumption patterns: Historic and future trends for Europe (<http://eupopp.net>).

Table 1 Overview of behavioural measures and related factsheets in housing

Behavioural measure	Related factsheets
Housing	
Bundle of heating related behaviours including reducing room temperatures	Abrahamse et al., 2007
Combined effect of reducing room temperatures and ventilation rates	Öko-Institut, 2000
Reduced use of electric ventilation	BC Hydro, 2007
Reducing space heating temperature (lowering room temperature)	BC Hydro, 2007; Bohunovsky et al., 2010; Gardner and Stern, 2008; Guerra Santin et al., 2009
Reducing heated space	BC Hydro, 2007; Bohunovsky et al., 2010; Gardner and Stern, 2008; Guerra Santin et al., 2009
Reduced use of space heating	BC Hydro, 2007; Bohunovsky et al., 2010; Gardner and Stern, 2008; Guerra Santin et al., 2009
Optimising thermostat settings of heating, leaving room temperatures at the same level	Dietz et al. (2009); Gardner and Stern (2008)
Optimising water heater settings	Dietz et al. (2009); Gardner and Stern (2008)
Optimised air-conditioning use	BC Hydro, 2007; Dietz et al., 2009
Reduced hot water use	BC Hydro, 2007
Optimised water heater settings	Dietz et al. (2009); Gardner and Stern (2008)
Replacement of electrical heating/electrical water heaters	Bürger, 2009; Dietz et al. (2009); Huenecke et al. (2010)

Time horizons of the studies vary greatly between only referring to the actual situation (e.g. Abrahamse et al., 2007) and 2030 (Huenecke et al., 2010). The scope of most studies is nationally with Austria (I), Canada (I), Germany (II) the Netherlands (II), USA (II) and once the EU-27. Thus, conclusions for the whole EU are difficult to draw as especially colder and warmer climate zones are underrepresented. The assessment methodology mainly relies on modelling exercises, only few studies refer to data on real



changes of behaviour. Effects (indirect, rebound, side-effects) besides direct effects are hardly analysed, and if mentioned at all, the analyses are very superficial; the same applies for cost estimates.

2.3 Non-residential buildings

The goal of this part of the literature overview is to provide insight in the behavioural options for heating/cooling energy conservation in non-commercial, non-residential buildings. Whereas residential energy conservation has received at least some attention in the literature (see literature overview on housing), less is known about behavioural options in the non-residential sector. In light of the project goals, the search for literature has been limited in the following ways:

- As mentioned above, only *behavioural* options are considered. Technical options (e.g. insulation, heating equipment, thermal control systems) are excluded from this review.
- The review is to focus solely on heating and cooling energy use. Conservation options in terms of lighting or office equipment are not included, since electricity use will eventually be covered by the EU ETS system.
- Since commercial enterprises are thought to base their energy behaviours and investments on rational economic arguments, they are excluded from this review. Public sector buildings like schools, universities, hospitals, government buildings and museums are included.

Due to this drastic reduction in topics to be covered, it is not surprising that appropriate literature is scarce if not non-existent. This is reflected in the IPCC's fourth assessment report (Levine et al., 2007), which names occupant behaviour as an important potential for energy conservation. At the same time, they note that little literature is available on the effect of so-called non-technical measures¹, and name electricity use and residential heating as the most important options. The majority of literature on behavioural options for energy conservations is focused on electricity, e.g. by motivating people to switch of the lights when they leave a room, or use power-saving modes on office equipment (e.g. Junilla, 2007; Scherbaum et al., 2008). In our view, the narrowing down of the topic only leaves three broad categories of measures that might influence energy performance:

- building occupants collectively agreeing on adjusting thermostats towards outside temperature (less heating in winter, less cooling in summer);
- keeping windows closed in buildings with climate regulation systems;
- allowing building occupants to individually regulate their room's climate control and motivating them to switch it off when not present.

These three options, and the available literature on the topic, are briefly discussed below.

¹ They estimate that, globally, approximately 29% of emissions could be avoided in the residential and commercial building sector through technical measures. Non-technical measures are not quantified due to lack of data.



Collective temperature adjustment

Perhaps the most obvious behavioural measure to conserve heating/cooling energy in utility buildings is to collectively adjust to an indoor temperature that is nearer to the outside temperature. This prevents heating in winter and cooling in summer, but it would require a collective agreement or management policy to centrally change the temperature². No literature was found on the potential energy conservation involved with such a measure. Any literature related to this field actually tried to achieve the opposite: to minimise the energy use by calibrating central climate management systems, while maintaining comfort levels of building occupants (e.g. Hoes et al., 2008). We consider this a technical solution.

Keeping windows and/or doors closed

In buildings with centralised climate control, users may have a significant influence on energy loss by opening windows: heat will dissipate out of the building, possibly counteracting the temperature regulation centralised climate control is trying to achieve. However, instead of trying to influence user behaviour on opening windows³, a whole body of literature is aimed at incorporating occupant behaviour and comfort in building energy models in order to optimise the performance of energy management systems (e.g. Rijal et al., 2007; Roetzel et al., 2010). The only study we found describing the effect of educating people on the use of opening windows, is one by Matthies and Hansmeier (2010). They investigated the effect of an information campaign on window-opening behaviour and thermostat regulation (see next paragraph), and observed a 3-4% reduction of energy consumption during the heating season. The topic is also briefly touched upon by Broc et al. (2006, see factsheet), who studied the effect of an information campaign on user-related energy consumption in French office buildings. Although mainly focused on electricity use, heat energy was included for part of the sample, and showed a reduction compared to a baseline period. It should be noted, however, that the sample used in this study was very small (four office buildings), and therefore difficult to extend to a European scale. A study related to this topic, is the issue of shopkeepers keeping their doors open during opening hours. While increasing energy use (i.e. by heat escaping through the open door in the heating season), shopkeepers claim that customers are more likely to enter their shop when the door is open. In light of the 'Close the Door' initiative in the UK to stimulate shopkeepers to keep their doors closed, Basarir and Overend (2010) investigated the energy loss incurred by keeping shops' doors open. Although the scale of the study is very small, and the study is slightly off-topic, a factsheet of this study is included in this review.

Individual climate regulation

If climate control is halted when users are absent, less energy may be consumed for a building's climate control. While generally applied by e.g. lowering thermostats outside of opening hours, it may be theoretically possible to achieve this by allowing individual users to control their room temperature. One principal problem in finding behavioural options to conserve heating energy in collective buildings is that their lay-out is generally designed in the opposite fashion. I.e. climate regulation is collectively regulated so that responsibility of energy consumption lies with the building supervisor, not the end-user. This set-up allows a high level of automation of climate control (e.g. centralised thermostat setting, use of efficient heating equipment), and

² Or a change to individual climate control; see below.

³ One way of achieving this, is by preventing windows from opening at all, but this is considered a technical option.



takes away responsibility of regulation from the end-user. This seems quite reasonable, given that end-users in utility buildings are usually uninvolved with paying the energy bills. In residential buildings, end-users are often responsible for paying energy bills, and thus have a higher incentive for conserving energy⁴. One way in which individual users may influence individual room temperature, is by turning down the radiator when they will be absent for a longer time. This behaviour was included in the intervention study by Matthies and Hansmeier (2010), but the effect of single measures could not be quantified.

Table 2 Overview of behavioural measures and related factsheets in non-residential buildings

Behavioural measure	Related factsheets
Non-residential buildings	
Collective temperature adjustment	-
Keeping windows and/or doors closed	Broc et al., 2006; Matthies and Hansmeier, 2010; Basarir and Overend, 2010
Individual climate regulation	Matthies and Hansmeier, 2010
Turning off lights/computers (electricity conservation)	Junilla, 2008

To sum up for the housing sector, only few behavioural options can be identified from the literature and many of them are related. They mainly refer to reducing the demand of energy for heating by either reducing room temperatures, reducing the amount of heated space, reducing the use of space heating at all. Additional areas analysed are either optimising the settings of water heaters and/or the space heating facilities or relate to ventilation behaviour. However, the list of options presented in the tables is longer as effects of different behavioural options are often studied together and data is only provided for combined effects.

2.4 Selection of behavioural change options

We have applied a three step process for selecting behavioural changes:

Step 1: Remove behavioural changes with poor data availability and lack of conceivable policy instruments

Behavioural changes with poor data availability do not allow for the calculation of GHG emission reduction potential and costs. Behavioural changes for which no policy instrument is conceivable are excluded because they cannot contribute to the study objective to 'analyse policy options for the further development of community policies and measures inducing changes in behaviour and consumption patterns'.

Step 2: Rank behavioural changes according to their mitigation potentials

In this second step the remaining behavioural changes are ranked based on their mitigation potential. The ranking process is complicated by the fact that for some behavioural changes the literature reviewed presented maximum potentials, while for other changes just 'realistic' potentials are given. In addition, the time horizon of the mitigation potential estimates differs

⁴ A similar issue arises when making decisions about investing in energy-efficient equipment: when the investor does not reap the benefits of the energy efficiency, he is not likely to invest in more expensive equipment, while users. Similarly, when end-users are not responsible for paying the energy bill, they are less likely to mind their spending. This is sometimes referred to as the principal-agent problem (Meier et al., 2007).



between studies (and hence behavioural changes). Therefore, the ranking of the various behavioural changes was performed by expert judgement based on the results of the literature review.

Step 3: Select options that have high policy relevance and/or are usually not covered by models

This step eliminates behavioural changes that have a relatively large GHG abatement potential but are already included in models, and changes that have a relatively large abatement potential but that are studied elsewhere or have little policy relevance for other reasons.

The selection process has resulted in the selection of three behavioural changes in the housing domain:

1. Reducing space heating temperature (=lowering room temperature).
2. Optimising thermostat settings of heating (e.g. leaving room temperatures at the same level, reducing temperature at night/if absent). And
3. Optimising ventilation behaviour.

The GHG impacts, costs, and barriers are studied in more detail in the next chapters.





3 Abatement potential and costs

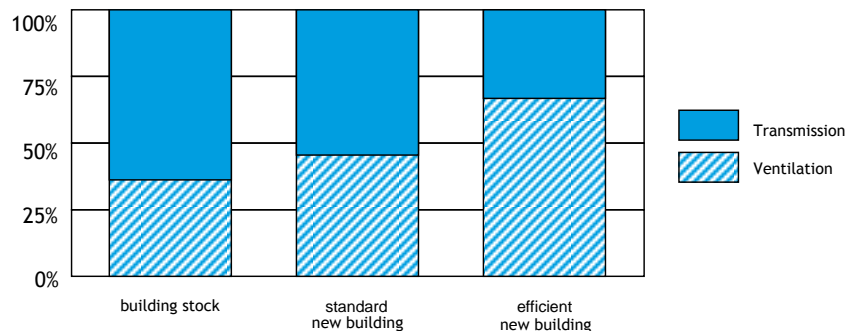
After applying a three-step selection procedure, three behavioural change options remained to be further analysed with regards to GHG impacts, costs and important side-effects, as well as barriers of these behavioural changes.

The energy consumption of private households is dependent of two classes of factors: building characteristics and user behaviour. Factors like dwelling size, location of the apartment within the house, the heating system, type of windows, insulation or climatic influences etc. are counted among the non-personal housing variables, whereas the very specific user behaviour of the residents, and furthermore occupancy rate (e.g. family or single household), occupancy time (e.g. employed or retired people) or living conditions (e.g. living with small children or elder people) are important determinants of the energy use in buildings.

In energetically not optimised and non-retrofitted houses, the absolute effect of energy savings due to curtailment behaviour is high, because the overall energy consumption is high as well.

In energetically optimised buildings on the other hand, where the technical energy potential is already more or less exhausted, the heating and natural ventilation behaviour have the highest impact on the energy consumption, given that the energy demand is mainly determined by the ventilation losses. Thus, the absolute potential is higher for old and non-retrofitted houses, but the relative impact and in this vein the importance of behaviour compared to technical changes rises with the quality of the insulation of the houses. The following figure shows the relative amount of manual ventilation (blue) and transmission (red) heating energy losses (transmission means losses due to thermal leaks at e.g. windows, walls and the roof).

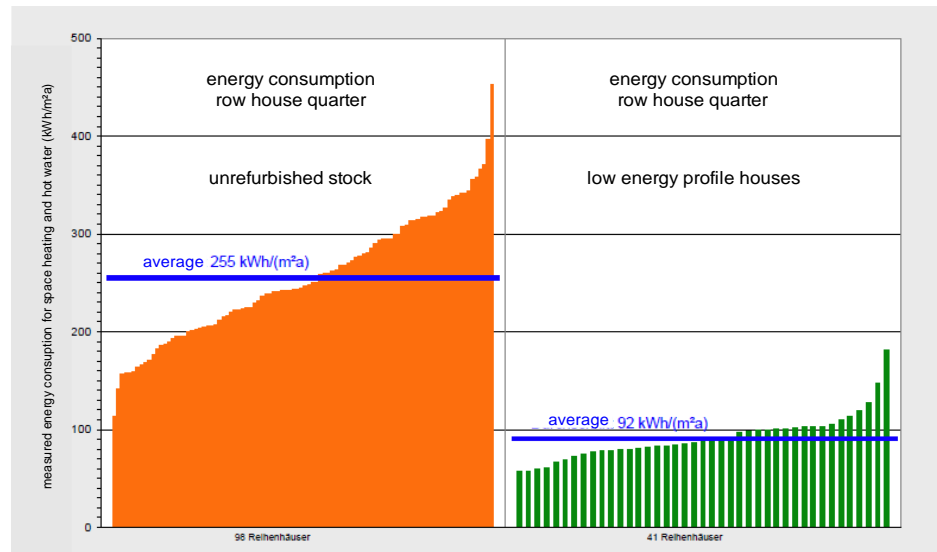
Figure 1 Relative contribution of transmission and ventilation to the overall energy losses of a building



According to Hacke (2009), the three selected behavioural changes even bear the largest energy reduction potential, stating that domestic energy demand is mostly influenced by temperature choice and manual ventilation behaviour. However, large bandwidths of what users perceive as comfortable room temperature or reasonable ventilation behaviour can be found. Figure 2 shows two examples of the effects of user relevant behaviour (see IWU, 2007). At the left side, there is the range of individual energy consumption data in non-retrofitted houses, and on the right of low-energy houses. Even though the average energy consumption in low-energy houses is significantly lower,

energy consumption can be as high as in an old or non-refurbished building due to individual preferences.

Figure 2 Specific Energy Consumption of semi-detached houses without and with energetic refurbishment



Source: IWU, 2007.

3.1 Assessment of the abatement potential of reducing space heating temperature

We first give an overview on how adequate heating behaviour is described in the literature and in various internet resources. Temperatures in the living spaces as well as in the sleeping rooms and in the kitchen are supposed to be 20°C on average (in the bathroom 24°C) (DIN EN 12831). When absent no longer than two days in winter, temperature should not be lowered beneath 15-16°C. If absent longer, temperatures should not be reduced to less than 12°C because of possible frost damages.

3.1.1 Abatement potential

Theoretical maximum emission reduction potential

Extensive research on the effects of reducing the space heating temperature inside the house suggests, that the emission reduction potential can be generally described by a rule of thumb. To lower the room temperature by 1°C leads to an energy saving of about 6% (Brunata-Metrona, 2011). The overall potential for lowering the room temperature is determined by comfort needs. A lowering of more than 2°C should not be assumed.

This potential is estimated based on heating degree days. Heating degree days are defined as the sum of differences between in- and outside temperature. The maximum emissions reduction potential of reducing space heating temperature can be estimated by transposing the below mentioned formula to the EU. Therefore for each country the heating days and the heating degree days are needed. With these values, the reduction potential per country can be calculated.

The reduction potential is then calculated as follows:

$$e = \frac{G - z \cdot \Delta t}{G}$$

With:

e relative energy reduction potential

G heating degree days

z heating days

Δt temperature difference

Table 3 shows the reduction potential for the EU's biggest countries. Heating days and heating degree days are average/representative values for the whole country.

Table 3 Reduction potential for the EU's biggest countries

	Heating days ⁵	Heating degree days ⁶	Reduction potential (1 °C)	Reduction potential (2 °C)
Austria	242	3,574	7%	14%
Belgium	275	2,872	10%	19%
Czech Republic	258	3,571	7%	14%
France	241	2,483	10%	19%
Germany	214	3,239	7%	13%
Great Britain	284	3,115	9%	18%
Greece	151	1,663	9%	18%
Hungary	233	2,922	8%	16%
Italy	194	1,971	10%	20%
Netherlands	276	2,902	10%	19%
Poland	258	3,616	7%	14%
Portugal	152	1,282	12%	24%
Romania	226	3,129	7%	14%
Spain	207	1,842	11%	22%
Sweden	292	5,444	5%	11%
EU-27	243	2,785	9%	18%

The magnitude of this reduction potential is supported by the other studies, e.g. Bohunovsky et al. (2010) derive a reduction potential of 16% for a 2 °C reduction with other accompanying measures.

The reduction potential is a relative value and therefore depends strongly on the development of the technically necessary energy demand for space heating in the residential sector. By now, the overall reduction potential for the year 2050 is about 27 Mt CO₂.

⁵ DWD: Weltklimadaten, Stand 2011.

⁶ Eurostat Data.



Table 4 Theoretical GHG mitigation potential

	2020	2030	2050
CO ₂ emissions for the housing domain	425 Mt CO ₂ ⁷	362 Mt CO ₂	299 Mt CO ₂
Theoretical maximum abatement potential (as % of total CO₂ emissions)			
Reduction by 1 °C	9%	9%	9%
Reduction by 2 °C	18%	18%	18%
Theoretical maximum abatement potential (as Mt CO₂)			
Reduction by 1 °C	38	33	27
Reduction by 2 °C	77	65	54

The potential decreases over time, for the projected overall emission of CO₂ declines until 2050 due to better insulation of houses and improved heating systems. The overall reduction potential is furthermore reduced by the non-behavioural constraints, which are described below.

Non-behavioural constraints to the implementation of the change

It can be assumed that the maximum technical mitigation potential of lowering the room temperature is limited by a considerable number of residential units, where the setting of the heating/radiators and thus the temperature cannot be adjusted (see IEE, 2007). Also passive houses, which are expected to have an increased share of the building stock, don't have this potential, for their response time on thermostat changes is much slower than for conventional buildings. An estimate of the amount of space heated surface where temperatures cannot be controlled has to be made.

Another essential constraint to lowering the room temperature is given by the personal needs of different groups of residents (IEE, 2007). In particular older people, as well as young children or people with special needs, e.g. due to medical reasons, prefer or even need to live in a warmer environment. In these cases, lowering the room temperatures cannot be suggested. Estimating the number of these cases as a limiting factor of the maximum emission reduction potential is however difficult. Demographical data of the EU citizens could be taken into consideration and categorised by age, leaving children and the elderly aside. But exceptions (for instance, older generations might be already used to save energy and have continued with this habit throughout their lives) will be impossible to identify. Furthermore, this is a non-linear effect, because one person with special needs will affect the energy consumption of a whole dwelling. Also people's behaviour varies quite a lot, but is observed to follow a normal distribution, so this effect is expected to level itself.

In this calculation example, the share of dwellings to be considered is the quotient of the number of dwellings with at least one inhabitant e.g. above 65 or e.g. below 5 years and the total number of dwellings.

Another limiting factor is that temperature reduction within buildings is only possible until a specific temperature while using a room; most experts refer to 15 or 16 °C (Approved Code of Practice (ACoP, 2007), referred to by London Hazards Centre (2011)). The overall heated space that is taken into consideration must thus be reduced by the residential space constantly heated to a minimum. If minimal room temperatures are not respected, high moisture rates and, as a consequence mould and fungus growth can occur. Such potential harm for the building substance as well as residents' health is to be identified as a non-quantifiable constraint.

⁷ PRIMES-GAINS EU-27 reference scenario 2010 (as e.g. described in European Commission (2011e): Roadmap for moving to a competitive low carbon economy in 2050, Impact Assessment, SEC(2011)288.



- The maximum realistic emission reduction potential is therefore the product of
- the relative reduction potential per dwelling;
 - the share of dwellings without the technical options to reduce the room temperature;
 - the share of dwellings with people with special needs concerning temperature levels;
 - the overall GHG emissions from space heating.

The second and the third value are time-variant variables. Nevertheless, for the assessment of the reduction potential the actual values of 2010 are used. The effect of an ageing population in some countries is therefore neglected. The following table gives an overview of the households with people with special needs in the EU countries. For the EU the share of households with these people is more than 35%.

Table 5 Share of households with young children and seniors (Eurostat, 2011)

	Children (0-5 years)	Seniors (>65 years)	Sum
Belgium	9%	25%	34%
Austria	8%	25%	34%
Bulgaria	11%	26%	37%
Cyprus	13%	22%	35%
Czech Republic	10%	24%	34%
Denmark	7%	24%	31%
Estonia	9%	26%	35%
Finland	7%	25%	32%
France	9%	26%	35%
Germany	7%	28%	35%
Greece	9%	26%	35%
Hungary	10%	25%	35%
Ireland	12%	21%	33%
Italy	9%	29%	38%
Latvia	10%	24%	34%
Lithuania	11%	26%	37%
Luxembourg	10%	20%	30%
Malta	11%	24%	35%
Netherlands	8%	23%	31%
Poland	11%	23%	34%
Portugal	11%	27%	37%
Romania	11%	24%	35%
Slovakia	11%	22%	33%
Slovenia	11%	24%	35%
Spain	10%	22%	32%
Sweden	7%	27%	34%
Switzerland	7%	25%	32%
United Kingdom	9%	26%	35%
EU-27	9%	26%	35%



For the technical options, no sound statistical data on the type of heating system is available. The share of district heating in Europe is 8,5%. Especially in eastern Europe, large flat buildings, which are often supplied with district heat, have centralised heating control systems. In addition, a certain percentage of buildings with other heating systems may not have a system for individual control of the room temperature. An assumption of 10% of dwellings without the technical options to control the room temperature seems reasonable.

Indirect effects

The reduction in the average energy use of households due to the lowering of room temperatures will also result in less energy use in the production phase of the energy carrier and hence potentially less GHG emissions.

Rebound effects

It is reasonable to assume the occurrence of a rebound effect deriving from the lowering of room temperatures and thus the saving of money for the residents. A usual behavioural pattern associated with rebound effects, is that the money saved due to energy saving will be invested in purchasing goods, especially electronic devices that in turn undo the saving by their electricity demand. Or that lowering the temperatures in the living room will, via the fact that less money has to be spent, lead to the decision to heat the bedrooms more which were formerly kept at lower temperatures. In the selected studies, no numbers of rebound effects were provided. They are thus too difficult to estimate, and hence cannot be further taken into account. Only studies could be identified, that deal with direct rebound effects in relation to the adoption of energy-efficient building technologies, fuel switching or decrease in prices for energy services (Haas and Biermayr, 2000; Hens et al., 2010; Sorrell, S., 2007; Sorrell et al., 2000). Most of those studies agree on a direct rebound effect of typically less than 30%. No study could be identified that investigated rebound effects as mentioned above, i.e. that derive from energy curtailment behaviour of residents, keeping all other factors (like building energy demand or existence of energy-efficient technologies) constant.

3.1.2 End-user costs

There are no direct expenditures related to the behavioural mitigation option of lowering the room temperatures. Neither capital nor operational costs are an obligatory prerequisite of behavioural change in this case. This means that the behaviour and its effects can certainly be facilitated by e.g. the purchase of setback thermostats (see next paragraph) or by isolating smaller window gaps by help of according material. However, with a controllable heating system, the behavioural change of manually lowering the temperature does not bear any further costs. What remains are the negative costs from the reduced energy consumption. Opportunity costs can at first sight not be quantified. Because of the one-shot characteristic and small possibility to assess the amounts spent, those costs can be ignored. As described in the project tender, the scope of the cost assessment excludes welfare costs. Since literature on this topic with regards to space heating energy reduction, and ventilation behaviour as well, is low or even non-existent, a quantification of welfare costs is not possible. A qualitative discussion shall however be provided. Reductions in room temperatures are resulting in comfort losses, hence in welfare losses. Given that the thermal comfort is considered very important for the majority of residents, those welfare costs can act as a main barrier to behavioural change, even if they can lead to considerable monetary savings.



3.1.3 Co-benefits

In the case of reduced room temperature within a reasonable scope (see description of behavioural change above), there are no positive or negative side-effects evident from an end-user perspective. As we have seen however in Figure 11, the individual perception of ideal room temperatures can vary enormously, and thus a negative approval of a certain temperature involves a reduction of personal comfort. On the contrary, should the saving behaviour be overdrawn, and temperature lowered to values beneath the suggested ones, it can result in health issues.

3.1.4 Conclusion: maximum realistic mitigation potential and net costs

The theoretical potential given in table has to be reduced due to the limitations described above. Therefore, in a conservative approach, only 60% of the theoretical potential can be assumed to be possibly realised.

Table 6 Maximum realistic GHG mitigation potential

	2020	2030	2050
Reduction of maximum abatement potential (as % of total CO ₂ emissions)			
People with special needs	35%	35%	35%
Technical constraints	10%	10%	10%
Realistic maximum abatement potential (as Mt CO ₂)			
Reduction by 1 °C	22	19	16
Reduction by 2 °C	45	38	32

3.2 Assessment of the abatement potential of optimising thermostat settings of heating

Thermostats control heating appliances in houses. A conventional thermostat regulates house heating at one temperature (for instance, in the winter, a thermostat setting of 20°C will activate the heating system when the house temperature drops below 20°C, or will shut the system off when the house air warms up past 20°C).

A setback thermostat gives the user the option of automatically ‘setting back’ the thermostat (reducing the set temperature) at night and also during the work day when the occupants have left the house. This can contribute to higher comfort levels of residents in the winter, profiting from the same energy savings of a lowered thermostat setting, while not having to wait for the house to heat up again.

Optimised thermostat settings can be characterised by leaving the temperature at the ideal levels described in Section 2.2, while choosing reasonable set back periods (e.g. 11 p.m.-6 a.m. during the night, and 9 a.m.-4 p.m. during the day, for working days) (Manning and Swinton, 2005).

3.2.1 Abatement potential

Theoretical maximum emission reduction potential

The theoretical maximum potential for emission reduction can be derived from studies which examine the influence of electronic thermostats, which allow case sensitive temperature control. Studies show, that a reduction of 10% of the overall consumption for space heating may be achieved. (Manning, 2005) This effect can only be achieved if the individual temperature in every room is adapted to the actual usage conditions. The variance of energy consumption in comparable houses supports the existence of such a potential. Nevertheless, this is a maximum value, not applicable to the average consumption, but to a dwelling with high specific consumption. If a normal distribution of the energy



consumption as shown in Figure 2 is assumed, the maximum impact must therefore be divided by two for the maximum reduction potential refers to the extreme values, not the average. Therefore a potential of 5% of the overall consumption seems realistic for optimal conditions.

Table 7 Theoretical GHG mitigation potential

	2020	2030	2050
CO ₂ emissions for the housing domain	425 Mt CO ₂	362 Mt CO ₂	299 Mt CO ₂
Theoretical maximum abatement potential (as % of total CO₂ emissions)			
Relative Potential	5%	5%	5%
Theoretical maximum abatement potential (as Mt CO₂)			
Absolute Potential	21	18	15

Non-behavioural constraints to the implementation of the change

The behavioural change is applicable for high-temperature radiator heating systems.

For heating systems, that do not possess modern radiator valves, the usage of thermostats is not possible. Old radiator valves must be exchanged for that purpose.

Also for passive houses without conventional heating, which are expected to increase over time, this option is not applicable.

There also are limitations for the use of programmable thermostats for homes with heat pumps, electric resistance heating, steam heat, and radiant floor heating (U.S. Department of Energy, 2011).

When a heat pump is in its heating mode, setting back its thermostat can cause the unit to operate inefficiently, thereby cancelling out any savings achieved by lowering the temperature setting. According to the U.S. Department's of Energy website (2011), some companies recently have begun selling specially designed programmable thermostats for heat pumps, which make setting back the thermostat cost effective. These thermostats typically use special algorithms to minimise the use of backup electric resistance heat systems.

Electric resistance systems, such as electric baseboard heating, require thermostats capable of directly controlling 120-volt or 240-volt circuits. According to the above mentioned U.S. data, only a few companies manufacture line-voltage programmable thermostats. This is however true for the U.S., the market situation in Europe needs to be assessed.

For steam heating and radiant floor heating systems, the problem is their slow response time: both types of systems may have a response time of several hours. This leads some people to suggest that setback is inappropriate for these systems. However, some manufacturers now offer thermostats that track the performance of your heating system to determine when to turn it on in order to achieve comfortable temperatures at your programmed time. Nevertheless this is no more a behavioural option, but a technical one.

The share of households without the ability to control the room temperature over time as described before has to be larger than the one for the first option. With increasing quality of the insulation, this share of buildings will furthermore be increased, because if the heating demand nears zero, no significant time variance of the temperature levels will occur.

The effect of people with special needs also influences this option. These people have much higher attendance rates at their dwellings and therefore a lower potential for reduction (comp. Section 3.1.1 for numbers).



Indirect effects

The mentioned indirect effects of behavioural change involving lowering the temperature can be cited here. Results will be the reduced energy use in the production phase of the energy, and hence potentially less GHG emissions. Furthermore, the production and merchandise of the thermostats requires certain amounts of energy input, which cannot be estimated in the framework of this project.

Rebound effects

For further reasoning on possible rebound deriving from room temperature reduction, please refer to Section 3.1.1.

3.2.2 End-user costs

Direct expenditures involved in the behavioural option in question, the use of (set-back) thermometers, is connected to the cost of purchasing and installing the thermometer (price for the item, travelling cost for shopping, etc.). Operational costs are assumed to be low, since a thermometer is usually not prone for abrasion and associated repairing costs.

3.2.3 Co-benefits

For further reasoning on possible side-effects deriving from room temperature reduction, please refer to Section 3.1.3.

3.2.4 Conclusion: maximum realistic mitigation potential and net costs

The maximum realistic mitigation potential highly depends on the possibilities to implement the technical measures to enable users to control their room temperature variant over time. For dwellings with conventional space heating systems, the potential can be fully used, but technical boundary conditions may limit the behavioural change.

The costs (better: benefits) from the energy saving are directly related to the decrease of energy consumption and can therefore not be assessed.

Table 8 Maximum realistic GHG mitigation potential of optimising thermostat settings

	2020	2030	2050
Reduction of maximum abatement potential (as % of total CO ₂ emissions)			
People with special needs	35%	35%	35%
Technical constraints	20%	15%	10%
Realistic potential	52%	55%	59%
Realistic maximum abatement potential (as Mt CO ₂)			
Absolute Potential	11	10	9

3.3 Assessment of the abatement potential of optimising ventilation behaviour

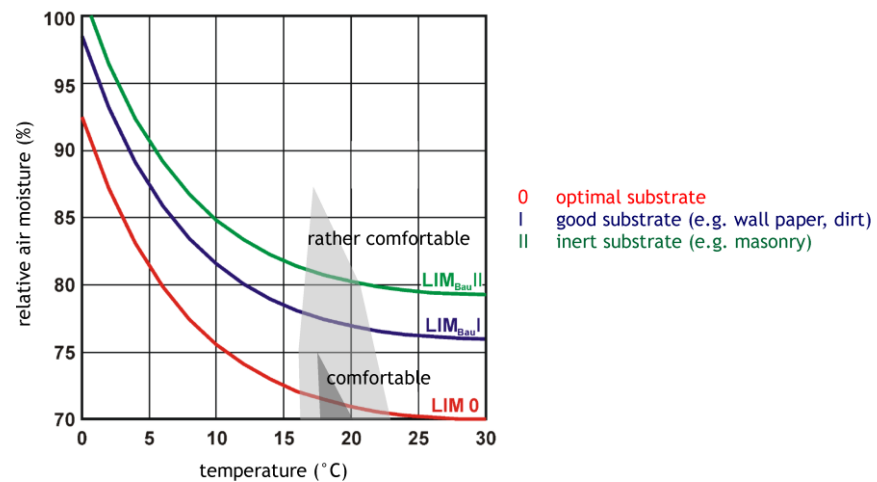
As many sources suggest, it is important that, in order to air an entire living space, residents apply a short-time full ventilation, with windows wide open. A medium or long-term intermittent ventilation with windows only partly open will provoke direct energy losses, as well as indirect energy losses due to temperature losses in walls which in turn provokes higher energy consumption while raising temperatures again to the former level. Depending on the season, it is suggested to ventilate the entire apartment, including opening all in-between doors, up to five times for up to seven minutes. If opposite windows are opened leading to maximum ventilation, a duration of 1.5 minutes might be sufficient. On the contrary, a total change of air would



take one hour with an only partly open window. While used warm air is lost due to transmissions, the radiator valve needs to be closed. This behavioural change has high interdependencies with the other two options. Temperature and humidity are no independent variables in building physics. Low room temperature combined with high moisture will lead to fungus. This is to be avoided in any case, for the benefits of energy saving will be thwarted by the negative impact of fungus on health and the building structure.

Figure 3 shows the interdependency of room temperature and moisture in buildings.

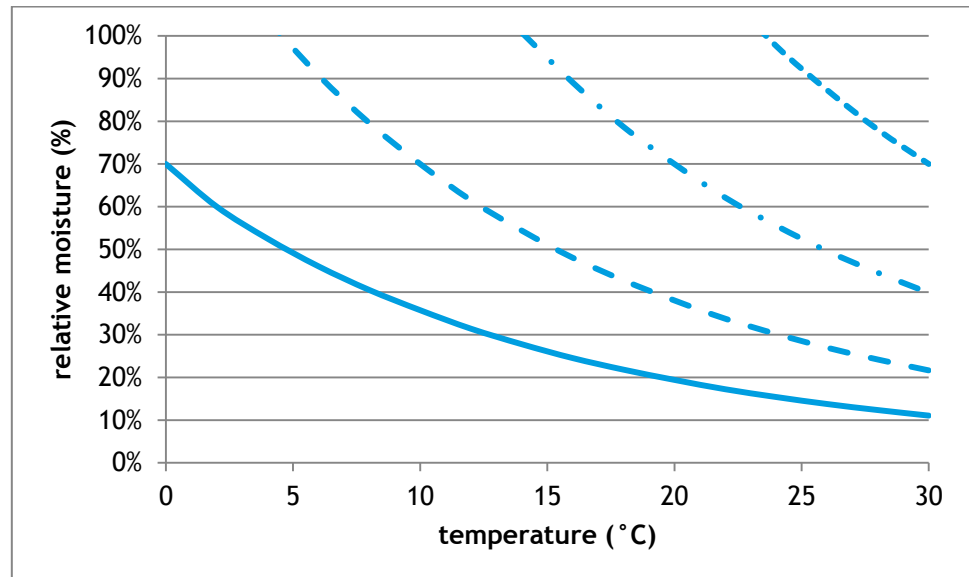
Figure 3 Interdependency of temperature and moisture for the growth of fungus (Zillig 2011, modified)



For the good substrates for fungus, which can be found in nearly any building, the maximum level of acceptable air moisture is between 75 and 80%. Also shown in the diagram is the comfort area, which defines acceptable ratios of moisture and temperature. Some of the acceptable ratios are endangered of fungus growth.

It must be considered, that the relative moisture is highly dependant of the temperature as shown in the following graph. A temperature decrease of 2 °C in a comfortable temperature area leads to an increase of the relative air moisture by 12%, for example a room with 20 °C and a relative air moisture 70% which has the same absolute air moisture as a room with 18 °C and a relative air moisture of nearly 80%

Figure 4 Isolines of constant absolute air moisture



The interaction between room temperature and moisture is complex and has to be handled with care. Detailed Information is therefore crucial to face the effects of ventilation behaviour. Non-informational instruments will not suffice and will lead to negative side-effects.

3.3.1 Abatement potential

Theoretical maximum emission reduction potential

The influence of ventilation behaviour on the overall energy consumption and thus the greenhouse gas emissions is quite high. The better the insulation of a building, the higher is the share of ventilation losses on the overall energy demand. A low standard house has ventilation losses of 25%, a low energy standard or passive house with conventional ventilation up to 55%. A building with recuperative ventilation has ventilation losses of only 10 (HMULV, 2011). Only this share of the energy consumption can be addressed by a behavioural change of ventilation behaviour. Studies suggest that the ventilation losses may double if windows are left partly open over the day. The maximum losses (e_{\max}) are twice the minimum losses (e_{\min}):

$$e_{\max} = 2 \cdot e_{\min}$$

This behaviour is not unusual, so the actual ventilation losses include this potential. If we assume a normal distribution of the user behaviour between completely appropriate and inappropriate behaviour, the average user will have ventilation losses (e_{average}), which are an average of the maximum losses and the minimum losses:

$$e_{\text{average}} = \frac{e_{\max} + e_{\min}}{2} = \frac{3}{2} e_{\min}$$

$$e_{\min} = \frac{2}{3} e_{\text{average}}$$

The reduction potential for the average user is therefore the difference between the average and the minimum ventilation losses:

$$\Delta e_{\text{average}} = e_{\text{average}} - e_{\min} = \frac{1}{3} e_{\text{average}}$$

Table 9 shows the theoretical maximum emission reduction potential. In the first data row, the specific energy demand per dwelling according to the PRIMES projection is given. In the second row, the ventilation losses are calculated. It is assumed that the building stock of 1990 consisted mainly of low standard houses with a ventilation loss of 25%. The ventilation losses are not highly affected by insulation measures. Therefore they are assumed to be constant over time, basing on the level of 1990. The other losses (radiation and transmission losses) are calculated as the difference between the energy demand per dwelling from the PRIMES reference and the assumed ventilation losses. They decline over time with the on-going renovation of the building stock.

Table 9 Theoretical GHG reduction potential

	1990	2000	2020	2030	2050
CO ₂ emissions for the housing domain			425 Mt CO ₂	362 Mt CO ₂	299 Mt CO ₂
Specific Energy demand (as ktoe per dwelling)					
Energy demand per dwelling (from PRIMES reference)	15.698	15.103	13.166	11.355	9.430
Ventilation losses per dwelling (e_{average}) (25% of losses in 1990, assumed constant)	3.925	3.925	3.925	3.925	3.925
Other losses per dwelling	11.774	11.179	9.241	7.431	5.506
Share of ventilation losses	25%	26%	30%	35%	42%
Reduction potential of ventilation losses			33%	33%	33%
Reduction potential of total losses			10%	12%	14%
Theoretical maximum abatement potential (as Mt CO₂)					
Improved ventilation			43	42	42

Non-behavioural constraints to the implementation of the change

It is possible, albeit unlikely, that residents in several kinds of buildings are not able to open the windows. This can rather be found in hotel rooms or working places. Prior focus here is given to private households, since these have the largest potential for heating energy savings.

Indirect effects

Appropriate ventilation behaviour will contribute to energy savings, which in turn will lead to reduced energy use in the production phase of the energy, and hence potentially less GHG emissions.

Rebound effects

For further reasoning on possible rebound deriving from room temperature reduction, please refer to Section 4.2.1

3.3.2 End-user costs

No capital costs can be associated with ventilation behaviour. It could be thought of assessing operational costs, e.g. this could be the time an employee spends on opening and closing the windows which will create a loss of work productivity. Nevertheless none of the studies quantified such effects.



3.3.3 Co-benefits/side-effects

The positive co-benefits from optimised ventilation behaviour, as described above, can reach or even excel the significance of its energy saving features from an end-user perspective. Significant for keeping the building stock's quality, regular ventilation prevents high moisture rates and possible growth of mould. It therefore makes a contribution to personal hygiene and health. There is also to mention the higher amount of oxygen, being beneficial for residents' health, as well as the perceived freshness and scent of the air, cleaned from any odours.

Negative side-effects for individual comfort by the obligation to house cleaning, could be those that opening the windows will provoke higher amounts of dust and other air particles in the dwelling.

3.3.4 Conclusion: maximum realistic mitigation potential and net costs

The maximum realistic mitigation potential highly depends on the quality of the building stock. For the future development, more efficient houses will penetrate the market and therefore increase the (relative) effect of ventilation on the overall energy consumption. Nevertheless, if technically advanced systems for automated ventilation become more and more common, the effect of individual behaviour will decrease significantly.

The theoretical reduction potential of the space heating energy demand depends on the composition of the building stock. If this is not included in the model itself, it must be reflected by an adaption of the relative reduction potential. This reduction mainly depends on the projected diffusion of ventilation technologies in the housing sector.

The baseline projection includes the effects of the energy performance buildings directive, which includes zero energy standards for future new buildings. So the effect of passive houses for new buildings is covered by the baseline projection.

For renovation, the situation is different. For now and the forthcoming years the effect of the diffusion of passive house technologies in renovated buildings may be neglected, so the full theoretical reduction potential may be used for this option on short and mid-term assumptions. For 2050, the diffusion of ventilation technologies is unknown, but not to be neglected. If we assume a 1% renovation rate as well as a 1% reconstruction rate, until 2050 nearly the whole building stock will be renovated or rebuilt. Taking the long-term targets serious, large parts of the building stock will have reached passive house standard by then, many of them incorporating technical ventilation.

The reduction potential of this behavioural option may therefore decrease significantly. Nevertheless, this is finally a positive effect, for the ventilation losses, from which this reduction potential arises, are reduced to a minimum by technical measures. Thus, the reduction potential will have been minimized because there may be nothing left to reduce. Technical improvements, fostered by an ambitious long term strategy may make the behavioural option obsolete.

Table 10 Maximum realistic GHG reduction potential of optimising ventilation

	2020	2030	2050
Realistic maximum abatement potential (as Mt CO₂) (without consideration of technical advancement)			
Absolute Potential	43	42	42
Reduction of maximum abatement potential (as % of total CO₂ emissions)			
Share of passive houses with recuperative ventilation	Not relevant	Not relevant	Relevant
Realistic maximum abatement potential (as Mt CO₂) (with consideration of technical advancement)			
Absolute Potential	43	42	<<42





4 Barriers, consumer segments and policy instruments

4.1 Introduction

In Section 2.4, we selected three relevant behavioural mitigation options aiming at a reduction of energy consumption and thus at climate change mitigation:

- reducing space heating temperature;
- optimising thermostat settings;
- optimising ventilation behaviour.

Those options pertain to the housing sector, and in particular to the reduction of space heating energy consumption (not electricity consumption in appliances).

Heating and cooling of dwellings and water heating are the single largest contributors to residential energy use, representing as much as 80% of total residential energy demand in OECD member countries (OECD, 2007). According to IER (2000), space heating alone accounts for 70% of total residential energy demand in most countries - corresponding to a 15-22% share of total final energy demand.

Furthermore, for research purposes it is important to establish a definition of the energy-related behaviour that we focus on, which will be described below. The assessment is based on existing literature, and there are manifold sources in the social science literature that deal with the determinants and the barriers of domestic energy saving. Often however, effects of empirical studies are not communicated for single behavioural options, but for a mix of comparable environmental behaviours. For those reasons, the structure of this chapter will be as follows:

A definition of the analysed behaviour will be followed by a short overview of theoretical reflections in the field. Some notes on the development of the research paradigm over time will serve as an introduction to the collection of studies comprising the barriers of domestic energy saving behaviours. In a first step, we will give an overview of the general findings of curtailment behaviour in housing; after that, a detailed classification of the barriers explicitly applying to the three specific behavioural options will be provided, wherever possible.

For the general domestic curtailment options, as well as for each selected option of behavioural change wherever possible, we will discuss their potential diffusion path and speed and the interactions with relevant barriers.

Definition of the energy saving behaviour at hand

From an environment-psychological point of view, two categories of domestic energy mitigating behaviour must be distinguished. The first is 'curtailment behavior', with examples in the residential sector like reducing room temperatures, drying clothes without using a tumble dryer, or turning off lights in unused rooms. In order to carry out this behaviour, no changes of the building's interior or exterior are necessary, neither does it require any (or significant) financial investments. However, daily routines and living habits, or what we may call lifestyles, have to be altered, and residents might happen to perceive this as a reduction of comfort. To sum up, those actions are steered by habits and routines, after persons have internalised them.



The other behavioural category related to domestic energy consumption is named ‘efficiency behaviour’, which deals with behavioural decisions related to the purchase of technologies and appliances that increase energy efficiency or the use of renewable energies in buildings. Those measures normally require substantial investments and often even structurally engineered alterations of the building. Those so-called ‘one-shot’-actions do not involve comfort losses; on the contrary, they usually provide higher comfort levels in the long run (Frey et al., 1987). Typical measures include insulation of roofs or facades, purchase of energy-efficient electric appliances, installation of solar thermal heating systems or the replacement of old windows. It is evident that for this kind of actions, conscious and deliberate reflexions act as prerequisite. Those decisions can often take a rather long time and are perceived as complex. Also, they require consensus among the household members, which adds to the difficulty of reaching a common decision (Kirchler, 1995). There are no routines in taking a decision on expensive, long-lived products.

Also in this chapter on behavioural change in the housing sector, a discrimination of the above mentioned behavioural categories is crucial for further research, given that customised practices and routines on the one hand, and one-shot actions in terms of strategic investment decisions on the other hand must obviously be determined by different psychological, socio-demographical and structural factors (Frey et al., 1987). These factors or barriers, as strong influential determinants, must be taken into consideration in the planning of interventions (e.g. policy instruments like campaigns). Table 11 categorises the above-mentioned behaviours by dividing them at the same time into measures related to consumption of electrical energy and consumption of heating energy (in this scheme, focus lies on district heating, oil or gas as heating energy source). The main focus on the behaviour analysed in this chapter is highlighted in grey. Thus, studies analysing efficiency behaviour were completely excluded (e.g. Antes et al., 2010; Faiers et al., 2006; for a literature overview in the domain of space heating see Gigli, 2008).

Table 11 Behavioural categories and domains of domestic energy consumption

		Behavioural category	
		Curtailment behaviour	Efficiency behaviour
Energy consumption domain	Space heating and domestic hot water	e.g. lowering room temperature; thermostat set-back	e.g. new heating system, insulation
	Electricity	e.g. turning off lights in unused rooms; reducing stand-by	e.g. purchase of energy-efficient fridges

Several empirical studies in the field of energy consumption behaviour are theory based, and it is not uncommon for them to be based on the Theory of Planned Behaviour (TPB) by Ajzen (1991; 2006), that acts as a framework for the categorisation of barriers (see Section 4.1.1).



4.1.1 Barriers of domestic energy saving behaviour: Reducing space heating temperature, optimising thermostat settings and optimising ventilation behaviour

As mentioned above, a number of studies based on a socio-ecological research paradigm have dealt with the barriers and determinants of domestic energy saving. An overview of barriers and influential factors will be provided, assuming that the absence of success factors can in some cases be interpreted as a barrier. A categorisation of barriers serves then to identify common patterns and characteristics for the various behavioural mitigation options. The scheme that was proposed earlier matched the categorisation in scientific reports to a great extent and therefore will be kept here. Effort has been made to rank the compendium of barriers, or rather determinants, in sequence of their relative impact on people's resistance to change behaviour, under each category. Since no study at hand evaluated the barriers with regards to their importance, this ranking is based on a qualitative understanding of conclusions in the literature. The studies that empirically accounted for the impact of the following factors will be cited.

Barrier category	Examples	Factor in Theory of Planned Behaviour
Individual (internal) barriers		
Psychological barriers	– No environmental concern	Attitude toward behavioural change
	– Emotions (e.g. health-related)	
	– No interest in energy-related topics	
	– Political attitudes	
	– Risk-assessment: no threat perceived	Subjective norm
Knowledge-based barriers	– Attribution of responsibility to others	Perceived behavioural control
	– Low self-efficacy	
	– Low behavioural control	
	– Lack of adequate information	Attitude toward behavioural change
	– Overestimation of own energy savings compared to others	
Unconscious behaviour	– Limited knowledge of consumers on their own space heating costs	Perceived behavioural control
	– Believe that no significant savings will occur	
	– Strong habits and routines (e.g. no habit to turn down heating)	No planned behaviour
Demographic factors	– Low income	Attitude toward behavioural change
	– Younger age	Subjective norm
	– Gender differences	Perceived behavioural control



Barrier category	Examples	Factor in Theory of Planned Behaviour
Societal (external) barriers		
Structural and physical barriers	– No possibility to adjust room temperature, install thermostat, open the windows	Perceived behavioural control
Cultural barriers	– Comfort is a priority – No social norms towards energy saving; traditions – No social ‘competition’ or comparison – Social image not related to energy saving	Subjective norm
Economic barriers	– Low or decreasing energy prices – Lack of incentives	Attitude toward behavioural change Perceived behavioural control
Institutional barriers	– Lack of direct consumption feedback – Heating costs included in monthly rent – Incredibility of experts and authorities – Political barriers	Perceived behavioural control

Individual (internal) barriers

Psychological factors

Concerning cognitive and psychological barriers hindering curtailment behaviour in housing, we found the following variables to be of relevance.

Information tends to result in higher **knowledge** levels, and as many studies indicate, knowledge seems to be one of the most important factors influencing the uptake of energy saving actions. As a first barrier, information might not reach the target groups because it is too general (Ose, 2010) or too complex. Knowledge is mostly referred to as the knowledge about the amount of the own energy consumption or energy prices and on how to save energy, and which are the options in the household with the highest saving impact. Also, some studies established correlations between a high knowledge about the current and future energy and climatic situation or residents’ knowledge about their own position of energy use compared to that of other households (Brandon and Lewis, 1999; Geller, 1981; Hutton et al., 1986; Staats et al., 1996; Seligman, 1979; Winett et al., 1979; Wortmann, 1994; BMVBS, 2007). Specifically for the three behavioural options in regard, Ose (2010) observed in his samples a lack of knowledge regarding efficient airing and healthy indoor temperatures (p. 31). When households believe that their knowledge on the above mentioned facts is reasonably high, even though it might not be, conservation behaviour can be inhibited (Öko-Institut, 2000). Borsutzky and Nöldner (1989) and BMVBS (2007) found out that residents underestimate energy consumption in the domain of space heating, whereas they overestimated energy consumption in other consumption domains, like electricity. They also tend to overestimate their own energy savings compared to other households. For instance, almost 44% of private households in a study by Borsutzky and Nöldner (1989) believed that they were consuming less energy than comparable households. Only little necessity for behavioural change might therefore be perceived. This is similar to the concept of



attribution of responsibility, which means that private households do not attribute responsibility to themselves, but hold other actors, like the government, science or similar others responsible for acting upon climate change or an energy crisis (Barr, 2005; Sauerborn, 2005; Seligman, 1979; Wortmann, 1994). Van der Pligt (1985) interprets this as ‘false-consensus effect’, i.e. even if residents might know about their high energy consumption, the fact that they think that others consume even more acts as a barrier to reduced consumption.

Environmental attitudes and concerns, values towards energy conservation as well as moral beliefs play a major role in forming intentions, and as a consequence for energy saving domestic behaviour. Many studies find high correlates between these attitudes and energy conservation activities (Becker et al., 1981; BMU, 2008; Brandon and Lewis, 1999; Heberlein and Warriner, 1983; Geller, 1981; Midden et al., 1983).

Even though personal **interest in energy-related** topics, innovation, technology and science plays a rather crucial role in explaining energy efficiency and investment behaviour, it also serves to explain curtailment behaviour. People with a technical understanding and also relevant practical skills tend to be more conscious about their energy consumption and therefore tend to make energy savings (Wortmann, 1994).

Many people believe that it will be difficult to make a difference, e.g. concerning the global climate crisis, as a single actor or household. In consequence, their perceived **self-efficacy** is low. They thus do not think it is worth the effort to save energy at home (Hacke, 2009; Ose, 2010; Wortmann, 1994). Related to this factor is the perceived **behavioural control** (see above Ajzen, 2006): as a prerequisite of conservational behaviour, households must have the perception of having the ability to behave in a certain way (Sauerborn, 2005; Wortmann, 1994).

Furthermore, **emotions** act as moderators of behavioural decisions: negative feelings like fear, concern, anger or guilt in relation to the energy situation could be observed as positively correlated to the uptake of energy saving behaviour (BC Hydro, 2007; Borsutzky and Nöldner, 1989). This is related to the psychological variable of **risk assessment**, i.e. the perceived threat of environment, climate, livelihood etc. (Barr et al., 2005; Curtis et al., 1984; Midden and Ritsema, 1983; Samuelson and Biek, 1991; Sardianou, 2007). But not only threat for the environment can be perceived, but also a potential threat for one’s own **health** (BC Hydro, 2007; Seligman et al., 1979): this is a barrier of turning down the space heating to lower degrees.

The empirical study of Wortmann (1994) found a correlation between energy saving and **political attitudes** in Germany, in the sense that people voting for conservative parties and with preferences for nuclear energy were less committed to domestic energy savings.

Unconscious behaviour

Habits and routines certainly play a major role as a barrier in domestic energy conservation (Barr et al. 2005; Midden and Ritsema, 1983; Samuelson and Biek, 1991; Seligman et al., 1979; Verhallen and Van Raaij, 1981). Residents must get conscious about these repeatedly demonstrated and little reflected daily usage behaviour, in order to be able to change them. Also, habits need to be turned into more sustainable behavioural patterns. Ose (2010) refers to a study with several consumer focus groups and expert interviews in six European countries. He concludes on habits, that they are hard to change because of the effort that energy saving demands. According to his study, the habits of



switching off and turning down are not well established over all these countries (p. 31).

Demographic factors

The research findings on age as a determinant of energy saving actions are not free from ambiguity. Quite a few studies suggest that the residents behaving in a more sustainable way were older (Barr et al., 2005; Brandon and Lewis, 1999; Painter et al., 1983); others point out medium age cohorts that were most interested in energy savings (Borsutzky and Nöldner, 1989; Curtis et al., 1984; Hirst, E. and Goeltz, R. (1982). Young age was found to be in favor of curtailment behaviour in Sardanou (2007) and Wortmann (1994).

A **low income** seems to be correlated with cutting energy consumption and thus financial spending at the household level (Öko-Institut, 2000; Dillmann et al., 1983).

Öko-Institut (2002) also found that **gender** can matter: women were more conscious towards energy mitigation behaviour on the household level.

There are studies that demonstrated acceptance of energy saving options to be more pronounced in higher **education** groups (Barr et al., 2005; Olsen, 1983), whereas results from Poortinga (2003) indicate that acceptance for curtailment behaviour was significantly higher in the lower education groups. People with higher education on the other hand seem to be more willing to invest in energy efficiency appliances.

Societal (external) barriers

Structural and physical barriers

As a matter of infrastructural barriers, no energy saving behaviour can occur when the behaviour is hindered to take place. For instance, there might be **no possibility to regulate** heating temperatures. The same is true for the possibility to install a thermostat or opening of the windows. Please refer also to the passages on non-behavioural constraints of the three behavioural options in Chapter 4.

Cultural and social barriers

The need for **comfort** is widely spread in studies on the barriers of domestic energy mitigation. As Ose (2010) points out, “whilst in other areas of domestic energy consumption participants maintained a ‘cost-benefit’ approach, the same did not apply for heating. Here, comfort and warmth took precedence over financial considerations.” (p. 32). The author interprets considerations regarding reduction of personal comfort and the habit of maintaining high indoor temperatures as a cultural/social normative barrier. Personal gain, according to him, is valued as more important than dealing with sustainability problems. The more difficult the action of domestic energy saving is perceived, the more it appears as a barrier (Wortmann, 1994). Regarding the action of lowering indoor temperatures, in the empirical sample in Lindén (2006), 62% of 600 Swedish households refused to do so. Also, 60% of the subjects did not air on a daily level during the winter season. Those findings can be interpreted as fallen victim to the need for comfort.

Social norms also play a crucial role towards daily energy savings. The fact, that other people who are perceived as very important to an individual (e.g. family members, friends, colleagues, teachers, etc.) put pressure in the sense of social norms toward energy saving behaviour. They express expectations and motivate actions (Barr et al., 2005; Black et al., 1985; Constanzo et al., 1986; Leonard-Barton, 1981; Midden und Ritsema, 1983; Wortmann, 1994).



Diverging family interests and lack of consensus in particular were found to be a barrier to the adoption of curtailment behaviour (Öko-Institut, 2000).

In this vein, the influence of a certain competition, a so-called **social comparison** can be mentioned (also similar to the concept of responsibility, see above). As Wortmann (1994) points out, when the own energy consumption is perceived as too disadvantageous compared to others, i.e. as much higher than the average, households felt motivated to reduce this gap.

In several cases, attempts to establish a more positive **social image** could be related to energy saving at home (Barr et al., 2005; Gram-Hanssen et al., 2007; Sadalla and Krull, 1995; Wortmann, 1994). On the other hand, Barr et al. (2005) equally pointed out, that non-energy savers labelled energy savers with an 'eccentric image', which might in turn mitigate positive effects.

Economic barriers

Besides the fact that low income groups tend to save more domestic energy, it seems logic to assume that financial considerations and the anticipation of financial savings act as a major success factor for energy reductions. With **decreasing energy prices**, energy saving becomes less attractive (Ose, 2010). If residents believe that there is a too small financial impact, and **no significant monetary savings** will occur, they will often choose not to become active (BC Hydro, 2007; Wortmann, 1994).

Some energy saving programmes or campaigns work with incentives, often of financial nature, to motivate saving actions. The lack of **incentives** was found as a barrier for household energy conservation in the study of Wortmann (1994).

Institutional barriers

Given that ESCOs provide feedback on space heating consumption in many cases only after a rather large time period, e.g. once a year, or that a lump sum is added to the monthly rent, there is a **lack of direct consumption feedback** for residents. This fact acts as a major barrier towards energy conservation, given that a high number of studies found positive correlations between more adjusted feedback and savings of household energy (Brandon and Lewis, 1999; Lindén, 2006; McCalley and Midden, 2002; Seligman and Darley, 1977).

Another problem of saving energy is that some **tenants** are not in charge of paying for energy, because the heating costs might be already included in the monthly rent. For instance in Germany, state welfare recipients must pay for their own electricity consumption, but not for space heating (mainly fossil fuels), the latter being provided by the local municipality. There are some restrictions however, but it has not been evaluated if a wide motivation to save heating energy exists within this target group.

A general observation that acts upon the uptake of saving behaviour is disenchantment with politics and in this vein incredulity of experts and authorities, that aim to give information and motivate behavioural choices (Gifford, 2011). Ose (2010) also mentions in his study that residential energy conservations is facing **political barriers** as well, given that institutions might be overstrained with the coordination of multiple initiatives.



4.1.2 Consumer segments and diffusion patterns

Öko-Institut (2000) found in their empirical study in Germany different consumer segments, stating that they differ in the way they prefer to obtain information. For employed couples and single persons, it seemed in to be of most importance that information is provided to them in a convenient and handy way. In general, however, they already feel very well informed. It is argued, that this social group has a comparatively high income, therefore a modern home equipped with various appliances, and is often in transit. This group's interest in new technologies is rather high. Traditional values like sufficiency and parsimony are below average compared to the German society. Furthermore the authors argue, that this consumer segment is unlikely to be motivated with traditional energy saving appeals or programmes, being not modern and innovative enough.

Further results to preferences depending on income are those of Stern and Gardner, who already 1981 argued that households with higher incomes are keener on investing in technologies, rather than curtailing their daily energy use behaviour. This result is confirmed by Clinch and Healy (2000), Poortinga et al. (2003) and Schipper and Hawk (1991). In this vein, Scott (1997) reported that Irish households with low incomes owned significantly less energy-efficient household and building appliances.

Furthermore, empirical results demonstrate that on the average, women seem to be more energy conscious than men, which leads to the conclusion that policy instruments should take this fact into consideration as well (Öko-Institut, 2000).

The interaction of age and financial resources is interesting in the way, that the elder generation in Germany with comparatively low income, shows lower information levels but at the same time a high interest to realise energy saving possibilities. Youth and adolescents tend to demonstrate lower knowledge levels despite the fact that they show an over average interest in climate change mitigation. Along with these results, Öko-Institut (2000) equally found behavioural preferences depending on age: the younger cohort preferred curtailment behaviours, while the older cohort were more in favour of purchasing energy saving bulbs or energy-efficient appliances.

The diffusion patterns of behavioural change options depend heavily on the type of barriers involved. Due to lack of literature, we need to make assumptions here and to regard the three behaviours in question as a bundle. Tackling the mentioned psychological or cultural/social barriers will take more time than removing infrastructural, economic or institutional barriers. Individual attitudes and beliefs as well as social norms are rather consistent over time, and they ask for long-term interventions to be changed. A lack of infrastructure or high investment costs, on the other hand, could be changed comparatively quickly: it would be of outmost importance, that more adequate and more frequent feedback on space heating consumption is provided to consumers (e.g. by smart-metering, see below). This increases the level of knowledge, and thus acts as a facilitator to behavioural change. Also financial or non-financial incentives can be provided in initiatives, and when combined with educational measures they might tend to have rather fast effects.

Inducing perceived personal self efficacy and putting societal pressure and social norms towards the adoption of responsibility, can decrease high demands for comfort. It is hard to tackle those variables with policy instruments, but even if it takes time, constantly informing different target groups on energy saving and inducing these norms have the potential to be



successful, as was evaluated over various programmes and initiatives (Abrahamse et al., 2005; Dwyer et al., 1993; see also Steg and Vlek, 2009).

4.1.3 Conclusion

When considering energy saving behaviour on the household level, a distinction of curtailment and efficiency behaviours must be made, the latter addressing investments in usually high-cost efficiency technologies in buildings. The focus of the report at hand lies on curtailment behaviour, which is driven by daily habits and routines and manifests itself as part of people's lifestyles (e.g. turning of the lights or the heating in unused rooms). A further distinction to understand barriers of the three behaviours in consideration (reducing space heating temperature; optimising thermostat settings; optimising ventilation behaviour) is to focus on heating energy provided mostly by fossil fuels or district heating on the one hand, and energy consumption through the use of electrical appliances on the other hand.

A categorisation of barriers according to a given framework was helpful for identifying common patterns and characteristics for the various behavioural mitigation options. To the most important barriers towards residential energy saving belong limited cognition, as lack of knowledge and awareness about one's own energy consumption. Furthermore, hindering factors can be worldviews that tend to preclude pro-environmental attitudes, comparisons with key other people (that usually act as a driver) or the attribution of responsibility to others, sunk energy costs, plugged-in behavioural routines and the lack of direct energy consumption feedback. Those barriers are usually strongly correlated to some demographic factors, e.g. low income and education or gender differences.

It can be suggested that for several patterns (e.g. particular behavioural routines of different societal groups), specific policy instruments will be helpful; whereas for common patterns that were found to be existing among the public (e.g. lack of knowledge, behavioural concern, social norms etc.) more general policy instruments may be preferred. As for diffusion patterns, governmental efforts are seen as a first step to act upon people's resistance to change by means of different communication and awareness rising instruments. Packages of policies, including instruments like e.g. financial incentives or provision of consumer feedback, seem to be appropriate to tackle barriers towards household heating energy reduction.

4.2 Policy instruments in housing

In this section we follow an integrated approach for the exploration and discussion of policy instruments. The three behavioural options at hand are interdependent in the sense, that they aid one another in order to reduce household heat energy consumption. Policy instruments are thus not identified per behavioural mitigation option, but for the combination of behaviours aiming at reducing thermal energy consumption at home. Table 12 shows an overview of possible policy instruments that can address the before mentioned behaviour.

Table 12 Overview of policy instruments in housing with examples

Policy category	Examples
Regulative instruments	Mandatory heating energy billing at frequent intervals More informative heating energy billing Mandatory energy performance certificates with real display orientation Obligation to include information in formal education
Economic instruments	Higher energy prices Taxation of high energy consumption Subsidies e.g. on purchase of smart-metering equipment or set-back thermometers Incentives for energy-efficient, adjustable heating infrastructure
Communication	Information campaigns (large scale; demonstration projects; informal advice networks; community progr.) Communicate best practices Communicate the direct link between GHG reduction and space heating consumption Creating ICT-based energy efficiency evaluation tools
Direct governmental expenditures	Public investments in infrastructure, like smart-meters
Procedural instruments	Voluntary agreements with companies, schools, etc. Voluntary contracting agreements with ESCO's

The housing sector in Europe is addressed by a wide variety of policy instruments, which mainly promote technical improvements of existing buildings or adequate technical design of new buildings. Nevertheless there are some aspects of actual legislation, which promote change of user behaviour. Wherever possible, the following analysis will provide an evaluation of the different instruments' effectiveness (pertaining to changing of behaviour and the reduction of GHG emissions). Possible side-effects are mentioned where appropriate. As for the cost-effectiveness, the aim to provide concrete numbers could hardly be fulfilled due to the lack of analyses for these very behavioural options.

Regulative Instruments

On a European level, the directive on the energy performance of buildings (EPBD), (2002/91/EC and its 2010 recast directive 2010/31/EU) requires energy performance certificates for buildings. These have been implemented gradually in the EU member states. The energy performance certificates mainly aim at investment decisions, e.g. for retrofitting, and should enable residents to include energetic aspects in their decision process. More efficient are even Display Energy Certificates (DECs), as they are used for instance in Great Britain in public buildings, and also in Germany, because they are based upon the actual energy usage of a building and thus increase transparency about the energy efficiency of buildings. Nevertheless, by providing information about the energetic performance of a building, a change in user behaviour is also aimed at. This is especially true for the DECs, where the actual energy use of the inhabitants is displayed. The impact of energy performance certificates so far still tends to be low (Amecke, 2011), which seems to be due to a lack of the instrument's spread and usage. This could be explained due to side-effects, as experts refer to the observation that possible tenants, if aware of their rights, are in reality often hesitant to demand the reading the certificates from the owners, especially in areas where the housing situation is tough. However, CIP (2011) states that even though energy performance certificates are not very effective, at least in Germany, they are



trusted more than other forms of information and could be more effective once they become fully mandatory. This can be indicative for the need of inclusion of regulative instruments into policy mixes.

Therefore the combination with other instruments, such as detailed billing or smart-metering can be helpful to provide users with sound information on their individual behaviour, that way enabling them to improve it. By using in-home energy displays, which communicate real-time information to consumers, awareness of energy efficiency benefits can rise if consumers are educated about how to use this information. UNEP (2007) refers to results of on average 10% of electricity saving by applying detailed billing and disclosure programmes (see Figure 5).

Figure 5 Summary table for detailed billing and disclosure programmes

Emission reduction examples	Cost-effectiveness examples	Barriers	Remedies	Advantages	Factors for success
Cal: 6.7% energy use reduction UK: 10.4 ktCO ₂ per year Br: 6.5-12.2 MtCO ₂ /yr with labelling	Br: -66\$/tCO ₂ UK: 8\$/tCO ₂ (for all programs of Energy Trust)	Too little correspondence between consumers and message	Better research on consumers	Can reinforce long-term effect of other measures	- Deliver credible and understandable message - Adaptation to audience

Source: UNEP, 2007 (p. 45).

Especially the installation of smart meters, which is mandatory for electricity, gas and district heating, due to the 'Energy Services Directive' or ESD (EU Directive 2006/32/EC on Energy End Use Efficiency and Energy Services), has a large potential for changing user behaviour by providing detailed consumption feedback. Nevertheless, momentarily research on smart-metering mainly focuses on electric power, which excludes most of the energy consumption for space heating. Furthermore, individual metering is not mandatory when technically impossible or not cost-effective in relation to the estimated potential savings in the long-term, whereas those evaluations are very difficult to carry out.

As regards informative billing of energy consumption, statements on the frequency of the billing ("billing on the basis of actual consumption shall be performed frequently enough to enable customers to regulate their own energy consumption", Article 13) are rather unsealed, and Member States shall ensure merely where appropriate that end consumers are provided with actual energy prices and energy consumption, relevant comparisons and consumers' organisations contact information together with their bill. In this regard, the observation of Ifeu (2007), that electricity bills in Germany tend not to be efficiently informative and comprehensible enough and appear too rarely, can be mentioned. Those facts from studies on electricity bills can surely be transferred to the billing of heating energy.

On a national and regional level the instrument of energy saving obligations (white certificates scheme), which is used - among others - in The UK, France and Italy, can include technical and informative measures which promote behavioural change to achieve a rational use of energy. In the United Kingdom, the Carbon Emission Reduction Target (CERT), (formerly the Energy Efficiency Commitment) is an energy reduction target imposed on the gas and electricity transporters and suppliers. 293 million tonnes of carbon dioxide (lifetime) are to be collectively achieved by suppliers from 2008 until the end of 2012. Not only technical measures are propagated, but also real time displays (RTDs) and



home energy advice packages (HEAs) as qualifying actions are included. The latest ofgem-update (August 2011) on CERT, where data collected from suppliers are published on a quarterly basis, states that behavioural measures, comprising of both RTDs and HEAs, have increased from 1.4 Mt CO₂ at the end of the last update to 2.2 Mt CO₂, increasing the portion of savings by behavioural measures from 0.8% to 1.1% (including carryover). This increase was predominantly a result of increased RTD activity. To sum up, a total of 1.1% of CO₂ savings could so far be realised due to behavioural measures.

An effective policy measure can be realised by including residential energy saving practices as mandatory part of schools' curriculum (manifold material are existent, see e.g. in Germany the 'KlimaNet', an interactive internet platform for pupils; or other projects of the UN Decade of Education for Sustainable Development (ESD) 2005-2014).

Economic instruments

Any policy with a direct or indirect influence on oil, gas or district heating prices, or electricity where used as heating energy source, has the ability to change user behaviour by reducing the demand. This was confirmed in the analysis of studies from different scientific backgrounds (OECD, 2008b: Chapter Taxes and Charges). For example, the so-called ecological tax reform (Ökologische Steuerreform; *Ökosteuern*) in Germany has led to significant reductions of overall energy use in households. The MURE database (www.mure2.com)⁸ references on evaluation studies that argue for a total cumulated impact of the ecological tax reform since its introduction in 1999 on final energy consumption, which amounts to about 78 TJ, meaning a reduction of total CO₂ emissions by 2.4 Mt. In the household sector about 35% of this reduction is achieved, which means a relatively high impact compared to the total energy consumption of this sector. To sum up, from an equity point of view, if an energy tax is increased, equity impacts will depend on how revenues are returned.

Instruments fostering investment in energy efficiency technologies could be thought to be extended towards behavioural curtailment behaviour in households, if only by taking advantage of communicating information to households already approached. To mention are the 'fiscal incentives for energy saving in the household sector' (Italy) or the 'reduction of income tax for RUE investments' in Belgium, similar measures being currently carried out in Finland, France and Sweden.

Another instrument, to our knowledge not applied yet, is that of progressively rising taxes per unit of consumed heating energy per capita within households. It is however crucial here to make sure that low-income households will not face any negative side-effects, which would be a rather complex undertaking (Ifeu, 2008). In this vein it was stated by ADEME (2009), *"far reaching policy on energy savings can lead to energy poverty, high costs that are difficult to cope with by poor families. Moreover, poor families pay relatively much money for energy due to the low quality of the houses. Therefore a specific policy on poor household must be part of savings policy. Some countries already have (conventional) policy measures in place that combat energy poverty as well. Examples are the UK fuel poverty schemes and the scheme for households with low income from Slovakia."* (p. 78).

The Community Energy Saving Programme (CESP) targets tenants across Great Britain, in areas of low income, to improve energy efficiency standards, and

⁸ The MURE II database is an information platform on energy efficiency policies in Europe and a policy evaluation tool. It is part of the ODYSSEE-MURE project and has been designed and developed within the framework of the SAVE and 'Intelligent Energy - Europe' Programmes by a team of European experts, led and co-ordinated by ISIS (Institute of Studies for the Integration of Systems, Rome) and the Fraunhofer Institute for Systems and Innovation Research ISI (Germany).



reduce fuel bills. It is funded by an obligation on energy suppliers and electricity generators, and promotes a 'whole house' approach i.e. packages of energy efficiency measures best suited to the individual property, including energy audits. The programme is delivered through the development of community-based partnerships between local authorities, community groups and energy companies, via a house-by-house, street-by-street approach. This is similar to the 'WarmFront' Scheme in Great Britain as well, where grants are available for improvements on gas, electric, liquid petroleum gas or oil heating systems, and also to the 'National Grid Affordable Warmth Solutions', where the installation of new heating systems and other energy efficiency measures is supplemented by tailored energy saving and tariff advice. In this vein, a case-study in Germany seems to be of interest: Low-income households can participate in the project '*Stromspar-Check*', where energy advices are given on the ground on a face-to-face level, concerning not only electricity saving, but also saving of heating energy. Small energy saving appliances are granted, like e.g. water savers (that will take effect on heating energy saving if warm water is produced by central heating), or thermo hygrometers, that can measure relative air humidity and temperature, thus indicate when lowering the room temperature or ventilation behaviour would be appropriate. An evaluation of the project's pilot study indicated possible savings of 2,500 kWh of power, more than 2,200 kWh of heating energy and more than 2 t CO₂ per household over the lifetime of the installed appliances, including the realisation of behavioural advices. Interesting enough, it was calculated that the expenditures by the local government for the sample in view (96,700 €) would be redeemed by 141,000 € due to future energy saving. Specifically, in the pilot study, the overall compliance of householders to heating energy saving advices was considerable: 31% of the target group indicates having switched over to efficient ventilation behaviour, and 25% declare to now lowering room temperatures in certain rooms or when absent. (Ifeu and ISOE, 2009). By now, more than 50,000 German households have been reached by this programme, which can equally be regarded as a communication instrument.

Further instruments that grant subsidies for different energy efficiency measures can be found e.g. in Norway ('Energy saving loans, *Husbankslån*', as of 1996), which also subsidises the installation of meters in heating systems for individual readings, and equipment for thermostatic control. An evaluation of the policy measure could not be found (see Mure: NOR12). Overall, wherever old and not adjustable heating systems (especially true for the eastern MS due to at times over dimensioned district heating schemes) are replaced by adjustable ones, this technical advancement leaves room for people to decide on manually lowering room temperatures as well. As it is suggested by OECD (2008) dealing with , incentive-based instruments probably belong to the most cost-effective in meeting an energy-saving objective.

Communication

A large variety of educational and informational programmes and campaigns or other more bottom-up initiatives (like e.g. community programmes), and schemes for consultancies and audits, exist on a national and even more often on a regional and local level. Aim of these initiatives is to promote behavioural change for more energy efficiency. The effectiveness of these measures is generally low compared to technical solutions, and also quite difficult to assess, for the measure-impact causality is uncertain and the real impact is difficult to quantify (Steg, 2008).



Examples of on-going or completed communication campaigns with a direct link to heat energy savings (even though no programme was found that *solely* focuses on behavioural change in the area of heating and ventilation) in Europe are summarised as follows, which were deduced from the Mure-database (www.mure2.com) on energy efficiency policies in Europe.

- Czech Republic (as of 2001) ‘Edification - state support to activities leading to reduction in heat energy consumption in the residential sector’. Description: Development and availability of various information concerning the reduction in energy performance of buildings rapidly improved over the last years. Impact evaluation: Savings of heat and electricity in the housing sector are calculated with 0.291 PJ between 2008-2016.
- Finland (1996-2005) ‘Energy conservation education for inhabitants of buildings, ‘the energy expert’-education. Description: Energy experts’ monitor the energy use and water consumption of the building, recognise possible problems and inform the maintenance personnel about them and, if necessary, prompt for action. Energy experts also distribute information on energy conservation and its cost effects to other inhabitants. They are link persons between inhabitants, janitors, house maintenance personnel and service companies. Impact evaluation: not available.
- Finland (2002-2006; 2007-2016) ‘Programme for energy conservation in oil-heated buildings, the “Höylä II + Höylä III” programme’. Description: information campaigns (by energy agencies, energy suppliers) for the general public. The programme’s primary aim however is to rise the rate of more efficient technologies, by ensuring that buildings and their oil heating systems are maintained in accordance with the specific energy efficiency requirements and by focussing on the energy efficiency of oil heating systems. Impact evaluation: not available.
- Germany (as of late 1970s) ‘Energy advice for private consumers’. Description: The independent information and advisory services on all questions related to efficient energy use, including the use of renewable energies by the consumer associations, is supported and carried out by the headquarter *Verbraucherzentrale Bundesverband (vzbv)* and consumer associations in the Federal Länder. In total, about 400 advice centres exist. Impact evaluation: the Mure references evaluation studies which state that CO₂ reductions of at least 300-600 kt were calculated for the year 2004. This is equivalent to final energy savings of 1-2 TWh (or 4-7 PJ).
- Ireland (as of 2006) ‘The Power of One’. Description: Mass media campaign that provides practical steps to help the public improve their own personal energy efficiency through small changes in behaviour and choices, including heating tips. Impact evaluation: An impact assessment on the behavioural changes concerning heat energy could not be found, however adoption rates of the electricity saving tips amount to 25-37% in average (e.g. Fully switch off electrical equipment rather than leaving it on standby) and consumer attitudes have also changed significantly (Cawley Nea\TBWA and OMD, 2010).
- The Netherlands (1991-2001) ‘Ecoteams’. Description: An Eco team is a voluntary group of eight people from different households. The Eco team members meet each month for eight months. The goal of those meetings is to minimise the environmental impact and energy use of the team members. In the meetings six themes are discussed: garbage, gas, electricity, water, transport and consuming behaviour. The members monitor their gas, water and electricity use, the weight of their garbage and the amount of car-kilometres they drive. These results are collected by the team members, discussed and sent to the regional Eco team centre. These regional centres recruit and support Eco teams and give monthly feedback to the teams. Impact evaluation: According to Mure, an



evaluation (in Dutch) on the Eco teams site shows that 10,000 households have been involved by the programmes during the period 1991-2001. Total amounts of 25 kt CO₂ have been avoided (including transportation), but no information is given on the amount of energy. In total, the measure impact level seems rather low.

- The Netherlands (as of 2000) ‘MilieuCentraal, COEN (Consumer and Energy) and HIER campaign’. Description: Several initiatives are carried out in this context.
 - Tailored energy advice (in Dutch ‘*Energie op maat*’): The ‘Energie op Maat’ website provides interested consumers with tips and instructions on how to make their energy consumption more Sustainable.
 - Helpdesk for consumers: MilieuCentraal answers questions by telephone and via emails that are sent to the Helpdesk.
 - Hier (in English ‘*Here*’): (www.hier.nu) is the name of a large Dutch climate program whose fundamental idea it is to stress the immediate necessity to implement adaptation projects and initiatives to climate change.

Impact evaluation: The impact can only be estimated in combination with many other policy measures. No evaluations have been made so far.

- Norway (as of 2003) ‘Energy information helpline (Enovas svartjeneste)’. Description: Information and advice are provided free of charge through a national energy information helpline. The information helpline covers all the country and may be contacted by telephone, e-mail or Internet/chat. The service includes information on energy efficiency measures, energy advises and ordering brochures, publications and other material. Private people may free of charge get energy advices, publications or other information material. Impact evaluation: none was found.
- Norway (as of 1999) ‘Energy act on informative billing, Energiloven’. Description: The regulations for invoicing of grid services aim to make the household aware of its electricity consumption. A household with an annual consumption of more than 8,000 kWh will as a minimum be invoiced every third month based on electricity meter reading. The electricity bill has to be easy to understand. Every electricity bill has to contain a graphical comparison of the consumption in the settling period of this year compared to the corresponding period last year. Electricity bills are based on actual consumption instead of an estimated consumption of each period. The focus on reducing electricity in Norway is of particular relevance also for heating purposes, given that about 70% of Norwegian households use electricity as main heating source (Sopha et al., 2010). Impact evaluation: According to MURE, bills that are easy to understand and at the same time informative, led to a decrease in energy consumption by 6% or 6,500 TJ of electricity.
- Romania (as of 2005) ‘Energy efficiency improvement of heating-cooling systems on individual housing’. Description: along with a regulation on minimum performance standards for boilers designed for heating and the supply of hot water and for household air conditioning devices, information campaigns are carried out along with measuring the consumption in individual homes. Impact evaluation: There is no specific quantitative evaluation of the measures.
- Great Britain (as of 2007; mass rollout 2014). ‘Smart Metering and Billing’. Description: The government confirmed its commitment to the rollout of electricity and gas smart meters to all homes in Great Britain. The foundation stage will enable the industry to build and test all the systems required to start the mass rollout, ensuring positive consumer engagement and delivering energy saving benefits. A key part of this will be learning from early installations. It will also enable the companies to test and learn what works best for consumers, and how to help people get the best from their meters. During this stage the Government will also establish the Data



and Communications Company, which will provide data and communications services for the smart-metering system nationwide. The Government expects the mass rollout to start in early 2014 and to be completed in 2019 (DECC, 2011).

- EU-23 (as of 2004; Campaign for Take Off: 1999-2003). ‘Public Awareness Campaign for an Energy Sustainable Europe’ in the frame of IEE. Description: The aims are to bring about a genuine change in behaviour and commitment towards more efficient, clean and sustainable energy production and consumption schemes. Changing behaviour through awareness activities is a demonstrated as a six-step process, starting with raising ‘awareness of the problem’, followed by the ‘acceptance of personal/corporate involvement’, an ‘attitudes’ phase, the ‘intention’ to change behaviour, the ‘experimental behaviour’ and, finally, the ‘habitual behaviour’. Different promotion/communication methods and tools are required throughout this process. Impact evaluation: not available yet.
- EU-11 Member States (as of April 2011) ‘ECCC European Citizens Climate Cup’. Description: ECCC addresses European private householders, families and singles, and is based on the energy consumption of their houses. Participants have one year to implement in their own houses strategies and measures to reduce their overall energy consumption. Winners will be the ones having adopted the best strategy to reduce their households’ energy consumption. Participants from the same country will compete against each other and also in team for the ‘Climate Cup’ title at European level. Impact evaluation: not available yet.

The developers of the above mentioned project ECCC, which is supported by Intelligent Energy Europe, have produced a very interesting summary on further existing campaigns and tools aiming to reduce energy consumption and dependence from fossil fuels at the domestic sector⁹. Figure 6 gives an overview of the fact sheet summarising the most interesting tools. Attention could be paid to especially interesting initiatives like ‘ECHO Action’, ‘Energy Neighbourhoods’, ‘energyoffice’, ‘Ecoville’ and others.

⁹ Retrieved from www.theclimatecup.eu; 31.08.2011.



Figure 6 Overview of communication tools in Europe

EU PROJECTS	ONLINE TOOLS		CAMPAIGNS	
	NATIONAL	EU/GLOBAL	NATIONAL	EU/GLOBAL
Energy Neighbourhoods	Online advisers_CO2online (DE)	Global Footprint Network	Target 2050 (UK)	You control Climate Change
Euro top ten	Homeworking webinar (UK)	ManagEnergy	Carbon watchers (UK)	10:10
SEC Tools	Act On CO2 (UK)	EnergyXchange	One Planet Homes (UK)	
Ecoville/KITH	Carbon Diet (UK)	Microsoft Hohm	Earth hour (GR)	
Clear Support Project	WWF Footprint calculator (UK)		Open house Project (IR)	
Eco Action	Home Energy Checks (UK)		Bamb project(IR)	
Econhome	Ecotopten (GR)		Klima Sucht Schutz (DE)	
Flick the switch	Domestic energy footprint calculator (MT,IR, LV, GR)		Klimaschutzinitiative(DE)	
Odysee Mure	Klimabarometer(DE)		1 Tonne Less (DK)	
Energyoffice	RWE Energiewelt Deutschland		Switch- to energy efficiency (MT)	
Energytrophy	Hausgeräte Plus (DE)		Stop the fever (IT)	
Enerbuilding	MY E-Home (DK)		Dzīvo siltāk (LV)	
	Quick calculators (DK)		Ahorra energía (ES)	
	Club 1000 (DK)		Hogares verdes (ES)	
	Husetsweb (DK)			
	Ekomāja (LV)			
	CeroCO2 (ES)			
	Laboratory to understand climate change (CAT)			
	Energy Efficiency advices and calculator for consumption (BG)			
	Energy saving advices of E.ON Bulgaria (BG)			

Source: ECCC European Citizens Climate Cup.

Another useful source on communication policy instruments is the IEE project (2007-2010) 'Energy Services: Reducing the Energy Consumption of Residents by Behavioural Changes' (BewareE), which has gathered examples of energy awareness services throughout Europe in the BewareE Database (www.izt.de/bewaree), from in total 139 energy awareness services, that were provided by housing companies, NGOs, utilities, consumer associations and similar organisations, and which address tenants and house owners, 36 'best-practices' were selected and analysed by five criteria: 1) resident acceptance; 2) potential market size (% of the whole market); 3) energy reduction potential (% of total domestic energy use); 4) initial costs (€ per service unit for enterprises, home owners or per household/year); 5) development stage.

As for ICT or Internet based communication tools, online information instruments can provide a valuable vehicle for delivering awareness-raising and educational messages. Interactive websites can provide households with further educational and practical information, learning tools, resources and peer-networks (OECD, 2010). But they are at times difficult to use, since they don't always provide tailored information (CIP, 2011) for certain target groups or the households particular circumstances.

Having so far mainly focused on top-down initiatives, it should be noted that special consideration has to be given to participatory ('grass-root') approaches, regarding the local people as experts for the issues at hand and empower them to find solutions for the reduction of heat energy consumption. As also the OECD (2010, p. 79) points out, in order to be effective, education and awareness strategies must go beyond addressing information asymmetries in individual transactions, and help promote critical and active engagement by consumers generally. Thus, the government can support local leadership programmes (informal advice networks) through the provision of training in communication and technical skills and providing scientists space for transdisciplinary research.

As it is often repeated in the literature (e.g. OECD, 2010), evaluating the effectiveness of education campaigns can be a complex undertaking. Even though it is mostly possible to quantify the costs, it is hard to measure the benefits since educational programmes often have long-term effects (as opposed to communication campaigns, which are seen to bear rather short-term effects). Furthermore, whereas it is mostly feasible to evaluate the amount of information and knowledge acquired by the consumers, it can hardly be proved that energy saving behaviours has occurred as a causal consequence of exactly this intervention (ibid.).

As a positive side-effect, information programmes can reduce the rebound effect which is bound to undo regulatory and control policy measures (UNEP, 2007).

Direct governmental expenditures

The government could set a good example within their own buildings by lowering room temperatures where appropriate, by means of manual lowering and right use of thermostat setting, in combination with adjusted ventilation behaviour. In this vein, the government can act as a role-model as well as actually reducing the CO₂ emissions in its usually vast building stock. As discussed above, subsidies for changing the heating infrastructure to more efficient and adjustable heating systems would be a way to facilitate user behaviour. As an example, the sustainable development service of the city of Mulhouse in France offered a 'Climate Box', which contained, among other appliances, three energy saving bulbs, two water saving appliances and one mercury thermometer to control space heating. As cited by the BewarE database, each household could save 110 kg CO₂ and about 90 Euro. Also, in line with the discussion on teleworking, synergies with working at home could occur when office occupation decreases.

Procedural instruments

Similar to the other areas in this report, voluntary agreements by the government with groups of organisations (like e.g. schools) could be concluded. An OECD Report (2003) based on different case studies in firms and households arrives at the conclusion, that the environmental targets were most often met. Given that voluntary approaches have the advantage that they require less preparation to put in place than regulatory measures (OECD 2003), and also that in this behavioural field any regulations can be difficult to install and monitor, they seem to be one of the most crucial instruments for behavioural change. By providing higher flexibility of the energy saving goals to be met, voluntary agreements can lead to a higher cost-effectiveness than regulations (ibid.).

Official voluntary agreements with households seem difficult, however there is to say that self-commitment of individuals and groups towards energy reduction is a method that is well known for being used in campaigns (Homburg and Matthies, 1998) and can unfold its effectiveness especially when combined with other individual measures, like e.g. competitions (see e.g. European Citizens Climate Cup (ECCC)). As for ESCOs, they could be convinced



by the government to provide their customers with set-back thermostats or even energy-efficiency appliances with higher costs, combined with counselling. Alternatively, energy performance contracting could be an option.

All policy instruments that lead to the saving of heating energy and the application of good ventilation behaviour bear the positive side-effect that the household will save money, thus mitigating fuel poverty. Especially ventilation can lead to higher comfort levels by improving the indoor climate, and targeted communication initiatives or consumption feedback can save time for households to collect this information on their own (ADEME, 2009). Negative side-effects, especially from communication campaigns, can result from the fact that people who feel restricted in their freedom of choice by external circumstances, which may be caused by policy instruments, tend to maintain or restore their freedom (psychological resistance). This implies that people may respond to policy instruments by refusing compliance or even display opposite behaviour to what was intended to regain freedom. For example, governmental communication to persuade consumers to heat less and wear warmer cloths may result in feelings of restrictions in free choice by consumers and hence will be ignored by these consumers.

Furthermore, encouraging people to manifest certain behaviours that they would have manifested anyway, mostly out of environmental concern, could remove their intrinsic motivation. Values and concerns may then not be the main reason anymore to optimise thermostat setting or ventilation behaviour. In the short term, the crowding out of intrinsic motivations will not lead to other behaviour. However, in the long run unwanted effects may be evoked. Firstly, if people attribute their behaviour to a policy instrument (e.g. a subsidy), they are likely to stop this behaviour when the policy instrument is being removed. Secondly, if the intrinsic motivation is crowded out in a specific area, people may generalise this to other (similar) areas. In that case people might not reduce their stand-by demand if only heating energy, but not electricity saving behaviour is subsidised.





5 Abatement potential and costs of policy packages

5.1 Policy packages

In this section a proposal for policy packages for behaviour related to the reduction of thermal energy in households is presented. Like in the chapter on the analysis of relevant policy instruments (Section 4.2) aiming to motivate the behaviours related to residential energy use (lowering the temperature, optimising thermostat settings and optimising ventilation behaviour), we again follow an integrated approach for the discussion of policy packages. The three behavioural options at hand are interdependent in the sense, that they aid one another in order to reduce household heating energy consumption. A policy mix will therefore not be identified per behavioural mitigation option, but for the combination of those three curtailment behaviours aiming at reducing thermal energy consumption at home.

The table below summarises the main barriers to reducing thermal energy consumption in households by combining them with the policy instruments most suitable to tackle those barriers. Furthermore, the time-frame is indicated during which the given policy instrument(s) will be able to become effective and manage to mitigate a barrier.

Table 13 Mitigation of barriers by adequate policy instruments and time frame of effects

Barrier category	Examples	Policy instrument	Time frame of policy effect
Individual (internal) barriers			
Psychological barriers	<ul style="list-style-type: none"> – No environmental concern – Emotions (e.g. health-related) – No interest in energy-related topics – Political attitudes – Risk-assessment: no threat perceived – Attribution of responsibility to others – Low self-efficacy – Low behavioural control 	<ul style="list-style-type: none"> – Information campaigns – Higher energy prices 	<ul style="list-style-type: none"> – Long-term

Barrier category	Examples	Policy instrument	Time frame of policy effect
Knowledge-based barriers	<ul style="list-style-type: none"> – Lack of adequate information – Overestimation of own energy savings compared to others – Limited knowledge of consumers on their own space heating costs – Believe that no significant savings will occur 	<ul style="list-style-type: none"> – Information campaigns – Mandatory heating energy billing at frequent intervals – More informative heating energy billing – Mandatory energy performance certificates with real display orientation – Obligation to include information in formal education 	<ul style="list-style-type: none"> – Short-term
Unconscious behaviour	<ul style="list-style-type: none"> – Strong habits and routines (e.g. no habit to turn down heating) 	<ul style="list-style-type: none"> – Economic instruments 	<ul style="list-style-type: none"> – Long-term
Societal (external) barriers			
Structural and physical barriers	<ul style="list-style-type: none"> – No possibility to adjust room temperature, install thermostat, open the windows 	<ul style="list-style-type: none"> – Public investments in infrastructure – Incentives for energy-efficient, adjustable heating infrastructure 	<ul style="list-style-type: none"> – Medium-term
Cultural barriers	<ul style="list-style-type: none"> – Comfort is a priority – No social norms towards energy saving; traditions – No social 'competition' or comparison – Social image not related to energy saving 	<ul style="list-style-type: none"> – Information campaigns – Obligation to include information in formal education 	<ul style="list-style-type: none"> – Long-term
Economic barriers	<ul style="list-style-type: none"> – Low or decreasing energy prices 	<ul style="list-style-type: none"> – Economic instruments 	<ul style="list-style-type: none"> – Short-term
Institutional barriers	<ul style="list-style-type: none"> – Lack of direct consumption feedback – Lack of incentives – Heating costs included in monthly rent – Incredibleness of experts and authorities – Political barriers 	<ul style="list-style-type: none"> – Communication instruments – Procedural instruments – Regulative instruments – Economic instruments 	<ul style="list-style-type: none"> – Short-term – Long-term



As the assessment of barriers showed, the main barriers for consumers to reduce heating energy demand are psychological and knowledge-based ones. In most cases, consumers are able to demonstrate the mitigation behaviour, but often they are not willing to, or not conscious about the environment or the energy reduction potential of changed behaviour. Therefore, a policy package should provide the consumers strong incentives that affect their willingness to change their curtailment behaviour.

Based on these considerations, the following policy package could be effective:

- *Various communication strategies, both for mass and individual target groups*; Those initiatives must not solely be developed and realised for the purpose of motivating household energy-efficient curtailment behaviour in the heating sector. Rather, information on the possibilities of lowering room temperatures, also by means of optimising thermostat setting, and optimised ventilation behaviour, can be easily integrated in any information campaign or any other policy instrument that evokes actions of households towards energy efficiency. The EU could be a role model by arranging wide-spread key campaigns and carry behavioural change messages to large samples of households; however nation- and especially region-wide initiatives play a major role due to their target group approach. Mounting campaigns on all levels is therefore highly recommendable. Communication campaigns seem to be the core instrument to address behavioural change; they reinforce the other policies in a very effective way.
- *Obligations for energy providers to distribute truly informative and adequately frequent heating energy bills*; The possibility to benchmark one's own energy consumption in a more effective way (with previous times; with relevant other people) supports the knowledge about household energy consumption and reduces biases in the judgement of adequate energy consumption.
- *Direct governmental expenditures like national governments' public investments in infrastructure, e.g. smart-meters*. This is especially relevant in the case that customers lack capital where inefficient appliances need to be identified and eventually replaced. As direct feedback on heating energy consumption is most crucial for adapting behaviour, this is an expensive but effective measure, that in addition provokes investment in new heating technologies or other energy-efficient measures and thus taps a great energy-saving potential. It is however crucial for the successful implementation of smart-metering systems be combined the above mentioned communication and information strategies, since customers are required to correctly use the equipment before actual savings can occur.
- The proposal of the Energy Efficiency Directive from June 2011 sets energy efficiency requirements also in the area of the widespread application of cost-effective technological innovations such as smart meters. Member states are free in their choice of instruments to ensure this. Within the Multiannual Financial Framework proposal of June 2011, it is noted that EU budget for mitigation efforts can act as a stimulus for national spending. Wherever possible, direct expenditures could be replaced by subsidies. Those should anyhow be applied to private customers' purchase of set-back thermometers.
- Financial incentives for reduced energy consumption or taxation of higher energy consumption; schemes that reward households with low energy consumption or penalise households with comparatively high heating energy consumption seem to be reasonable and effective instruments. Possible obstacles and imponderabilities have however to be taken into account, only to mention the problem connected to fuel poverty. A



framework enabling altered taxation of heating fuels is currently thought of (2011 revision proposal of directive 2003/96/EC of 27 October 2003). Given the necessary integrative approach of evoking household behavioural change in the heating sector, the combination of measures is assessed in the following part.

5.2 Abatement potential

The policy package defined above comprises four instruments aiming at all the behavioural options. Therefore the addressable potential for the policy package is the combined mitigation potential of the three behavioural options. Nevertheless, as mentioned before, there are some constraints to the combination of the options.

Thus, not the whole summed up potential can be realised. The following table shows the realistic mitigation potentials of the single options. Especially the first option (lowering room temperature) and the last one (improved ventilation) are not independent. For the overall assessment therefore the lower reduction potential for the room temperature option will be chosen. As shown in Figure 3, the risk of high moistures can be limited, if temperature levels are held rather high. So for the further assessment, a reduction of 1 °C is taken into account for the discussion.

The given potential can be widely addressed by the policy package in theory. The policy package has been chosen in a way, which most of the relevant barriers are addressed properly.

The short- and medium-term barriers can be addressed by the informational instruments.

The long-term barriers are addressed by the financial incentives, which have a direct impact on user behaviour, if a certain threshold is exceeded. Continuous information and education is nevertheless necessary to overcome the barriers completely.

A comprehensive assessment of a combination of the policy instruments has not been carried out within the analysed studies.

Studies on informational tools show great success of these instruments if they are applied appropriately. Nevertheless, only parts of the realistic potential will be raised, due to the strength of behavioural barriers. A share of 25-33% of the potentials may be addressed by informational tools on short terms, but there is no sound empirical evidence for that. The results from studies in this field are mainly short-term observations of smaller groups in pilot projects, which are appropriate for potential analysis but less suitable for studying mid- and long-term effects. They show a reduction of less than 5% (e.g. Matthies and Hansmeier (2010)), compared to a potential of more than 20%.

Long-term effects may be assumed much higher, for the habitual barriers may be overcome by continuous information and education combined with financial incentives, but there is no empirical proof in the studies on heating and ventilation behaviour.

Financial instruments will also not be able to overcome the barriers completely. Though, recent developments in Europe - for example the eco-tax in Germany - show that there is a certain correlation between energy prices and consumption, but consumers turned out to be less sensitive to energy prices than expected.

The impact of energy prices on user behaviour is taken into account in the models, and therefore does not need to be considered here.



Table 14 Total mitigation potentials addressed by the policy package

	2020	2030	2050
CO ₂ emissions for the housing domain	425 Mt CO ₂	362 Mt CO ₂	299 Mt CO ₂
Realistic maximum abatement potential (as Mt CO ₂)			
Lowering Room Temperature			
Reduction by 1 °C	22	19	16
Reduction by 2 °C	45	38	32
Optimised Thermostat Settings	11	10	9
Improved Ventilation	43	42	42
Total (2 °C)	99	90	83
Total (1 °C)	76	71	67
Policy Impact (only informational)	25%	33%	33%
Potential realistically addressed by the policy package (only informational) (1 °C)	19	23	22
Share of potential compared to total CO ₂ emissions for the housing domain	4%	6%	7%

The Impact of this impact is rather large, raising from 4% of the total CO₂ emissions of the housing domain in 2020 to 7% in 2050. Especially the increasing relative impact highlights the importance of these measures.

5.3 Costs

The cost effects of the different policy instruments are quite different, and may also differ between the different countries due to their size. Costs of the informational instruments are rather low, when compared to subsidies and financial incentives. For larger entities (e.g. energy providers), the specific costs for these instruments are lower, because many of the costs connected to these instruments are independent of the number of customers addressed. Set up costs of informational campaigns as well as detailed bills are defined by technical and organisational conditions. Only if communication campaigns incorporate direct (face to face) customer contact, the number of addressees will become relevant. Costs for such measures vary widely and are not properly quantified in studies in correlation to their effect.

The direct governmental expenditures or subsidies will of course result in corresponding costs. The analysed studies give no detailed information on these costs. According to current publications, it can be estimated, that these cost will not exceed 100 € per dwelling. This is at the moment the maximum cost for a smart meter, which is one of the possible devices for subsidy. The other device in question are electronic thermostats, which will cost 20 € per piece, if the heating system is equipped for thermostats at all. Further investments would be a larger change of the heating system, which is no more a behavioural option.

A raise of energy taxes will generate additional income for the state; the induced reduction will decrease the revenues from energy taxes. If the tax raise is balanced in an optimal way, the opposing effects will neutralise each other. As experiences from energy tax raise show, this is normally not the case; the additional income outweighs the effect of reduced energy consumption (and therefore increase energy costs for the final consumers).



Table 15 Costs of policy measures

	Cost	Cost paid by	Comments
Communication Strategies	Unknown	State Utilities	
Detailed billing	< 10 € per dwelling and year	Utilities	Additional costs for data acquisition and processing
Direct Government expenditures	100 € per dwelling	State	Smart meter costs
Energy taxation	Balanced	State	



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[http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/
mytopic=12720](http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12720)

Accessed at 04/06/2011

Vlieden, 2007

Karin van Vlieden

Snelheidsgedrag : motieven en beïnvloedende factoren

Diepenbeek : Steunpunt verkeersveiligheid, 2007

Verhallen en Van Raaij, 1981

T.M.M. Verhallen and W.F. Van Raaij

Household behavior and the use of natural gas for home heating

In: Journal of Consumer Research, Vol. 8, No.3 (1981); p. 253-257

Van Raaij, W.F. and Verhallen, T.M.M., 1983

A behavioral model of residential energy use

In : Journal of Economic Psychology, 3 (1), 39-63



Visser and Ramos Martin, 2008

J. Visser and N. Ramos Martin

Expert Report on the Implementation of the social partner's Framework Agreement on Telework

Amsterdam : University of Amsterdam, 2008

Weidema et al., 2005

B.P. Weidema, M. Wesnaes, J. Hermansen, T. Kristensen and N. Halberg, Environmental Improvement Potentials of Meat and Dairy Products, JRC (IMPRO Study)

Seville : European Commission, Joint Research Centre, Institute for Prospective Technological Studies, 2005

WHO/FAO, 2002

Joint WHO/FAO expert consultation on Diet, nutrition and the prevention of chronic diseases

Geneva : WHO/FAO, 2002

Wilhite et al., 1996

H. Wilhite, H. Nagakami, T. Masuda, Y. Yamaga and H. Haneda

A cross-cultural analysis of household energy use behaviour in Japan and Norway

In: Energy Policy, Vol. 24, No. 9 (1996); p. 795-803

Winett et al., 1979

R.A. Winett, M.S. Neale and H.C. Grier

Effects of selfmonitoring and feedback on residential electricity consumption

In: Journal of Applied Behavior Analysis, Vol. 12, No.2 (1979); p. 173-184

WWF, 2009

Virtual meetings and Climate innoVation in the 21st Century : Can offsetting CO₂ emissions from flights by investing in videoconferencing be a way to support transformative change?

Stockholm : WWF, 2009





Annex A Fact sheets

A.1 Abrahamse et al., 2007

Abrahamse, W., Steg, L., Vlek, C., Rothengatter, T. (2007): The effect of tailored information, goal-setting and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents, <i>Journal of Environmental Psychology</i> , 27, pp 265-276	
Description of study	
Description of behavioural mitigation option	Tailored feedback as a means for households to reduce direct energy use, including heating.
Description of BAU scenario applied	Control group without intervention (n=55 households).
Time horizon of the study	Current
Scope of the study	Groningen, Netherlands - sample included more men than women, is slightly older and wealthier than the Dutch average. Overrepresentation of home-owners. Energy use below average.
Assessment method applied	Measurement of behavioural change of two types of interventions in two experimental groups (n=71 and n=66).
Data sources used	Own data (questionnaire data from study participants)
Mitigation potential	
Direct effects	<p>Interventions</p> <ul style="list-style-type: none"> – No intervention (control group) – Tailored information, individual goal (-5%), tailored individual feedback (experimental group 1) – Tailored information, individual goal (-5%), tailored individual feedback, group goal (-5%), group feedback (experimental group 2) <p>Total energy use is calculated at household level (before and after intervention). Total energy use included direct (electricity, fuels, natural gas) and indirect energy (e.g. purchase of products). Energy savings were calculated based on self-reports of behaviour. Households in the experimental group reduced their energy use by 5.1% (11,951 MJ) (5,0% for group 1 and 5,3% for group 2) compared to a slight increase in the control group (0.7%). Savings of direct energy added up to 7466 MJ group 1) and 10,802 MJ (group 2). Direct energy use included options like lowering the thermostat day or night, turning off when absent/leaving/in empty rooms, leave on while air from outside is coming in, closing doors between rooms. Low-cost behaviours, i.e. in terms of time, effort and convenience, e.g. lowering thermostat. Detailed quantifications for behaviours are not provided in the paper. Benders et al. (2006) presenting data from the same project estimate the average energy reduction from lowering the thermostat during daytime to 1250 MJ/household and to 720 MJ for night-time; fewer heated rooms and closing inner doors contribute 350 MJ each on average. No future effects estimated.</p>
Indirect effects	No
Rebound effects	No
Costs and side-effects	
Cost estimates	No
Side-effects included	No
Additional remarks	
Further information on the study and the intervention instrument used is provided by Benders, R.M.J., Kok, R., Moll, H.C., Wiersma, G., Noorman, K.J. (2006) New approaches for household energy conservation—In search of personal household energy budgets and energy reduction options. <i>Energy policy</i> , 34, pp 3612-3622.	



A.2 BC Hydro, 2007

BC Hydro (2007), Conservation Potential Review by the Canadian utility BC Hydro, http://www.bchydro.com/etc/medialib/internet/documents/info/pdf/info_2007_conservation_potential_review_summary_report.Par.0001.File.info_2007_conservation_potential_review_summary_report.pdf (24/01/11)	
Description of study	
Description of behavioural mitigation option	Space heating - behavioural options and lifestyle changes
Description of BAU scenario applied	2006 is used as a baseline, the BAU scenario assumes that no new measures on demand management are implemented and predicts values for 2026 based on the baseline. Electric consumption is estimated to be 68,665 GWh/a, 22,156 GWh/a for the residential sector.
Time horizon of the study	Electricity conservation potential until 2026
Scope of the study	British Columbia/Canada.
Assessment method applied	Effects assessed via specifically developed/adjusted models (RSEEM (Residential Sector Energy End-use Model), CSEEM (Commercial Sector Electricity End-use Model) as well as MetroQuest, developed by the University of British Columbia and Envision Sustainability Tools Inc)
Data sources used	Various data sources including company data from BC Hydro
Mitigation potential	
Direct effects	Savings potential for all behavioural options in the residential sector estimated to be up to 1377 to 720 GWh/a in 2026. Behavioural options included computers, domestic hot water use, lighting and space heating and refer to actions which include habitually saving energy within daily routines (25 behaviours analysed); further details on options analysed are not provided. For the Commercial sector, savings potentials for electrical efficiency behaviours were estimated to lie within the range of 548 GWh/a and 410 GWh/a. Behaviours were included, if they could be easily performed by employees without decreasing productivity. Main potentials were seen with lighting and plug loads, i.e. outside the scope of this project. For the residential sector, lifestyle changes were analysed as well including the management of heating and cooling. Possible reductions in electricity use for all lifestyle options are estimated to add up to 2,017 GWh/a in 2026 whereby the effect of optimised air conditioning is estimated around 70 GWh/a, for water heaters around 150 GWh/a, for space heating nearly 500 GWh/a and for ventilation around 60 GWh/a.
Indirect effects	No
Rebound effects	No
Costs and side-effects	
Cost estimates	No
Side-effects included	No
Additional remarks	
Further information on the study (additional reports):	
<ul style="list-style-type: none"> - The Potential for Electricity Savings through Behavioural Changes, 2006-2026 - Residential and Commercial Sectors in British Columbia - The Potential for Electricity Savings through Lifestyle Changes, 2006-2026 - Residential Sector in British Columbia. 	



A.3 Bohunovsky et al., 2010

Bohunovsky, L., Stocker, A., Großmann, A., Hutterer, H., Arends, G. Haslinger, J., Wolter, M.I., Madlener, R., Endl, A. (2010), Szenarien eines nachhaltigeren Energiekonsums Ausbau erneuerbarer Energien, Erhöhung der Energieeffizienz und Verhaltensänderungen im Energieverbrauch bis 2020, e-co Working Paper Nr. 2.	
Description of study	
Description of behavioural mitigation option	For heating, the combined effects of a reduced room temperature, a reduced amount of heated spaced, less time of heating and an increased number of inhabitants per dwelling are analysed.
Description of BAU scenario applied	BAU assumes that no further action is taken regarding renewable energies and energy efficiency besides those already implemented. Further development is estimated based on historical data until 2020. For heating, 232.769 TJ of energy are expected for 2020.
Time horizon of the study	Until 2020
Scope of the study	Austria
Assessment method applied	Effects are estimated via modelling.
Data sources used	Model e3.at, see Großmann, A., Wolter, M.I (2010): Dokumentation des Modells e3.at, e-co Working Paper Nr. 3, for details.
Mitigation potential	
Direct effects	The combined effects of a reduced room temperature (-2°C), a reduced amount of heated spaced (e.g. not heating of bedrooms), less time of heating (night-time) and an increased number of inhabitants per dwelling (-8% of square meters per dwelling) are estimated to add up to 195.117 TJ in 2020.
Indirect effects	No
Rebound effects	No
Costs and side-effects	
Cost estimates	No investments are assumed for the options analysed.
Side-effects included	Effects on building structure due to the rising number of inhabitants per dwelling are included.
Additional remarks	



A.4 Öko-Institut, 2000

<p>Öko-Institut (2000), Klimaschutz durch Minderung von Treibhausgasemissionen im Bereich Haushalte und Kleinverbrauch durch klimagerechtes Verhalten, Band 1: Haushalte, Forschungsbericht 204 01 120, für das Umweltbundesamt.</p> <p>Deutscher, P., Elsberger, M., Rouvel, L. (1999): Klimaschutz durch Minderung von Treibhausgasemissionen im Bereich Haushalte und Kleinverbrauch durch klimagerechtes Verhalten, Anlagenband zum Band 1.</p>	
Description of study	
Description of behavioural mitigation option	General analyses of behavioural mitigation in the housing sector identifies heating as the option holding the highest potential.
Description of BAU scenario applied	Scenario from another project, 'Politiksznarien für den Klimaschutz - II' are used and further developed for the BAU. For heating, the scenario uses an estimated average standard demand baseline value which is estimated to add up to 437.159 GWh/a for Germany in 1995.
Time horizon of the study	Possible effects are quantified for 1995, 2005 and 2020.
Scope of the study	Germany
Assessment method applied	The mitigation potential is estimated based on different theoretically developed scenarios, e.g. room temperature varying between -4K and +2K around the assumed standard temperature.
Data sources used	Ikarus-Database plus various data-sources and own analyses (cp. Anlagenband by Deutscher, Elsberger and Rouvel for details)
Mitigation potential	
Direct effects	The effects of combining various room temperatures and ventilation rates are estimated and add up to a range between +78% and -35% of energy demand compared to the standard case. Future effects (for 2005 and 2020) are only quantified including all options under study, i.e. also including potentials from electric appliances etc. Two scenarios are presented - a maximum and a realistic scenario. While the maximum scenario includes potentials of 118 (2005) and 117 (2020), the realistic scenario leads to the values of 175 (2005) and 159 (2020) compared to 179 (2005) and 170 (2020) in the BAU (million tons of CO ₂). The realistic scenario assumes that for every year 1% of the potential can be realised.
Indirect effects	No
Rebound effects	No
Costs and side-effects	
Cost estimates	No. It is assumed that the behavioural change options analysed do not imply investment costs for households.
Side-effects included	No
Additional remarks	



A.5 Bürger, 2009

Bürger (2009), Identifikation, Quantifizierung und Systematisierung technischer und verhaltensbedingter Stromeinsparungspotenzial privater Haushalte. TRANSPOSE Working Paper No 3.	
Description of study	
Description of behavioural mitigation option	Analysis of the potential of behavioural mitigation options for household electricity. Options include 1) investing in technical measure which contribute to saving energy (e.g. replacing inefficient appliances while keeping functionality) 2) changed user behaviour/changed routines. Main relevant scope is the replacement of electric heating systems and electric water heaters.
Description of BAU scenario applied	The current electricity demand of German households is used as a baseline. Current isn't specified, the study probably refers to 2006 (+/- one year).
Time horizon of the study	Time horizons aren't explicitly provided.
Scope of the study	Study analyses untapped electricity savings potential in the German residential sector.
Assessment method applied	Potentials are estimated using the theoretical maximum savings.
Data sources used	<ul style="list-style-type: none"> – ISI/CEPE 2003 - Der Einfluss moderner Gerätegenerationen der Informations- und Kommunikationstechnik auf den Energieverbrauch in Deutschland bis zum Jahr 2010 - Möglichkeiten zur Erhöhung der Energieeffizienz und zur Energieeinsparung in diesen Bereichen. – ISI et al. 2005 - Technische und rechtliche Anwendungsmöglichkeiten einer verpflichtenden Kennzeichnung des Leerlaufverbrauchs strombetriebener Haushalts- und Bürogeräte. – ISI et al. 2004 - Energieverbrauch der privaten Haushalte und des Sektors Gewerbe, Handel, Dienstleistungen (GHD). – RWI/forsa 2005 und 2008 - Erhebung des Energieverbrauchs der privaten Haushalte für das Jahr 2003 bzw. 2008.
Mitigation potential	
Direct effects	<p>It is estimated that 1) the purchase of efficient household appliances and the replacement of electric heating and electric hot water generators will add up to ca. 90 TWh/a; 2) changes in usage patterns/habit will add up to 30TWh/a (60% and 20% of the current electricity demand respectively). These numbers refer to the overall savings potentials of all options analysed. Data for each option is also provided; no specific data is provided for changed user behaviour with regard to electric heating / water heaters as the study focuses on potential which is specific for electric appliances and the behavioural change options in these cases are identical to those that exist if other energy carriers are used for heating / water heating.</p> <p>The paper specifies savings which are possible by a) replacing electrical heating b) replacing electrical water heaters.</p> <p>Potentials are estimated using the theoretical maximum savings, e.g. without considering the age of actual appliances etc., for changed behaviour no investments are assumed. Technical progress and anticipated exchange rates are not taken into account.</p>
Indirect effects	If electrical space or water heating systems are replaced by other technologies other energy sources have to be used. Savings potentials are estimated compared to the primary energy used in this case.
Rebound effects	No
Costs and side-effects	
Cost estimates	For replacement investments it is assumed that they are only economically sensible if a replacement is necessary anyway (e.g. due to the age of the existing electrical heating system). Investments for replacing an electrical heating system by another technology is only efficient for apartment buildings if all necessary costs e.g. installation of pipes are included.
Side-effects included	No
Additional remarks	
Study also analyses the replacement of other appliances, etc. and identifies the most promising options for saving electricity. These include replacing electrical heating systems.	



A.6 Dietz et al., 2009

Dietz, T., Gardner, G.T., Gilligan, J., Stern, P., Vandenberg, M.P. (2009): Household actions can provide a behavioural wedge to rapidly reduce US carbon emissions, <i>Proceedings of the National Academy of Science (PNAS)</i> , November 3, vol. 106 (44), pp. 18452-56.	
Description of study	
Description of behavioural mitigation option	Broad analyses of behavioural mitigation options, including replacing HVAC (heating, ventilation, air-conditioning) equipment, efficient water heaters, change air filters of HVAC equipment, tune up AC, temperature of water heater, thermostat setbacks.
Description of BAU scenario applied	Current (2005) energy use by US-households as a baseline which was 626 million tons of CO ₂
Time horizon of the study	Time-span of ten years, i.e. 2015
Scope of the study	US households; Authors assume that percentage of about 50% of those estimated for the US may be achievable in the EU.
Assessment method applied	Possible effects are estimated using the potential emissions reduction (PER) and weighing them by behavioural plasticity, i.e. the proportion of current non-adopters that could be induced to adopt (corrected for double counting, e.g. smaller behavioural effects in case of more efficient equipment) resulting in the so-called reasonably achievable emissions reductions (RAER). Adoption rates are estimated based on successful intervention studies.
Data sources used	Various data sources/own calculations.
Mitigation potential	
Direct effects	Option analysed → potential emissions reduction/million tons of CO ₂ , estimates for 2015, reasonably achievable emissions reductions <ul style="list-style-type: none"> – replacing HVAC (heating, ventilation, air-conditioning) equipment → 25.2; – efficient water heaters → 6.7; – change air filters of HVAC equipment → 8.7; – tune up AC → 3.0; – temperature of water heater → 2.9; – thermostat setbacks → 10.1.
Indirect effects	No
Rebound effects	No
Costs and side-effects	
Cost estimates	No. Usually measures either do not imply major investment or investments that should be economically efficient as well.
Side-effects included	No
Additional remarks	
Data probably similar or identical to the one presented in Gardner, G.T., Stern, P. (2008) The Short List The Most Effective Actions U.S. Households Can Take to Curb Climate Change. <i>Environment</i> , Sept./Oct. 2008, www.environmentmagazine.org	



A.7 Gardner and Stern, 2008

Gardner, G.T., Stern, P. (2008) The Short List The Most Effective Actions U.S. Households Can Take to Curb Climate Change. <i>Environment</i> , Sept./Oct. 2008, www.environmentmagazine.org	
Description of study	
Description of behavioural mitigation option	27 possible individual actions including curtailment und efficiency behaviours
Description of BAU scenario applied	Current (2005) energy use by US-households as a baseline
Time horizon of the study	Not specified.
Scope of the study	US households
Assessment method applied	General assessment of possible reductions
Data sources used	Various data sources incl. U.S. government statistics / own calculations.
Mitigation potential	
Direct effects	<p>Percentage of energy saving estimated for households who do not have taken this action / adopted the technology.</p> <ul style="list-style-type: none"> – Heat: Turn down thermostat from 72°F to 68°F during the day and to 65°F during the night: 2.8%; – A/C: Turn up thermostat from 73°F to 78°F: 0.6%; – Heat: Install/upgrade attic insulation and ventilation: Up to 5.0%; – A/C: Install/upgrade attic insulation and ventilation: Up to 2.0%; – Heat: Install a more efficient heating unit (92% efficient): 2.9%; – A/C: Install a more efficient A/C unit (SEER 13 or EER 12): 2.2%; – Heat: Replace poor windows with high-efficiency windows: Up to 2.8%; – A/C: Replace poor windows with high-efficiency windows: Up to 0.9%; – Heat: Caulk/weather-strip home: Up to 1.9%; – A/C: Caulk/weather-strip home: Up to 0.6%; – Turn down water heater thermostat from 140°F to 120°F: 0.7%; – Install a more efficient water heater (EFS .7 unit): 1.5%.
Indirect effects	No
Rebound effects	No
Costs and side-effects	
Cost estimates	No. However, it is assumed that most options come at low-, no-, or negative-cost.
Side-effects included	No
Additional remarks	
Data probably similar or identical to the one presented in Dietz, T., Gardner, G.T., Gilligan, J., Stern, P., Vandenbergh, M.P. (2009): Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions, <i>Proceedings of the National Academy of Science (PNAS)</i> , November 3, vol. 106 (44), pp. 18452-56.	



A.8 Santin et al., 2009

Guerra Santin, O., Itard, L., Visscher, H. (2009): The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. Energy and Buildings, 41, pp. 1223-1232.	
Description of study	
Description of behavioural mitigation option	No behavioural option analysed but the effect of occupant behaviour on energy consumption for space heating by determining its effect on the variation of energy consumption while controlling for building characteristics.
Description of BAU scenario applied	No BAU-scenario but aiming in explaining variability.
Time horizon of the study	Recent (2000) - no predictions.
Scope of the study	Housing in the Netherlands.
Assessment method applied	Estimates are derived from household survey data.
Data sources used	Data from Kwalitatieve Woning Registratie (KWR) of the Ministry of Housing of the Netherlands (VROM), survey from 2000 including 15,000 houses from the Netherlands including variables on occupant behaviour (e.g. time spent at home, ventilation frequency).
Mitigation potential	
Direct effects	Most important behavioural variables (descending order) explaining variations in energy use for heating after controlling for building characteristics and type of dwelling: number of heated bedrooms, temperature during the evening, temperature during day, presence of inhabitants during day, temperature during night, heating included in rent, weekend-presence and private rent. It is estimated that per degree of increase in temperature during evening and night energy use increases by 990 and 969 MJ respectively and during day by 736 MJ. Overall, 7.2% in variance were explained by occupant patterns.
Indirect effects	No
Rebound effects	No
Costs and side-effects	
Cost estimates	No
Side-effects included	No
Additional remarks	



A.9 Huenecke et al., 2010

Huenecke, K., Fritsche, U.R., Brohmann, B. (2010), Sustainability of consumption patterns: Historic and Future Trends in Europe, ERSCP-EMSU conference, Delft (NL), October 25-29.	
Description of study	
Description of behavioural mitigation option	Investment in energy-efficient electric water heaters as a type of electric household appliance.
Description of BAU scenario applied	Trend projections (based on saturation, specific consumption) from the Primes model are used as a baseline.
Time horizon of the study	Potential effects are analysed up to 2030.
Scope of the study	The scope of the study are the member states of the European union (EU-27) which are divided into four regional clusters.
Assessment method applied	The analyses assume that the best available technology (BAT) will be fully applied by 2030 given logistical restrictions and stock exchange rates.
Data sources used	PRIMES model and its respective data.
Mitigation potential	
Direct effects	The potential for all appliances under study is estimated to 300 TWh in 2030 (120 million t CO ₂ eq.) as a maximum potential. Specific data for electric water heaters are not specified.
Indirect effects	No
Rebound effects	No
Costs and side-effects	
Cost estimates	No
Side-effects included	No
Additional remarks	



A.10 Matthies and Hansmeier, 2010

Matthies, E., Hansmeier, N. (2010), Optimierung des Energienutzungsverhaltens in Organisationen - Das Beispiel der Ruhr-Universität Bochum. Umweltpsychologie 14 (2), 76-97	
Description of study	
Description of behavioural mitigation option	Campaign to reduce energy for heating in a university focusing on keeping windows closed and turning down thermostat when absent
Description of BAU scenario applied	No specific BAU - situation before intervention used as baseline
Time horizon of the study	Effects are measured for two winters (2006-2007) and compared to data from 2000-2005
Scope of the study	University in Mid-Western Germany (Ruhr-Universität Bochum)
Assessment method applied	Behavioral intervention and comparison of pre-/post-data.
Data sources used	Data based on actual energy consumption.
Mitigation potential	
Direct effects	Energy reduction of 3-4% in the heating season. This is a realistic bandwidth potential. Unit: MWh saved. Year: 2006/2007
Indirect effects	None
Rebound effects	None
Costs and side-effects	
Cost estimates	None - costs for campaign not specified.
Side-effects included	None
Additional remarks	

