Behaviour Oriented Optimisation Strategies for Energy Efficiency in the Residential Sector

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ABSTRACT

The aim of this paper is to combine the approaches of engineering and sociology in the assessment of behavioural influences on the energy demand of residential buildings and to define a common language and strategy for their description. For this purpose the calculation methods of the German Energy Conservation Regulations[1] (EnEV 2007) further defined in the DIN 4108-6: 2003-06 will be evaluated to illustrate the relevant linkages to behavioural approaches. So far, there are few attempts to differentiate the large influence of individual behaviour (see Richter 2003, Loga 2003). The assessment of these values and their behavioural implications require a sociological approach towards energy relevant practices. Based on the calculation of the building's energy balance an analytical framework will be suggested to link the heat demand with the lifestyles[2] of consumers.

NEED FOR ENERGY AND ENERGY DEMAND

In the realisation of energy efficiency strategies and the performance of buildings the user has a strong influence by defining the parameters according to his or her needs and controlling the system to match those parameters. Following the definition given by Dennerlein (1990) "need" is in this framework understood as a subjectively felt lack combined with the wish or intention to overcome this situation. In those cases where this can be done through material goods the need is transferred into a "demand". Applied to the energy consumption an ambient temperature which is seen as a need is corresponding with different energy demand depending on the heating system and the building (ibid.). Figure 1 illustrates the described path from needs to the energy demand that finally results in the consumption of energy. It is these interdependencies the paper seeks to further explore while focusing on the user perspective.

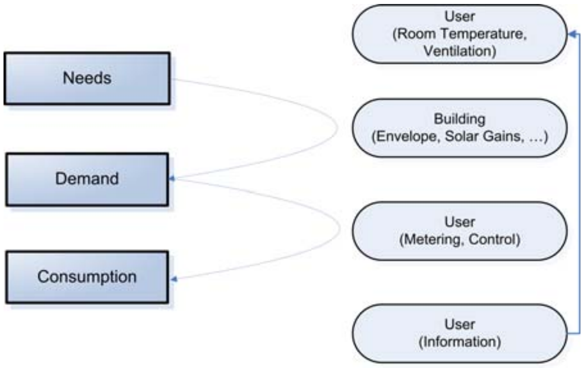

Figure 1. From needs to consumption

In order to discuss the behavioural influences on the heat demand different social practices will be identified and their relevance will be assessed. To focus on the demand as a technical expression of needs this paper builds on the calculation method commonly used in the stationary heat demand calculation as defined by the DIN 4108-6. Secondly the user's awareness or information about the interconnections between energy demand and behaviour and how to influence the building's energy

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[1] Verordnung über energiesparenden Wärmeschutz und energiesparende Anlagentechnik bei Gebäuden – Energieeinsparverordnung (EnEV), 24.7.2007

[2] Lifestyle approaches in this context seem more applicable as they consider not only classical social stratification criteria such as income and educational level, but also include the normative dimension of peoples' life (see Schulze 1992, Schneider/ Spellerberg 1999, SINUS Sociovision 2007; Prose/ Wortmann 1991).

balance is expected to play a mayor role in the outcome of the process (i.e. in the final consumption). An analytical framework to describe the different factors will be developed and ways to refine the analysis suggested. For this purpose a static condition of the building is assumed. Building measures (e.g. insulation of building parts, change of the heating system, etc.) will not be included in the discussion.

ANNUAL HEAT DEMAND

The calculation of the annual heat demand for residential buildings as prescribed by the Energy Conservation Regulations (EnEV 2007) is further specified by the DIN 4108-6: 2003-06 (DIN 4108-6)[3]. As a normative user profile is defined for the calculation, a number of factors can be identified reflecting user behaviour. These factors will be described in the following section to then assess their significance for the annual heat demand. A comparable approach to identify relevant influences was followed by (Loga et al. 2003) in their study to assess the consequences of user behaviour for the consumption based energy accounting.

The annual heat demand (Q) in the calculation as described by DIN 4108-6[4] is defined as the heat demand (Q_h), the heat demand for warm water provision (Q_W), the system losses of heat and warm water supply system (Q_t) and then subtracts the amount of energy brought into the system by regenerative sources (Q_r).

$$Q = Q_h + Q_W + Q_t - Q_r$$

As the latter two parameters are not affected by user behaviour the discussion will in the following focus on the heat demand for space heating and warm water provision. Arguably all the factors can potentially be changed by building measures or changes in the heating system, those interventions will however not be part of this first approach as its focus lies on changes in the behaviour that could therefore be applied by all kinds of inhabitants - owner-occupiers as well as tenants.

[3] EnEV 2007 Annex 1, 2.1.1 The [...] annual heat demand Q_h shall be calculated according to the monthly balance method defined by DIN EN 832:2003-06 [...] the simplifications given in DIN V 4108-6: 2003-06 may be applied (translation by the authors)

[4] If not stated otherwise all formulas given in this paper are referring to the DIN 4108-6 or are directly deducted from the calculation method.

Heat Demand For Space Heating

The general calculation model establishes a balance of heat gains and losses for the building with the demand for space heating (Q_h) as the resulting difference between the two. It could also be described as the additional energy that has to be fed into the system to maintain a defined condition. The losses are split into transmission losses (Q_T) and ventilation losses (Q_V). On the side of heat gains two sources are included in the calculation: solar gains and internal gains; the latter resulting from all activities and appliances within the building envelope such as presence of people but also household appliances emitting heat. In the balance both are limited by the capacity of the building to store the heat expressed in an additional factor. The resulting term represents the usable heat gains in the heating period.

$$Q_h = F_{Gt} (H_T + H_V) - \eta (Q_S + Q_I)$$

The transmission losses (H_T) describe the amount of energy lost by transmission through building envelope. In addition to the building parts (i) that are described by the correction factor ($F_{x,i}$), the U-value (U_i) and the surface (A_i) the losses through thermal bridges H_{WB} are accounted for. As changes in the structure are not covered in this discussion the transmission losses as such require no further description.

$$H_T = \Sigma_i (F_{x,i} U_i A_i) + H_{WB}$$

The ventilation losses (H_T) are calculated by multiplying the density (ρ_L) and the specific heat capacity (c_{pL}) of air with the air exchange rate (n) and the ventilated net volume (V).

$$H_V = \rho_L c_{pL} n V$$

Amongst these factors only the air exchange rate can be influenced by the user. As Loga (2003) points out the ventilation through open windows is only part of the total air exchange, which does also occur in an uncontrolled manner through the building envelope and in controlled through a mechanical ventilation system.

The sum of the losses is then multiplied with the factor F_{Gt}, which is defined by the differences from the daily mean values of the interior temperature and outer temperature over the length of the heating period ($Gt_{x/y}$).

$$F_{Gt} = 0.024 \cdot Gt_{x/y}$$

The interior temperature is directly influenced by the user. Here the above mentioned transfer from needs to demand can be seen as the control of the heating system. The interface (e.g. thermostatic valves, thermostats per room, etc.) can be assumed to have a large influence on how precisely the user can match his or her needs with the demand.

The sum of the gains are considered in the calculation by applying an efficiency ratio η which is mostly dependant on the building itself and reflects the fact that only a part of the gains are usable. In the DIN 4108-6 η is given as a factor of 0.95. Within the heating period solar gains are described as the sum of solar heat gain through the transparent openings in the building part i and the orientation j with the surface A_{ij} and the energy transmission coefficient g_{ij} further influenced by reduction factors for the frame of the window ($F_{F,ij}$), shading ($F_{S,ij}$) and shading devices ($F_{c,ij}$). The solar gains Q_s are then calculated using the solar radiation I_{ij}.

$$Q_s = \Sigma_{ij} I_{sj} \Sigma_{ij} (F_{F,ij} \cdot F_{S,ij} \cdot F_{C,ij} \cdot g_{ij} A_{ij})$$

Of the above given formula only the shading devices and the cleanliness of the windows can be influenced by the occupant. To factor in dirt a percentage of 90 % is usually assigned. While the shading device is operated by the user, the positioning (i.e. inside or outside the building or in between layers of glass) and material of the device has a strong influence on the solar gains.

As a final parameter in the calculation of the heat demand the internal gains within the heating period are added to the solar gains. The internal gains are expressed as the gross heat gains (q_i) in relation to the usable surface (A_B) multiplied by the length of the heating period (t_{HP}).

$$Q_{i,HP} = 0{,}024\ q_i\ A_B\ t_{HP}$$

The internal heat gains are strongly influence by the behaviour or rather lifestyle of the inhabitants as for example appliances will usually continue working once the decision to install them has been taken[5].

For non residential buildings the values will greatly vary depending on the time of day. Therefore the average specific internal heat gain is calculated as a mean value from gains during office hours ($q_{itA}\ t_A$) and gains during non-office hours ($q_{i,tNA} \cdot (24h - t_A)$).

[5] For example the average internal heat output of freezer is given with an amount of 90 W (DIN V 4108-6 Table 2)

It should be noted that in both cases the concurrence of the individual sources has to be considered in order to understand the total value of the heat gains from persons, appliances, and lightning.

Warm Water Provision

In the calculation of the heat demand for warm water provision the main values that can be influenced are the Volume of warm water (V_W) and the temperature of the provided water (θ_W). The volume specific heat capacity ($(\rho c)_W$) is provided as a constant value ($(\rho c)_W$ = 1.161 kWh/(m^3 · K)), the water temperature before entering the warm water system (θ_0) is regarded as a given.

$$Q_W = (\rho c)_W\ V_W\ (\theta_W - \theta_0)$$

The standard value for the volume of warm water used for the calculation along the DIN 4108-6 is 0.75 m^3 or 750 l per person and month with a temperature of 50 °C (122 °F).

SIGNIFICANCE OF THE IDENTIFIED FACTORS

The technical description of the various factors in the annual heat demand calculation showed that a wide range of practices is very likely to influence the heat demand of buildings and is at the same time considered in the calculation method. To determine the relevance of the individual factors in the next step the significance of modifications of the standard values will be further explored to provide the basis for the identification of relevant behaviour patterns or lifestyles in connection with the heat demand.

In a calculation based on the monthly balances also defined in DIN 4108-6 the different variables were tested for their relevance. This kind of calculation will be used as a first indication and should be further tested with more refined simulation tools such as TRNSYS, which was used by Richter (2003). It is encouraging, however, that the results generated for a free standing single family house from the late 1960th modelled after the German building typology (IWU 2003) quite precisely match the findings of the study of Richter (2003) both in absolute and relative terms despite the different approaches. The only limitation that possibly can be attributed to the method applied is the lack of a precise representation of solar gains. The relative influences of the modification of shading devices lies even bellow the simulated values (ibid.). There, however, the influence was also deemed too low for a further in depth description so that the methodological shortcoming seems acceptable. In accordance with the results presented in this paper Hausladen (2003) concludes that the influence of internal shading and dirt particles on the glazing can be neglected in the simulation of factors influencing the heat demand.

The main parameters that have been varied in the building's heat demand calculation are the average room temperature, the air exchange rate, the internal gains and finally the warm water demand. To assess the relevance the average room temperature was modified in three steps: -1K, +1K and +2K around the standard value of 19°C (66.2 °F). The air exchange rate was modified around the standard value[6] of 0.7 h^{-1} with a variation of +- 0,1 h^{-1} additionally the value of 1.0 h^{-1} (+0.3 h^{-1}) was calculated representing a realistic value for an existing building. For the internal gains even though the DIN 4108-6 provides more detailed values that would allow to specify a mix of appliances the concurrence of different heat gains seems hard to assess in the framework of this studies. Therefore a modification of the standard value of 5 W/m^2 by +- 1 W/m^2 was calculated.

To assess the relevance of warm water consumption the volume of consumed warm water was modified as the most direct way of user interaction. The possible change of the standard water temperature of 50 °C (122 °F) was not followed for it might not in every case be possible to change the outlet temperature for example when warm water is centrally provided in apartment buildings. From the formula given it follows that a rise in temperature is directly proportional to the heat demand. The modifications made represent a change in behaviour by translating additional use of warm water into the use of cubic meters and then adding the difference of the calculated absolute value and the standard value of heat demand for warm water provision of 12.5 kWh/m^2 to the total annual heat demand. Even though it is acknowledged that the water temperature will be lower with an optimised building standard (Ebel 2003) as the heating system will be laid out to operate on a lower temperature level and therefore in absolute numbers losses should be diminished. The standard value of 750 l or 0.75 m^3 of warm water per person and month seems quite low compared to a measured average value of 570 l/m^{2}a or 1500 litres per person and month[7] (techem 2005). It should be noted that the measurements included consumers with a demand over 2000 l/m^2 such as a nursery school and medical practices that increased the mean value. The relatively large modification seems justified given the high variation in warm water consumption observed by Ebel (2003) where a spread by the factor of seven was measured. Diefenbach (2005) uses a value of 15.6 kWh/m^{2}a that matches the first modification more closely than the standard value provided by DIN 4108-6. In the calculation a monthly consumption of 1094 l per person and month representing an additional shower per week and an additional value of 1524 l per person and month or an additional bath per week were tested.

From the mathematical structure of the energy balance of buildings described above it logically follows that when reducing the overall heat demand the relative importance of the user behaviour increases. Therefore the modifications of user influenced factors were applied to three different building envelopes based on the same layout and volume. The first condition represents the non-renovated building with an annual heat demand for space heating and warm water provision of 270.4 kWh/m^{2}a under standard conditions[8]. The second condition of the building is assumed to be renovated to just match the current energy conservation regulations for new constructions resulting in an annual heat demand of 111.8 kWh/m^{2}a. The third case is calculated according to a performing renovation with an annual heat demand of 64.6 kWh/m^{2}a and thus can be labelled a low energy building (see Diefenbach 2005, Ebel et al. 2003). Although the inclusion of an example of a passive house would have been interesting, the calculation method of the DIN 4108-6 would not provide the means to assess the energy demand of a passive house correctly as the lack of a realistic inclusion of changes in the solar gains already indicated. The then needed change of calculation methods and tools would make the results incomparable. The conducted calculations, however, already show a trend which is additionally supported by comparable results (Richter et al. 2003, Ebel et al. 2003).

Average Room Temperature

Table 1 illustrates the above described modifications made in the calculation of the heat demand. Columns number three, six and nine give

[6] 0.7 h_{-1} is the standard value given in DIN 4108-6 for a building without testing of air tightness.

[7] The measured value of 570 l/m^2 was translated using an average floor space per person of 34,3 m^2.

[8] Standard conditions are given by the standard calculation values of DIN 4108-6: a mean interior temperature of t=19 °C an air exchange rate of n=0,7 h^{-1}, internal heat gains of q_i=5 W/m^2 and a consumption of 750 l of warm water per person and month.

1	2	3	4	5	6	7	8	9	10	11
		non-renovated			refurbished			performing refurbishment		
		kWh/m2a	dQ		kWh/m2a	dQ		kWh/m2a	dQ	
Standard conditions		270.4			111.8			64.6		
Avg. room temperature (t)										
	-1 °C	244.7	-25.7	-10.5%	100.6	-11.2	-11.1%	57.9	-6.7	-11.6%
	+1 °C	297.7	27.3	9.2%	123.7	11.9	9.6%	71.7	7.1	9.9%
	+2 °C	326.9	56.5	17.3%	136.3	24.5	18.0%	79.4	14.8	18.6%

Table 1. Absolute and relative influence of a modified indoor temperature

the calculated values for the annual heat demand for space heating and warm water provision, columns four, seven and ten show the absolute difference to standard conditions in kWh/m^{2}a, while columns five, eight and eleven show the relative difference as a percentage of the total demand[9]. It can be shown that while the absolute values decrease the relative importance of the changes in the average room temperature slightly increases. This is explained by the improved building envelope that reduces the thermal losses and therefore the amount of heat needed to maintain the interior temperature. The high absolute values that the changes in the temperature induce underline the importance of a thorough investigation of the behavioural aspects influencing the average room temperature. In absolute terms the improved performance of the building envelope lessens the negative effect an above average room temperature has on the energy balance.

Air Exchange Rate

The air exchange rate is the product from three main factors, which are the exchange through mechanical ventilation[10], air exchange through joints and finally open windows (see Loga 2003). The latter two also depend on the exposure of the facades and the wind pressure (Eicke-Henning 1999) a fact not taken into account in this first overview. The results of the calculation shown in Table 2 illustrate that though the relative influence rises with a better building standard the absolute changes induced stay nearly constant.

The fact that the absolute value first increases from the non-renovated to the renovated condition can be attributed to the fact that in the transition from one to the other an exchange of the windows was included. The windows and the situation of their placement stayed the same from the refurbished to the performing refurbishment. Here only the quality of the glazing and frames were adjusted.

The underlying standard value of an air exchange of 0.7 h-1 can be judged optimistic for a non-renovated building, it should be noted that even though the value is not unrealistic given the improvement of the standard the share of air exchange through windows will be larger. (Recknagel 2005) provides a bandwidth of 0.1 h-1 to 0.8 h-1 for the air exchange through joints. This high value is reduced to 0.1 h-1 in renovated or newly constructed building (ibid.). The values in Table 3 show that the influence of users can go far beyond the relatively small changes of the air exchange rate calculated in the given examples. Before this background the increase of the heat demand by 21.2% for an air exchange rate of 1 h^{-1} in a low energy house is highly relevant for the overall performance of the building.

1	2	3	4	5	6	7	8	9	10	11
		non-renovated			refurbished			performing refurbishment		
		kWh/m2a	dQ		kWh/m2a	dQ		kWh/m2a	dQ	
Standard conditions		270.4			111.8			64.6		
Air exchange rate (n)										
	-0,1 1/h	264.8	-5.6	-2.1%	105.8	-6.0	-5.7%	58.8	-5.8	-9.9%
	+0.1 1/h	276.0	5.6	2.0%	117.8	6.0	5.1%	70.4	5.8	8.2%
	+0.3 1/h	287.3	16.9	5.9%	129.6	17.8	13.7%	82.0	17.4	21.2%

Table 2. Absolute and relative influence of a modified air exchange rate

[9] The following tables are structured in the same way.
[10] In the framework of this paper it is assumed that no mechanical ventilation is installed in the building.

1	2	3
	lower limiting value in h^{-1}	upper limiting value in h^{-1}
Windows, doors closed	0	0.5
Windows tilted, no blinds	0.3	1.5
Windows half opened	5	10
Windows completely opened	10	15
Windows, doors opened on opposing sides		40

Table 3. Approximate values for air exchange rate, source RECKNAGEL 2005

Internal Heat Gains

As could be expected from the applied calculation method the absolute values of the internal heat gains remain nearly constant through all three cases while the relative importance increases. Even though the internal gains theoretically offset a part of the energy demand as the negative values in Table 4 indicate problems can arise during summertime or in high performing buildings where the increased internal gains have to be compensated by a cooling demand. In a background paper published in 2006 the Federal Environment Agency stated that despite the increase of efficiency of household appliances the energy demand is expected to rise due to the increased usage. For example the number of personal computers used in private households tripled between 1993 and 2003 (UBA 2006).

1	2	3	4	5	6	7	8	9	10	11
		non-renovated			refurbished			performing refurbishment		
		kWh/m2a	dQ		kWh/m2a	dQ		kWh/m2a	dQ	
Standard conditions		270.4			111.8			64.6		
Internal gains (Qi)										
	-1 W/m2	277.0	6.6	2.4%	118.0	6.2	5.3%	70.0	5.4	7.7%
	+1 W/m2	264.0	-6.4	-2.4%	105.9	-5.9	-5.6%	59.4	-5.2	-8.8%

Table 4. Absolute and relative influence of modified internal gains

Warm Water Consumption

As described above as a simplification the value of dQ remains constant, while the relative importance rises. One additional shower per week results in an additional consumption of 5.78 kWh/m^{2}a while an additional bath per week results in an additional consumption of 12.9 kWh/m^{2}a or about the standard value for the total warm water consumption. The results shown in Table 5 demonstrate the high and early constant influence that can be attributed to warm water consumption.

1	2	3	4	5	6	7	8	9	10	11
		non-renovated			refurbished			performing refurbishment		
		kWh/m2a	dQ		kWh/m2a	dQ		kWh/m2a	dQ	
Standard conditions		270.4			111.8			64.6		
Warm water (Vw)										
Shower	+ 1/week	276.1	5.7	2.1%	117.5	5.7	4.9%	70.3	5.7	8.1%
Bath	+ 1/week	283.3	12.9	4.6%	124.7	12.9	10.3%	77.5	12.9	16.6%

Table 5. Absolute and relative influence of modified warm water consumption

DISCUSSION OF THE RESULTS

As expected the influence of the user's behaviour rises with the energy performance of the building. The improvement of the standard has the largest influence on the significance of the average interior temperature; here the absolute losses caused by a higher temperature are partly compensated through the better insulation.

From the initial description of the calculation method it follows that the effects are in theory cumulative even though there seems to be no evident connection between the underlying actions. A cumulating of various effects was not calculated for this paper's intention merely is to identify the significance of the various factors. A combination of different practices would only deliver meaningful results when connected to individual lifestyle patterns allowing predictions about the behavioural aspects described above the air exchange rate, the internal gains and the warm water consumption this discussion now seeks to widen the scope again to discus every-day practices in connection with the calculated modifications.

Regarding the four fields of influence the consciousness of the user's interaction can be expected to vary. While the connection between warm water consumption and heat demand is quite obvious, it can be doubted that the influence of internal gains is considered in the use of home appliances for both the possible positive and negative impacts described above. The use of technical appliances will also be largely connected to spheres of interest other than the use of energy.

In between the two extremes the average room temperature and the ventilation could be located. The former has an obvious connection to the heat demand that can be assumed to be understood by consumers as it is the heating system's main function to provide a constant temperature. The fact that the building's insulation reduces the influence of the average room temperature is a logic conclusion from the calculations but might be less well understood. In general a user changing the average room temperature will be aware of the demand of additional or less heat supply to match his needs. In comparison to that the air exchange rate is less clearly linked to energy awareness. As Haberda and Trepte (Haberda/Trepte 1988, quoted after Richter 2003) points out the "strong rootedness of window opening behaviour in functional daily routines (e.g. airing of bed linen; removal of smells from cooking; sleeping with opened windows)"[11] makes an operationalisation of ventilation behaviour quite impossible.

As a conclusion from the identification of the relevant parameters it is suggested to structure the different behavioural aspects in an analytical framework defined trough the user's level of awareness and the means to change the individual behaviour (Figure 2). Awareness is in this context defined as an understanding that one's own behaviour is influencing the energy demand as well as knowledge about all aspects that are relevant to the energy demand. The means include both the technical means and the necessary level of precision and usability to interact.

[11] Translation by the authors after Richter (2003)

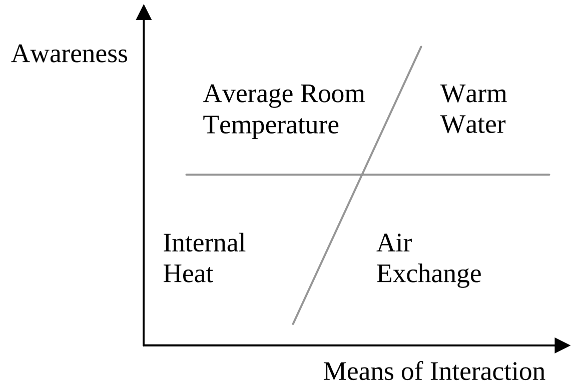

Figure 2. Means of Interaction and awareness

The localisation of the different areas of action is in this first approach based on a qualitative assessment, while further research could help to verify the suggested analytical method.

The internal heat gains are currently not necessarily understood as part of the heat demand balance. The focus of public campaigns such as the initiative for a higher energy efficiency[12] of the German Energy Agency (dena) for the residential sector lies on the electrical power consumption and does not consider the number and simultaneous use of appliances. The use of many household appliances is essential to certain lifestyles, reducing the number of consuming devices would mean a restriction in the needs or wants in a field not perceived as related to heat demand at all. Therefore the internal heat gains are located in the lower left corner of the diagram (Figure 1). With a focus on energy demand there are few possibilities to influence the heat gains and a low level of awareness is assumed.

In the case of the air exchange rate only a partial awareness exists as discussed above many practices are not seen as connected to the heat demand. Other practices like opening the windows for ventilation purposes are more clearly linked to consuming more energy. For this case Haberda and Trepte (1988) state that many occupants did not "perceive tilted windows as a measure of ventilation"[8]. On the other hand the means to influence heat losses through window ventilation are understood, even if it can be doubted that an efficient behaviour is possible (Eicke-Henning 1999) for a lack of immediate feed-back.

[12] Initiative Energieeffizienz, http://www.initiative-energieeffizienz.de/

For the mean room temperature the situation is quite the opposite. Even though there will usually be a device to interact with the heating system such as the in the German context widely used thermostatic valves in many cases the scale of control is not transparent for the user as it depends on the installation, positioning and possible coverage of the valve. The average installed valve has a precision of 2K (Clausnitzer 2004) which would not be precise enough to differentiate between the variations in parameters discussed in the calculations. The possibilities to precisely control the system therefore increase by 20% to 30% (ibid.) when installing thermostats per room allowing for a higher precision as well as options to programme the heat demand. Regarding the awareness an understanding of the interconnection of high indoor temperatures and a high energy demand can be presumed. Finally looking at the volume of warm water consumed it can be expected that again the user is aware of a direct link to the energy demand but in this case is also informed about measures to reduce his or her consumption by substituting bathing with showering or reducing the time per shower, etc..

It follows from the hypothesis postulated above those different behavioural aspects of heat demand require different approaches to improve the overall demand. Following the categorisation of the warm water demand there are barriers preventing substantial savings in energy demand that are neither problems of information nor of technology. The possible behavioural solution would be a change of lifestyle as promoted by the Wuppertal Institute in the developed concept of "Suffizienz" (see Linz 2004, 2002). While in the case of the mean room temperature a more technological approach of improving control devices could be suitable. If the description of the current situation of temperature regulation can be verified the precise control of the heating system should play a much larger role in energy assessments as the devices installed can be assumed to have a large influence on how precisely the user can match his or her needs with the demand. The calculations show a deviation of +-18.6% in a low energy house's heat demand caused by a difference of 2K, the limit of conventional thermostatic valves' precision.

Known Limitations of the Approach

The already discussed limitation that solar gains could for methodological reasons not be considered in the assessment of the significance of behavioural influences on the annual heat demand is deemed acceptable as both Hausladen (2003) and Richter (2003) eventually did not consider solar gains as well for lack of significance. The latter delivered comparable results with a more sophisticated calculation model which suggests that the simplifications made in the calculation method used do not excessively influence the results. In case the investigation would be enlarged to encompass passive houses the calculation method and the assessment of the significance of the solar gains would have to be revised.

As a theoretical approach the study conducted did not investigate the influence of different building standards on the needs of the inhabitants. In their analysis of user influences on the performance of a passive and low energy house settlement Ebel (2003) found the average interior temperature in passive houses to be higher than in low energy houses. This suggests that behaviour can be expected to change within a different environment.

Finally the discussion was focused on the means of interaction still it is not well understood what triggers this interaction. The system of Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) as described in the PMV-PPD indices (ISO 7730, see also Recknagel 2005) could provide a useful approach to describe the willingness to change behaviour or to implement building measures.

Need For Further Research

The aim of investigation in the behavioural aspects of energy demand and consequently consumption is to identify paths towards a higher level of energy efficiency or more sustainable energy consumption. When further specified and validated on a statistical basis a framework as suggested in the discussion of the results would be able to form a first step towards a comprehensive concept of lifestyles or milieus as both acknowledge that "not the social situation of people but their awareness and lifestyle"[13] (INWIS 2003) form the relevant factor. The linkage with the technological point of view delivered through the assessment of factors of the energy balance of buildings provides a promising approach. Despite the relative importance the user behaviour has with increasing energy standards a "comprehensive behavioural approach" (Wortmann/ Schuster 1999) enabling communication between social science and engineering disciplines still has to be found.

Additionally a concept identifying parameter specific communication or technical measures would

[13] Translation by the authors after INWIS 2003

help to improve the efficiency of energy services for consumers. For a complete overview of the residential heat demand different types of housing should be assessed and the results validated through thermal simulation. In a further step the balancing procedures used could be replaced by those defined by the DIN V 18599[14]. This would not only allow the assessment of non-residential buildings but would also provide a method to describe individual occupancy scenarios and deliver results that in absolute terms can be expected to match the actual energy consumption for space heating more accurately (Erhorn et al. 2007).

To further support the argument laid out in this paper additional data could be collected by parallel interviews and measurements to identify the significance of different aspects of lifestyle. Such a twofold proceeding has been used in the monitoring of passive houses by Ebel (2003), though it did not encompass a wider field of lifestyle specific questions that would be necessary to better understand the strong linkages between behaviour and energy consumption.

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[14] Also values for the residential sector should in that case be recalculated as both calculation procedures among other differences use different reference surfaces.

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