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# **Should it be automatic or manual – the occupant's perspective on the design of domestic control systems**

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## **Abstract**

The level of automation is one of the central issues in designing control systems. Occupant attitudes towards different levels of automation in domestic control systems were studied using a qualitative interview method. The following systems were considered: (1) control of indoor thermal environment, (2) peak load management, and (3) own energy production. For each system, four solutions representing different levels of automation were created. The interviewees gave comments on the solutions and chose the alternatives they preferred. The results show that decisions on the level of automation should be made carefully, taking account of the special qualities of each system without neglecting the individual differences between users. Full automation is not suitable for systems that considerably affect indoor environmental comfort. The interviews revealed a large amount of mistrust towards automation. An important question is how to improve the level of trust between the occupants and automation, i.e. how to make the occupants trust the automation in cases where better results would be gained through the utilisation of automation. The following system characteristics may potentially improve the level of trust:

(1) carefully chosen level of automation, (2) predictability, transparency and feedback, (3) simplicity and usability and (4) suitability for everyday life.

Keywords: level of automation; domestic automation; manual control; individual control; trust in automation; qualitative interview study; thermal comfort; peak load management; own energy production; individual differences

## 1. Introduction

In an ideal world, the indoor environment would adjust itself fully automatically and continuously to individual preferences and no interaction with the occupant would be needed. It is optimal that no user interaction is needed because there is a cost involved in the exercise of temperature control [1].

In reality, some amount of user interaction is necessary in order to create individually comfortable environments. The reasons for the need for user interaction are highlighted below, using the example of the control of the indoor thermal environment:

- Thermal comfort depends on room air temperature, mean radiant temperature, relative air humidity and relative air velocity [2]. The real time measurement of all of the variables requires a great deal of instrumentation. For control purposes, room air temperature (and humidity) are the only levels typically measured.
- Clothing and activity level influence thermal comfort [2]. To work optimally, automatic control systems should adjust the thermal environment taking account of the current activity level and clothing, which is only possible in futuristic scenarios.

- Thermal comfort also depends on one's psychological state<sup>1</sup> (e.g. [4–6]). It is not possible to predict how an individual is going to regard the thermal environment at any particular time.

So it is not enough to measure indoor environment variables: individually comfortable conditions can only be created when the occupant is involved in the control loop. The need for personal control is widely recognised in thermal comfort studies (e.g. [2, 7–8]). There are, however, different ways of producing effective control over the indoor environment for the occupants. It is not wise for the system to disturb the users now and then by asking, "Is the room temperature fine for you?" It is probably a better idea for the occupant to be responsible for initiating the interaction. However, it is clear that the room temperature should be easily adjustable - and the effect on the room temperature should be rapid [9-12].

The second example here concerns demand-side management, an approach to reducing peak power demand in a smart grid. An ideal system would reduce the peak load largely without interfering with the occupants and household activities in any way and allowing the normal use of all domestic appliances all of the time. In reality, only a limited reduction in peak load can be achieved without any user inconvenience. The question here is the following: What kind of role should the user have so that they can accept the way in which the system works while achieving a significant reduction in peak load? Should we create fully automatic systems? Or should the occupants be given the central role in peak load management? To achieve a good balance between automation and manual operation, we need to understand the users, i.e. their needs in everyday life, their motivating factors and their ways of using such systems.

The third example concerns own electricity production in households. The target is to produce a major part of consumed energy locally using solar collectors, wind turbines or other sources of renewable energy. The surplus energy can be sold to the energy grid for the use of other consumers (if the necessary contracts have been put in place). It may also be possible to store the surplus energy in the house for future use. The occupant of the household should be able to monitor the amount of energy used and produced and the balance between them. The system could work automatically with no interaction with the occupants. But is it reasonable to give the occupants a role in controlling the system? Should they somehow be able to decide when to sell energy and when not to buy it, or it is wiser for a pre-programmed control strategy to be responsible for making such decisions? Is there any profit to be gained from the active incorporation of occupants in the control of renewable energy production (the installation of such systems is outside the scope of this paper)?

The purpose of this article is to investigate the role of the occupants in the control of energy systems in residential buildings. The aim is to study the attitudes of end users towards different kinds of automation solution and to find out what kinds of solution are preferred by end users. Particular attention is paid to the appropriate level of automation.

## **2. Level of automation**

For each system, one can raise a question on the appropriate level of automation. Automation is able to perform repetitive tasks quickly, accurately and without fatigue. Humans have intelligence that is very difficult or impossible to reproduce in artificial

intelligence. A number of measurements can be performed in a building, but the occupants are the principle source of information on their own comfort.

A scale of automation levels was created by Sheridan and Verplank [13] (the version here is adapted from their work):

1. Automation offers no assistance, human must do everything.
2. Automation offers a complete set of action alternatives, and...
  - a. narrows the selection down to a few, or
  - b. suggests one, and
    - i. executes the suggestion if the human approves, or
    - ii. allows the human a restricted time to veto before automation execution, or
    - iii. executes automatically, then necessarily informs the human, or
    - iv. informs the human after execution only if the human asks, or
    - v. informs the human after execution if the automation decides to.
3. Automation decides everything and ignores the human.

Table 1 presents examples of different levels of automation in the three systems chosen for the analysis. The analysed systems are: (1) control of indoor thermal environment, (2) peak load management and (3) own energy production. Four levels of automation are presented for each system. A descriptive scenario for each is shown in the table.

[Table 1]

The target of this work is study user attitudes regarding the level of automation in domestic energy systems.

### **3. Methods**

Interviews were performed to study occupant attitudes to different kinds of control system with different levels of automation. The systems included were: (1) control of indoor

thermal environment, (2) peak load management and (3) own energy production. For each system, an introductory scenario was written and four alternative solutions were prepared. The interviewees were asked to give their comments on each of the solutions. In addition, they were asked to choose between the four alternative solutions, i.e. they reported which option they would prefer for their own use. The introductory scenarios and alternative solutions are shown in Table 1. The interviewees have previous personal experience of the control of indoor thermal environments but most of them are not familiar with the other two systems studied in this work. It is clear that attitudes may change when actual use is experienced.

The interviews were semi-structured: not all of the questions were designed and phrased beforehand, but many questions were created during the interview, allowing for flexible discussion. The comments given by the interviewees were written down during the interviews.

A total of 14 interviews were carried out in Finland. The participants were chosen from diverse educational backgrounds, so the study involved people with education levels ranging from basic to university degree. Four of the interviewees had their educational background in technology (or in a related field) and ten of them did not have that kind of background. The participants were between 20 and 70 years of age, and six females and eight males were interviewed. The interviews were performed in Finnish and the comments given by the interviewees have been translated from Finnish into English for this publication.

#### **4. Results**

The qualitative interviews were performed to study occupant attitudes towards various systems representing different levels of automation. The interviewees were presented alternative solutions on which they gave their comments and they finally chose the alternative that they preferred. The alternative solutions are shown in Table 1 along with the related scenarios. The results are presented in Tables 2–4.

[Table 2]

The interviewees clearly preferred automation levels 2/4 and 3/4 for the control of the indoor thermal environment (Table 2), i.e. the occupants want to have thermostats and it is important to be able to adjust the room temperature set points. This result is in agreement with thermal comfort studies that highlight the need for individual control (see Introduction).

However, it is common for thermostats to be used only rarely, as described by the interviewees: “We use thermostats only a couple of times a year at home” [i3] and “I/we do not use the thermostat often but I/we want to have the possibility to use if I/we want to” [i6,i12]. This means that thermostats are important even if they were not used because they give the possibility of adjusting the room temperature if the occupant is hit by “the crisis of discomfort”.

Two of the interviewees living in apartments disagreed, i.e. their view was that occupants should not be given any opportunity to adjust room temperatures because this leads to increased energy consumption. There is no individual metering of heating energy in apartments, so the heating costs are shared (for example, based on square metres), i.e. the additional energy used for increasing the room temperature above the norm is paid for not only by the occupants who want to have a higher room temperature but by everyone.

This is the reason why some respondents would limit the possibility of controlling the room temperature in each apartment.

[Table 3]

The results regarding own energy production (Table 3) show that only some of the interviewees were ready to leave the decisions on when energy is produced, stored and sold to the automated system. This group does not want to bother their daily life with energy production and does not want to act as the operator for such a system.

However, many others were interested in making the decisions on when energy is produced, stored and sold. Most of them are not experts in such systems but still want to be able to program the system and affect how it works. They explained their willingness to act as the operator using their mistrust for automation, i.e. they want to be in control of a system in which they do not trust.

[Table 4]

For peak load management, most of the interviewees chose automation level 3/4 which gives a compromise between automation and manual operation (Table 4), i.e. savings in energy costs are gained automatically but the occupants are able to override the restrictions and use all of their systems and devices even when the price of electricity was very high.

The fully automatic system that prevents energy use and gives no opportunity for override was considered too restrictive and was not chosen by anyone. Neither was the first option in Table 4 chosen by anyone, even though it was assumed in the introductory scenario that the effect on the yearly electricity bill would be reasonably small (max 5–10%).

Several interviewees considered option 2 (automation level 2/4) not suitable for everyday life, because it is not trouble-free to plan one's own electricity use in advance. However, some others said that they could make decisions on their energy use based on the energy price for the next day. The most positive attitudes came from those living in a single-person household.

The interviewees were also asked to give their comments on smart washing machines and dish washers which turn on in reaction to a price signal, i.e. when the electricity price is low enough. A few interviewees said that they would use such a system to gain savings, but many others were sceptical about its suitability for everyday life. The attitudes were mostly negative:

- I do not want to keep dirty clothes in the washing machine. I want the washing machine to start soon after the clothes have been put in the machine. [interviewee 1]
- I would not like it if the machine started during the night because of the noise. [i1]
- I do not want to leave the tap (for the washing machine or dish washer) open for a long time or when I'm not at home. The insurance would not cover the possible water damage. [i1]
- Sounds terrible. I do not like the washing machine to run when I am not home, because there is a risk of water damage. And if the clothes are not instantly taken out of the washing machine when it finishes, they will become mouldy. I understand that savings are gained, but the cost of electricity used by the washing machines is not important. [i12]
- It is an interesting idea to have a smart washing machine or dish washer. It may work if there is no instant need for washing. In a family with children it would not work. You need to use the washing machine twice a day. We cannot leave the machine on when we are not home (because of safety reasons regarding fire or water damage). [i3,i14]
- I could postpone washing my clothes if I was informed how many euros I was saving by doing this. [i14]
- Not a good idea. When I wash clothes (/dishes), I want them to be ready quickly. [i4,i11]
- No real savings in a single person household. [i10]
- This could work if it sent a message to the mobile phone when it had finished washing the clothes. However, you need to know the approximate time when it will be finished beforehand. I cannot leave wet clothes in the machine for the whole working day. [i13]

The interviewees were told about the idea of adaptive control systems that learn from the occupants' behaviour and could be implemented in each of the three systems considered in this study (control of room temperature, own energy production, peak load management). Many respondents saw that they could benefit from the adaptive systems while others were sceptical about whether the systems really understand the needs of the occupants. Concerns were also raised about the costs and the increased amount of technology involved.

The following comments describe the occupants' attitudes towards adaptive systems:

- It is generally a good idea to have that kind of automation if it really does what the occupant wants [i1,i11]
- This works in a single person household, but when there are more people their preferences will diverge. [i1]
- It is a good thing if there is no need to make frequent adjustments. [i2]
- This may lead to savings and improve the ease of use. [i2]
- I personally prefer not to have too much technology. [i3]
- I am away from home for ten hours a day. The room temperature could be lower during the period. The temperature could be lower also when I am asleep. [i6]
- It could work for controlling room temperature. [i10]
- I sense the room temperature by myself, so there is no need for such a system. [i14]
- Could be useful if it saves heating energy. [i13]
- I do not think that much additional value is gained by this kind of system, but there will be additional costs. A lot of occupant behaviour is already known through the hourly measurement of electricity. [i9]
- I do not believe that the system can understand my motivations. For example, if I go to the sauna on Thursday after I return from skiing, it may incorrectly learn that I want the sauna to be heated every Thursday. The mathematical calculations are based on statistical probabilities and do not understand my needs. [i12]

## 5. Discussion

Decisions on the level of automation are very important for the performance of control systems and user acceptance. Parasuraman and Riley [14] state that the role of operators should be defined based on the operators' responsibilities and capabilities, rather than as a by-product of how the automation is implemented. Previous studies have mostly been concerned with the professional operation of control systems and do not deal with domestic environments in which every one of us can act as the operator.

This study examined occupant attitudes towards different control systems. The results show that the suitable level of automation is not constant between different systems and different users, i.e. decisions on the level of automation should be made carefully, taking into account the special qualities of each system without neglecting individual differences between the users. It is clear that the occupants should have a central role in the control of room temperature. There are individual and time-dependent differences in how thermal environments are experienced, and the occupants are the only reliable source of information on their thermal satisfaction.

The interviews revealed a large amount of mistrust towards automation. Many respondents clearly stated that they want to be in control of the system (e.g. their own energy production). It is remarkable that although the occupants generally have very limited knowledge on how the energy systems work, they still want to remain in control of such systems. In some cases, it can be supposed that a fully automatic system would work better in reality, i.e. an automated system may be more capable of controlling separate sub-systems of energy production than a manually operating occupant who is not an expert in such systems. However, a small minority of occupants are capable and have the motivation, and could successfully act as the operators of complex energy systems.

It is well known that people are not always willing to put sufficient trust in automation, or, on the other hand, they may rely on automation inappropriately (e.g. [15]). A considerable amount of mistrust of automation was also found in the present study. This mistrust may be partly related to the special qualities of the domestic environment. There is a tradition (at least in Finland where this study was executed) that domestic work tasks are performed by the occupants themselves. Many people have even built the houses they live in by themselves. So it somehow seems natural that they would want to be in control of all of their domestic systems.

An important question is how to improve the level of trust between the occupants and automation, i.e. how to make the occupants trust the automation in cases where it could be supposed that better results would be gained through the utilisation of automation rather than through manual operation by the occupants.

The following system characteristics may potentially improve the level of trust between the occupants and domestic automation. The list is partly based on previous studies not dealing with domestic automation and is not validated in this work.

- Carefully chosen level of automation
  - Automation is implemented on a level that is appropriate from the point of view of the occupants.
  - Repetitive tasks are performed by the automation but the most important decisions are made by the occupants (assuming that there is a good reason for occupant interaction).
  - Full automation is not suitable for systems that considerably effect indoor environmental comfort. For such systems, the opportunity for individual control by the occupants is necessary. In particular, if an energy system is

prone to have a negative effect on occupant comfort, it should not be fully automatic but allow user control. An example of that kind of system is a heat pump (air conditioner) that may produce noise and draughts.

- Predictability, transparency and feedback
  - Predictability, transparency and feedback are important to understand why the automation is working like it is. The concept of predictability refers to the extent to which a user can predict the effects of their own actions, and the concept of transparency refers to the extent to which a user can understand how the system works [16].
  - The occupant should receive a suitable amount of feedback. Parasuraman and Riley [14] state that the more removed the operator is from the process, the more feedback is needed to compensate the lack of involvement. Vastenburg et al. [17] state that people want to be informed of urgent messages as soon as possible, whereas non-urgent messages should not be presented at all. It is also important to maintain a low level of false alarms, since false alarm problem is prone to producing mistrust [14]. Both the decision threshold and the base rate of the hazardous condition must be chosen carefully in order to avoid false alarms and to gain the trust of operators [14].
- Simplicity and usability
  - Simplicity is one of the key issues in designing systems that perform well in the real building environment. Bordass and Leaman [18] write that overly complex building systems are a major deterrent to efficient and effective building operation. User satisfaction studies have revealed significant gaps between the design intent and the performance of buildings [19].

- Usability is a quality attribute that assesses how easy and pleasant the system is to use. It is closely related to the above-mentioned concepts of predictability, transparency, feedback and simplicity. Users are more willing to use systems that are usable than those that are hard to learn and use efficiently.
- Suitability for everyday life
  - A system that does not fit in with everyday life but demands an unwanted change in occupant behaviour is not welcomed and accepted. Instead of adding more responsibilities to the occupants' lives, domestic technology should add more freedom. The interviewees in this study gave very critical comments about smart washing machines, i.e. they see many practical problems in fitting them in to their everyday life.

It is clear that there are large differences in the capabilities of occupants to act as the operators of domestic energy systems. Most of the occupants do not have any special knowledge about these systems, but a minority could be considered to be experts. Some are very motivated to act as the operator. Vassileva et al. [20] stress that occupants should be considered as a diverse group of people with different needs and lifestyles.

Parasuraman and Riley [14] state that better operator knowledge of how the automation works results in the more appropriate use of automation. They also believe that knowledge of the automation design philosophy may encourage more appropriate use.

It is unrealistic to suppose that we could educate occupants to be experts in automation and energy systems. Domestic energy systems should be suitable for different kinds of user, for those who are experts in such systems and for the majority who have a very limited knowledge of these systems.

The concept of adaptable automation has been described in the literature, with the idea that the level of automation should be adjustable *during* system operation (e.g. [21–24]). Miller and Parasuraman [23] state that operators should be able to choose a point on the spectrum for their interaction with automation. This means that the decision about how much and what kind of responsibility to delegate lie in the hands of the operators at execution time, rather than having been defined and fixed by the designer of the system. Adaptable automation could have potential in domestic systems because of the large individual differences among occupants. A disadvantage of adaptable automation is that it adds complexity to the system.

The level of automation may have a relationship with user engagement (as stated by one of the interviewees). If the energy system is not fully automatic but the user is able to control the system, the user may develop a closer relationship with the system, which in turn may lead to an increased interest in energy efficiency and lower energy consumption. More work is needed to study the prospects for occupant engagement (see e.g. [25]).

## **6. Conclusions**

The level of automation is centrally important for the design of automation. Decisions on the level of automation should be made carefully, taking into account the special qualities of each system without neglecting individual differences between the users.

The interviews revealed a large amount of mistrust towards automation among the occupants. The occupants stated in the interviewees that they want to be in control of the systems. In some cases it can be supposed that better results in terms of energy efficiency could be gained if the automation was responsible for controlling the system and the role

of occupants was limited. This is because the occupants are not experts in such systems and are often not capable of acting as the operator. There are, however, large individual differences in this capability and motivation among the occupants.

The important question is how to improve the level of trust between the occupants and automation, i.e. how to make the occupants to trust the automation in cases where it could be supposed that better results would be gained through the utilization of automation rather than through manual operation by the occupants.

The following system characteristics may potentially improve the level of trust between the occupants and domestic automation: 1) carefully chosen level of automation, 2) predictability, transparency and feedback, 3) simplicity and usability, and 4) suitability for everyday life.

Finally, it is important to note that full automation is not suitable for systems that considerably affect indoor environmental comfort, i.e. it is important there to provide individual control opportunities.

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## Footnotes

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<sup>1</sup> Thermal comfort is defined as "the condition of mind that expresses satisfaction with the thermal environment" [3]

## Tables

Table 1. Example solutions representing different levels of automation for three domestic systems.

	<b>Control of indoor thermal environment</b>	<b>Own energy production</b>	<b>Peak load management</b>
Introductory scenario	The house is heated by radiators.	The occupants also produce energy. Solar panels have been installed on the roof. Energy is also produced by a ground heat pump. The occupants are able to sell the energy if they do not need it for their own use. The occupants receive information on the amount of energy they have produced and consumed.	The price of electricity for occupants is not constant but changes every hour. The average price of electricity (per kWh) is similar to a constant tariff but the hourly price of electricity can be 10 or 100 times higher for short periods of time. These situations are, however, quite rare and only slightly affect the price of the yearly bill (max 5–10%).
Low level of automation	The radiators that heat the rooms can be turned on and off by the occupant depending on their own preference. The user may need to perform this often, even several times a day, if the outside temperature or other factors change. There are no thermostats in the system for sensing and controlling the room temperature.	The occupant is able to program the system and can affect how the system works. With these settings, the occupant is able to make decisions on when energy is produced, stored and sold.	The electricity system is not aware of the current price of electricity and the operation of the electricity systems is not affected in any way by the changes in the electricity price. The occupants pay according to the changing price, which may be 100 times higher than normal for a short period of time. The effect of this on the yearly bill is small.
Automation level 2/4	The heating system is equipped with thermostats which keep the room temperature in a level that is satisfactory on average. The occupant can alter the temperature within a degree or two Celsius by adjusting the thermostats. If the occupant has restrictive requirements on room temperature, they need to adjust the settings occasionally.	The occupant can make decisions on which system primarily produces energy. The occupant can inform the system of the amount of energy that the household will need in the near future. The system utilises all of this information in the energy production.	The occupants are informed about the high price of electricity beforehand, during the previous day. They can make decisions on their energy use based on this information, i.e. they can advance or postpone heating the sauna and using the washing machine, for example.
Automation level 3/4	The heating system is equipped with thermostats that keep the room temperature at 21–22 °C. The occupant	The occupant can inform the system of the amount of energy that the household will need in the near future. The	The electricity system is automatic and aims at saving costs by preventing the usage of those systems and

	<b>Control of indoor thermal environment</b>	<b>Own energy production</b>	<b>Peak load management</b>
	can adjust the temperature between 19 and 24 °C. The control system keeps the room temperature close to the chosen value until the setting is changed.	system utilises this information in the energy production.	devices that consume a large amount of electricity. The restriction of use is only activated in situations in which the electricity price is both high and higher than it will be during the following hours. The occupants can override the restriction and use all of the systems and devices even when the price of electricity is very high.
High level of automation	The heating system is fully automatic. It keeps the room temperature at a level (21–22 °C) that is comfortable for an average occupant. The heating system does not allow the occupant to adjust the temperature.	All of the systems that produce energy are fully automatic. The occupants are not able to affect the way in which the systems work.	The electricity system is automatic and aims at saving by preventing the usage of those systems and devices that consume a large amount of electricity. The prevention of use is only activated in situations in which the electricity price is both high and higher than it will be during the following hours. This means that some systems/devices (for example, electric sauna or washing machine) cannot be used during certain hours. This results in a lower electricity bill than in the other cases above.

Table 2. Occupant attitudes towards various automation levels of control of the indoor thermal environment. Only a selection of comments given by the interviewees is presented (together with the code numbers of the interviewees). The column on the right shows the code numbers of the interviewees who preferred the alternative over the others. The scenario presented to the interviewees is shown in Table 1.

	<b>Description</b>	<b>Comments</b>	<b>Preferred by interviewees</b>
Low level of automation	The radiators that heat the rooms can be turned on and off by the occupant depending on their own preference. The user may need to perform this often, even several times a day, if the outside temperature or other factors change. There are no thermostats in the system for sensing and controlling the room temperature.	<ul style="list-style-type: none"> <li>• The temperature is changing too much [i4]</li> <li>• This is worst of all because the system bothers the occupants continuously [i2]</li> <li>• No thermostats, no one wants this nowadays [i5]</li> <li>• Older people may be used to this kind of system [i3]</li> <li>• Infeasible, too much work [i9,i10,i11]</li> <li>• This is my choice. I want to decide when I am heating and when not [i14]</li> </ul>	i14
Automation level 2/4	The heating system is equipped with thermostats which keep the room temperature in a level that is satisfactory on average. The occupant can alter the temperature within a degree or two Celsius by adjusting the thermostats. If the occupant has restrictive requirements on room temperature, they need to adjust the settings occasionally.	<ul style="list-style-type: none"> <li>• It is better not to be able to control the temperature within more than two degrees (in a building owned by a housing company) from the point of view of the overall performance of the heating system and energy consumption [i3]</li> <li>• One or two degrees is not enough [i9]</li> </ul>	i3
Automation level 3/4	The heating system is equipped with thermostats that keep the room temperature at 21–22 °C. The occupant can adjust the temperature between 19 and 24 °C. The control system keeps the room temperature close to the chosen value until the setting is changed.	<ul style="list-style-type: none"> <li>• Automation and the possibility to adjust the temperature – this is my choice [i10]</li> <li>• I prefer this because two degrees (in the alternative above) is not enough [i2,i6]</li> <li>• This is best, I want some rooms to be colder than others [i5]</li> <li>• I have rheumatism and need a higher temperature than most other people [i11]</li> <li>• It is pleasant to have a lower temperature than 21 °C during the nights (and savings are made on heating costs) [i13]</li> <li>• This is trouble free and gives individual control. If the heating costs raise considerably, I can lower the room temperatures [i12]</li> </ul>	i1,i2,i4,i5,i6,i8,i9,i10,i11,i12,i13

	Description	Comments	Preferred by interviewees
		<ul style="list-style-type: none"> <li>• Not much difference between this and the alternative above [i1]</li> </ul>	
High level of automation	The heating system is fully automatic. It keeps the room temperature at a level (21–22 °C) that is comfortable for an average occupant. The heating system does not allow the occupant to adjust the temperature.	<ul style="list-style-type: none"> <li>• It is very unpleasant not to be able to affect the temperature [most interviewees]</li> <li>• I'd like to have it colder in some rooms [i10, i14]</li> <li>• I learned in my plumbing training that it is best not to give the occupants the possibility to adjust room temperatures. Enormous energy savings are gained if occupants are not able to adjust temperatures. 20–21 °C is suitable according to the norms [i7]</li> </ul>	i7

Table 3. Occupant attitudes towards various automation levels of their own energy production. Only a selection of comments given by the interviewees is presented (together with the code numbers of the interviewees). The column on the right shows the code numbers of the interviewees who preferred the alternative over the others. The scenario presented to the interviewees is shown in Table 1.

	<b>Description</b>	<b>Comments</b>	<b>Preferred by interviewees</b>
Low level of automation	The occupant is able to program the system and can affect how the system works. With these settings the occupant is able to make decisions on when energy is produced, stored and sold.	<ul style="list-style-type: none"> <li>• Not for an average family. There is already enough activity in life without producing energy. This leads to additional stress. Suitable only for those who want to have this as a hobby [i1]</li> <li>• I have no need to make decisions on which system produces the energy and which part is sold, so this is not my choice [i6]</li> <li>• Too complicated [i12]</li> <li>• Occupants may make incorrect choices with this kind of system. However, for me this could be the best alternative. For many others full automation is more suitable [i3]</li> <li>• This is best because I have the possibility to control it by myself [i5]</li> <li>• I do not trust automation and I want to control it by myself [i7]</li> <li>• I'd like to program the system by myself if it is easy enough [i9]</li> <li>• This in my choice although I do not have the capability to operate such system [i11]</li> </ul>	i3,i5,i7,i9,i11
Automation level 2/4	The occupant can make decisions on which system primarily produces energy. The occupant can inform the system of the amount of energy that the household will need in the near future. The system utilises this information in the energy production.	<ul style="list-style-type: none"> <li>• It is good to have an opportunity to adjust the system [i4]</li> <li>• How could I know how much energy is needed in the near future [i5,i6]</li> <li>• It could inform the system when I want to use the heat pump and when not (the interviewee is worried about the noise and draughts that a heat pump may produce) [i8]</li> <li>• I would like to choose which system produces the energy but we have no special use of energy to inform it about [i12]</li> <li>• I'd like to be able to inform the system that we are not at home during the next two weeks [i14]</li> </ul>	i2,i4,i10,i12,i13,i14

	Description	Comments	Preferred by interviewees
		<ul style="list-style-type: none"> <li>I want to make some decisions by myself [i13]</li> </ul>	
Automation level 3/4	The occupant can inform the system of the amount of energy that the household will need in the near future. The system utilises this information in the energy production.	<ul style="list-style-type: none"> <li>This is simple [i14]</li> </ul>	i8
High level of automation	All of the systems that produce energy are fully automatic. The occupants are not able to affect the way in which the systems work.	<ul style="list-style-type: none"> <li>May be suitable for many others, but if I invest in such a system, I want to use it as efficiently as possible. I do not fully trust the automation but I want to control by myself [i2]</li> <li>Suitable for an apartment house [i4]</li> <li>I do not understand how the automation can know which system to use [i5]</li> <li>I do not know this system so I cannot trust the automation and do not want this [i7]</li> <li>I think I should have more control over the systems [i10,i14]</li> <li>I do not trust a fully automatic system - I think that the automation will get stuck and I have to ask someone to fix it [i12]</li> </ul>	i1,i6

Table 4. Occupant attitudes towards various automation levels of peak load management. Only a selection of comments given by the interviewees is presented (together with the code numbers of the interviewees). The column on the right shows the code numbers of the interviewees who preferred the alternative over the others. The scenario presented to the interviewees is shown in Table 1.

	Description	Comments	Preferred by interviewees
Low level of automation	The electricity system is not aware of the current price of electricity and the operation of the electricity systems is not affected any way by changes in the electricity price. The occupants pay according to the changing price which may be 100 times higher than normal for a short period of time. The effect of this on the yearly bill is small.	<ul style="list-style-type: none"> <li>I would like to avoid the use of the electric sauna when the price of electricity is high, so I do not like this option [i6]</li> <li>This is OK because the effect on the yearly electricity cost is small [i9]</li> </ul>	
Automation level 2/4	The occupants are informed on the high price of electricity beforehand, during the previous day. They can make decisions on their energy use based on this information, i.e. they can advance or postpone heating the sauna and using the washing machine, for example.	<ul style="list-style-type: none"> <li>It is good to be informed about the electricity price although I don't think that it will be remembered the next day [i2]</li> <li>It is terrible if I have to know beforehand when I want to go in the sauna [i5,i12]</li> <li>This is not suitable for everyday life [i4]</li> <li>I could use a computer to check the energy price for the next day and make decisions on energy use based on that [i7]</li> <li>I could plan my electricity use one day ahead [i9]</li> <li>It is good to know about the high prices beforehand [i10]</li> </ul>	i6,i7,i10,i14
Automation level 3/4	The electricity system is automatic and aims at saving by preventing the usage of those systems and devices that consume a large amount of electricity. The restriction of use is only activated in situations in which the electricity price is both high and higher than it will be during the following hours. The occupants can override the restriction and use all of the systems and devices even when the price of electricity is very high.	<ul style="list-style-type: none"> <li>This is my favourite. The energy price is monitored by the system but the occupants are able to override it [i2,i9]</li> <li>I do not understand much about these systems but this sounds good [i4]</li> <li>It would be troublesome to use the override [i6]</li> <li>It sounds strange to prevent the usage of electricity [i7]</li> <li>I do want the system to control the usage of electricity [i14]</li> <li>It is good to be able to use all of the devices not depending on the electricity price [i8]</li> <li>This is my choice but I want to</li> </ul>	i1,i2,i3,i4,i5,i8,i9,i11,i12,i13

	Description	Comments	Preferred by interviewees
		know the price of electricity beforehand. It is too late to get this information when we have decided to go in the sauna [i13]	
High level of automation	The electricity system is automatic and aims at saving by preventing the usage of those systems and devices that consume a large amount of electricity. The prevention of use is only activated in situations in which the electricity price is both high and higher than it will be during the following hours. This means that some systems/devices (for example, electric sauna or washing machine) cannot be used during certain hours. This results in a lower electricity bill than in the other cases above.	<ul style="list-style-type: none"> <li>• This is the worst option of all. There is no sense if the system decides what one can do at home. Acceptable only in a crisis situation [i2]</li> <li>• This is too restrictive [i4,i14]</li> <li>• Not acceptable [i8,i11,i13]</li> </ul>	

## Highlights

- The level of automation is one of the central issues in designing control systems.
- Occupant attitudes towards different levels of automation were studied.
- The interviews revealed a large amount of mistrust towards automation.
- System characteristics that may improve trust are listed.
- Full automation is not suitable for the control of the indoor environment.