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User friendliness and building automation - A conceptual approach to understanding perceived control

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Abstract

Building automation systems provide potential to optimise the energy consumption of buildings as well as to detect failures in the operation of buildings. Providing the occupants with control over the indoor environment is widely accepted to positively affect the occupant's satisfaction. The system building-HVAC-automation-user is becoming more complex. So what does the term 'perceived control' really mean? Psychological constructs from social learning theory and personality psychology transferred to the field of personal control of the indoor environment will be discussed. There are already several models describing man-environment interaction or the importance of control for persons. These models exist in parallel and have not been interconnected and translated into models for the built environment, yet. The aim of this paper is to show how these models could be interconnected and to develop a conceptual approach explaining the role individual control plays for user satisfaction.

Keywords: perceived control, adaptive opportunities, building automation, indoor environment, conceptual approach

1 Motivation and aim

Building automation systems are becoming more important. Today, technical facility management is hardly conceivable without building automation systems. The application of building automation systems provides potential to analyse and optimise the energy consumption of buildings as well as the detection of failures in the operation of buildings. Building automation has also been applied to control devices and systems conditioning the indoor environment at workplaces.

User friendliness or usability of a product is according to ISO 9241-11 (1998) generally defined as to depending on the context of the product usage. The context thereby includes the user with his experiences and expectations, the work task, work equipment, the physical environment, and the social environment. Three main criteria are used to assess the usability of a product: effectivity in solving a task or problem (task completion by users), efficiency in handling the system (task in time), and satisfaction of the user.

On the one hand, there is a potential to improve the user friendliness by the application of building automation systems. On the other hand, building automation is expected to offer more than just providing set points and automatic control algorithms in order to improve the indoor environmental conditions and the energy efficiency. The system building – HVAC – automation – user is becoming more complex. Operating real buildings with building automation systems shows that sometimes

occupants feel to be dominated by automatic systems. But to what degree should the indoor environmental conditioning systems be automated? In order to achieve a high percentage of occupants being satisfied with their workplaces, how should we design and configure building automation systems?

Although many studies investigating thermal comfort, sick building syndrome or user satisfaction in buildings found perceived control as to be a key variable we do not have a comprehensive understanding of the term 'perceived control'. The implementation of the adaptive model of thermal comfort into the European standard EN 15251 (2007) opened a discussion among building services manufacturers, engineers and designers of what adaptation or control really means.

Providing the occupants with control over the indoor environment is widely accepted to positively affect the occupant's satisfaction and has been used as an argument to increase the automation level accompanied with increasing the number of controls in a space. Some believe if there was the possibility for each person to freely adjust the environment or adjust to the environment by behaviour there would be no discomfort anymore.

Excellent work has been done and very useful recommendations and guidance of practical relevance has been provided by the work of Adrian Leaman and Bill Bordass from the Usable Buildings Trust in the UK (UBT several years).

Cabanac (e.g. 1996) first described the phenomenon of allesthesia which was recently revisited by de Dear (2011). Cabanac also described the role of pleasure and joy in thermal comfort. There are models explaining thermal adaptation (e.g. de Dear et al, 1998) or the impact of perceived control on thermal comfort (e.g. Nicol & Humphreys, 2002; Paciuk, 1990). There are general psychological approaches which could help to more comprehensively understand what perceived control could mean (Rotter, 1982; Bandura, 1997; Johnson, 1974). Environmental psychologists developed models explaining the interactions of organisms with their environment (e.g. Bell et. al 2001; Veitch & Arkkelin 1995).

All these models exist in parallel and have not been interconnected and translated into models for the built environment, yet. Boerstra et al. (2012) already discussed some of the above-mentioned models and summarised the key ingredients for a future model.

The aim of this paper is to show how these models could be interconnected and to develop a conceptual approach explaining the role individual control plays for user satisfaction. This approach could help to better understand what perceived control really means and then how we could design for high perceived control in buildings. On the basis of a literature review first the models from different fields of research are introduced and main results from studies investigated personal control will be summarised. Then, a new integrated conceptual approach, applied to the indoor environment in buildings will be presented.

2 Comfort, pleasure, and adaptation

Comfort is often defined as the subjective satisfaction with the thermal environment (ASHRAE Standard 55, 2010; ISO 7730, 1995). Cabanac (1996) explained why this definition is inadequate.

Cabanac (1996) founded the phenomenon of allesthesia. De Dear (2011) revisited this concept. Allesthesia describes the dependence of the sensation of a stimulus on the

subject's internal state. How a certain stimulus is perceived by the subject depends on whether the stimulus contributes to improve the internal state of the subject (positive, pleasant) or impairs the internal state of the subject (negative, unpleasant). As soon as the normal internal state of the subject is reached again, a positive stimulus turns to be unpleasant. Sensory pleasure is the pleasant sensation of a certain stimulus. Comfort is different from sensory pleasure. Comfort is the subjective indifference to the environment. Cabanac explained the different character of comfort and pleasure:

"A feeling of comfort indicates therefore that everything is right, but this is not a very exciting feeling, whereas pleasure indicates, in a troubled situation, a useful stimulus that should be consumed but will not last once the trouble is corrected".

According to Cabanac, comfort is stable and can last whereas pleasure is transient. Pleasure serves to reward behaviour and to provide motivation to exercise behaviour beneficial for physiological processes. Subjective satisfaction with the thermal environment includes therefore indifference and pleasure. Cabanac explains that "...in the same way as there are two different elements in sensation [author's note: pleasure and comfort]….it is possible to recognise two elements in the affectivity of global consciousness: positive and transient joy, and indifferent but stable happiness." Sensory pleasure is a strong motivator for behaviour suitable to restore homeostasis.

Adaptation is described by de Dear et al (1998) as to consist of three components: adjustment, habituation and expectation, and acclimatisation. Fig. 1 shows the behavioural feedback loop and the psychological feedback loop including the mediating or moderating effect of the built environment and the social environment (de Dear et al, 1997).

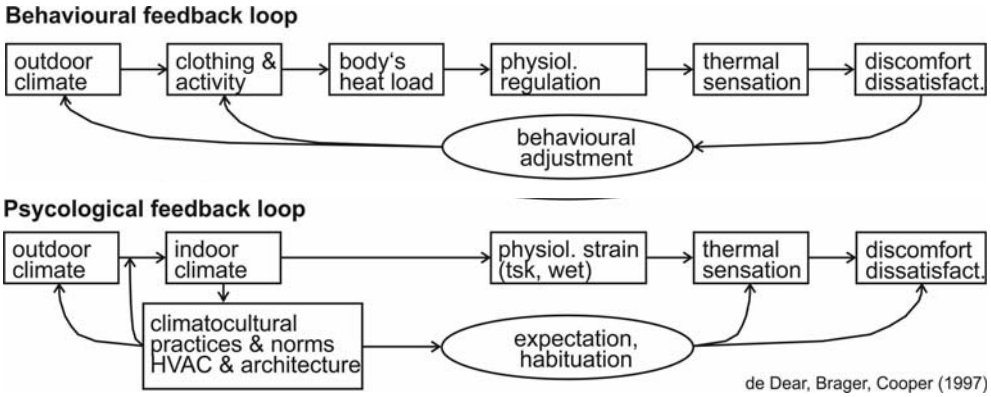

Figure 1. Adaptation to indoor climate: Behavioural and psychological feedback loops from de Dear et al (1997).

3 What does control mean to persons?

What control means to persons has been widely discussed in general psychological literature. General psychological approaches including control are mentioned in this paper merely to underline the importance control plays for humans and to show what a lack of control could induce in humans.

In the 1950ies Rotter (1982) developed his social learning theory. His main idea was that personality is a result of the interaction of the individual with his or her environment. To understand behaviour both the individual with its experiences and

the environment the individual is responding to and behaving in has to be considered. Rotter introduced the term 'locus of control' which is a concept of generalised expectancies for control of the behaviour outcome. A strong internal locus of control means people believe that they are responsible for the behaviour outcome by themselves, independently of success or failure. People with a strong external locus of control believe that the outcome of behaviour is controlled by luck, chance or powerful others.

In the 1970ies Bandura (1994) developed the theoretical construct of self-efficacy. Self-efficacy is a person's belief in his or her capabilities to produce certain outcomes that exercise influence over events that affect his or her life. High self-efficacy is related to a person's belief in his or her own competences. It influences the level of motivation, resilience to adversity and vulnerability to stress. Sources of self-efficacy include:

1. Mastery experience: Success in exercising behaviour (direct)
2. Vicarious experience: Seeing people similar to oneself manage task demands successfully (indirect)
3. Social persuasion: Verbally persuade people that one has the capabilities to succeed in given activities (symbolic)
4. Interferences from somatic and emotional arousal (sign for own competences)

Both, the construct of locus of control and the concept of self-efficacy and whether they mean more or less the same have been widely discussed. The attribution of an agent to an event is locus of control. Self-efficacy is seen as to be more related to the ability or skills of a person. Both concepts could be regarded as complementary.

The vicious cycle (Fig. 2) is according to rotter's social learning theory a process which leads to confirmation of low expectations and can be regarded as a kind of self-fulfilling prophecy (Rotter, 1982). In case people have low expectations they do not believe their behaviours will be successful. Hence, they put only little effort into their behaviours. If they do not try to be successful they are likely to fail. The failure will confirm their low expectancies.

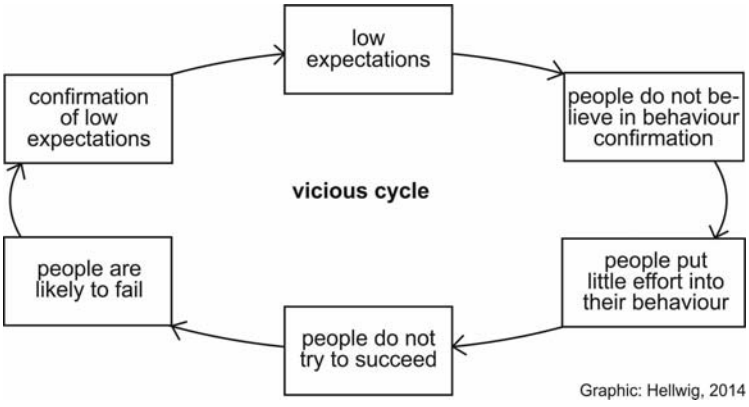

Figure 2. Vicious cycle according to Rotter's social learning theory.

A comparable construct is that of learned helplessness developed by Seligman meaning that repeated efforts to regain control fail (Bell et al 2001). As a consequence

people might think that their behavioural activities have no effect on the situation and stop trying to exercise control.

Constraints can limit or interfere with behaviours persons would like to execute. The belief that there is a constraint could be a constraint itself. Constraints can cause negative affects or discomfort. There are three basic steps in the behaviour constraint model: perceived loss of control, reactance, and learned helplessness (Bell et al, 2001).

Johnson (1974) defined four stages during which people may influence their outcomes (Fig. 3):

- Outcome selection control: is the process of selecting a desirable outcome among several potential outcomes. The outcome could be to attain a preference condition.
- Behaviour selection control: Among several behavioural strategies the one behaviour has to be selected which will be employed in order to attain the outcome selected.
- Outcome effectance: is to create the desired outcome.
- Outcome realisation control: is how to interpret and evaluate the outcomes received. Outcomes realised are the subjective effects.

Behaviour selection control may be perceived as quite stressful compared to outcome selection control. The greater the number of behavioural options offered to a person and the more likely it is that the various options lead to the chosen outcome, the more difficult is someone's task of selection. This is because of the absence of distinguishing reasons to decide for a certain behavioural option.

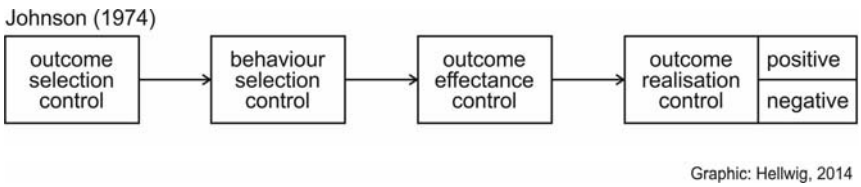

Figure 3. Flow chart explaining personal control using the definition of Johnson (1974).

4 Conceptual models of control and man-environment interaction

Boerstra et al (2012) already looked into available models of control. They divided the models into models describing: physiological processes and actions, psycho-social phenomena, physiological and psycho-social, hybrid models. Küller (1991) posits that interaction between man and environment goes on in four steps: activation, orientation, evaluation and control.

The model of Bell et al (2001) shows the relationship between environment and behaviour (Fig. 4). In the description of the model Bell et al posit that homeostasis is reached either when the environment is to be regarded as within optimal range of stimulation or as to be congruent with the intended behaviour. In the more specific models of Bell et al applied to noise and weather perception the term 'pleasure' was added to the box containing homeostasis. In this model we find control as to be part of the coping strategy and as part of the two boxes standing for the physical and social environment.

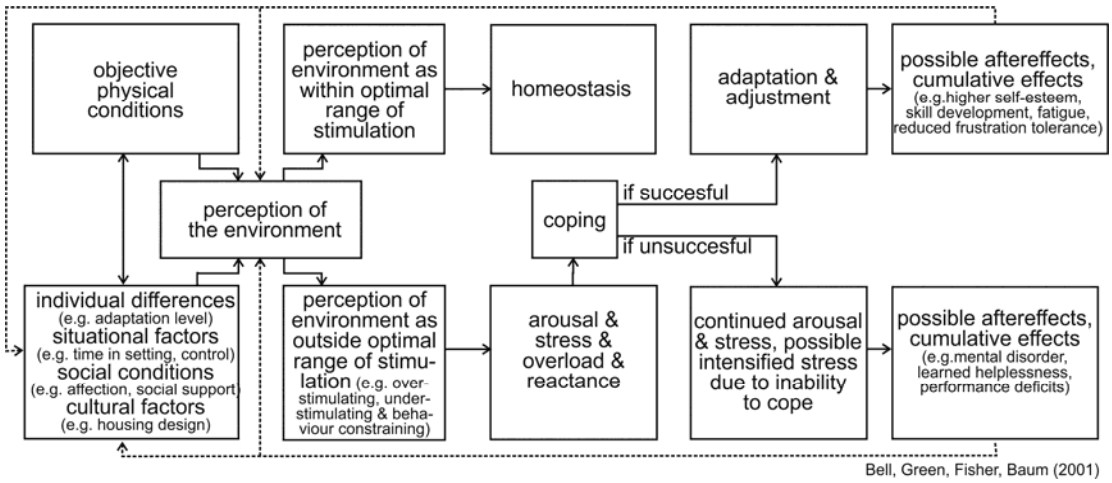

Figure 4. Flowchart of the theoretical concept of environment - behaviour relationship (Bell et al, 2001).

Veitch & Arkkelin (1995) developed a model explaining how the environment indirectly influences behaviour through the role of moderators and mediators (Fig. 5). Moderators increase or decrease the impact of the setting in contrast to mediators which are internal perceptual, cognitive and affective processes in response to environmental conditions. The degree of control felt is seen as an affective process as a result of the social situation and the success or fail in exercising behaviour. The emotional state can influence the expectations and goals of persons. The availability of control means provided by the environment is not shown.

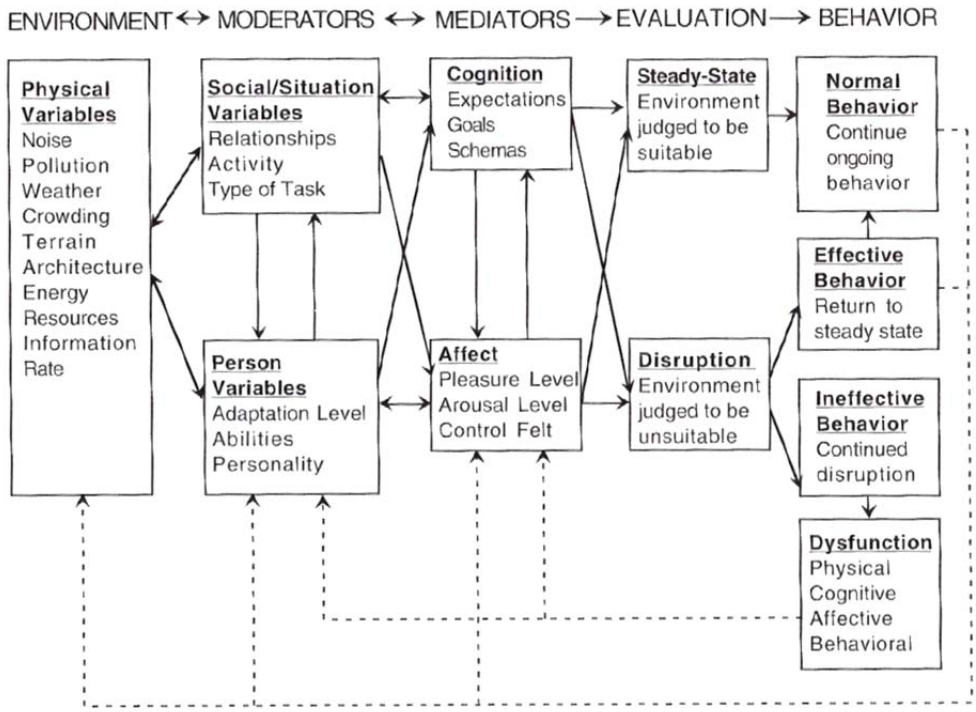

Figure 5. A model of environment – behaviour relationships (Veitch & Arkkelin, 1995)

5 What is perceived control?

In the ProKlimA study 85% of office workers out of 4394 wished to have control over their indoor environment (Hellwig, 2005). Correlations between perceived control and comfort or overall satisfaction could be shown in a number of studies (Kim & de Dear, 2012; Boerstra et al, 2013; Leaman & Bordass, 1999; for overview see Ackerly et al, 2012). Information about perceived control in these studies was gained by asking the occupants: “Do you feel you have control over…” or “How much control do you have over…” (Ackerly et al, 2012).

Paciuk (1990) defined three levels of control (Fig. 6): available, exercised, and perceived control. Available control thereby means not only the control means provided by the building or HVAC system but also organisational norms such as dress code or the degree of manipulation of control means given to the occupants. Paciuk defined perceived control as to be related to both available and exercised control. The knowledge about available controls and the feedback about the effectiveness of exercised control form different levels of perceived control.

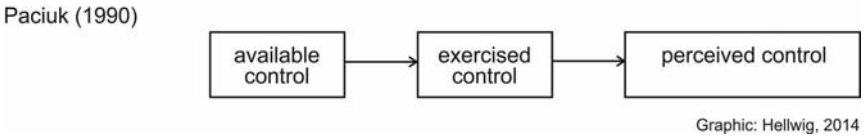

Figure 6. The distinction of control levels according to Paciuk (1990).

Bordass & Leaman (1997) distinguish three components of perceived control: 1. actual control including the zoning of the building, the environmental services, and the use of the area, 2.fine-tuning capability, 3. speed of respond to demands.

Ackerly et al (2012) discussed how to define the availability of controls and how to classify available controls: physical – behavioural; passive – powered controls; direct – indirect or just organise the controls according to the environmental parameter the control is assumed to effect.

Comparing the more general approach of Johnson (1974) with the distinction Paciuk (1990) made parallelism could be seen (Fig. 3 and 6). Available controls represent several behavioural strategies among which one has to be employed (behaviour selection control). Obviously, outcome effectance control and exercised control refer to the same stage. A positive evaluation of outcome (outcome realisation control) may result in a high degree of perceived control because the person succeeded in control. How the outcome realised will be evaluated by a person depends on personal, social and cultural factors. Thus, perceived control may be different in several contexts.

Johnson (1974) distinguishes between primary and secondary control. Primary control behaviour causes outcomes directly. Secondary control is caused by behaviours which increase the likelihood that a primary controlling behaviour will be successful. Secondary control is regarded to be “always at least one step removed from outcome attainment” and thus, secondary behaviour has the potential to be stressful. Hence, the degree of control perceived with primary control will be higher than with secondary control.

Fig. 7, depicted from Baker & Standeven (1997) shows how the availability of adaptive opportunities can expand the individual’s neutral zone. In the case of poor or zero adaptive opportunities a room which does not meet the needs of an individual will lead to stress in the individual. Baker & Standeven posit the importance of the

perceived adaptive opportunity even if the opportunity is not exercised. Nicol & McCartney (1999) found that just adding the number of controls does not give a good measure for the adaptive opportunities in a building.

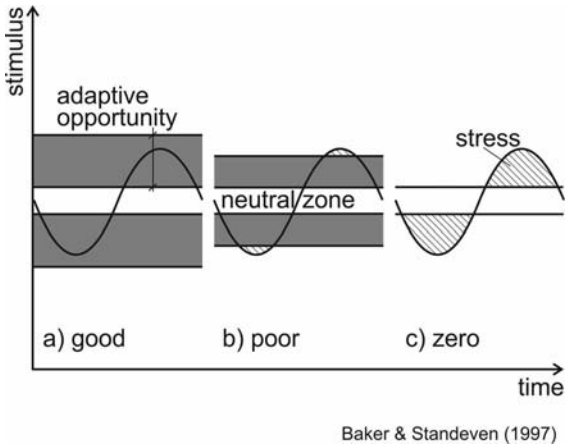

Figure 7. Comfort range, individual neutral zone, availability of adaptive opportunities and stress. From Baker & Standeven (1997).

It has often been argued that the indoor environment of a building has to be provided according to the occupant's needs. But what this argument means is that a building should provide exactly the environment a person needs. This argument overlooks the context dependency and the individuality character of a person's needs which are the most important issues and have been pointed out in environmental psychology literature (e.g. Bell et al 2001; Veitch & Arkkelin 1995) as well as in literature on physiology and behaviour (see section 3 e.g. Cabanac, 1996) or thermal comfort literature (e.g. Nicol & Humphreys 2002, de Dear et al 1998). Thus, the character of the needs can vary. How could the HVAC system of a building know about the exact need of a certain occupant sitting somewhere in the building on day 1 which may be different from his need on day 2?

Having control over onset and termination of a stimulus will result in better adaptation than having control over only either onset or termination of a stimulus (Bell et al 2001, p115). Lee & Brand (2010) found that personal control over the physical environment mediated the relationship between perceived distractions and perceived job performance. Boerstra et al (2013) suggested looking at control (available, exercised and perceived) as a moderator of the relationship between indoor climate (stimulus) and comfort, health and performance (response).

Based on the work of Humphreys and Nicol constraints in the building context were summarised by de Dear et al (1997) as constraints due to climate, economics, social custom or regulations, task or occupation and design.

From the implementation phase of passive house in Germany it is known that many people have expressed reservations about moving into such a house. The reservations are founded in the indoor environment as to be perceived as artificial and providing no control, and the restrictions which planners as well as researchers put onto the occupants not to open the windows. Later this restriction was identified not to make the passive house concept attractive for people and research effort was undertaken showing that opening the window will not considerably change the energy consumption of the house.

Sherrod & Cohen (1979) point out that perceived control may result as a consequence of actual control but could also be gained from prior control experiences, from information, and from self-inferences.

All building users have experiences with buildings, positive or negative. From these experiences they develop expectations on how an environment should be or will be. In dependence on their own experiences with buildings they rate the subjective importance of environmental factors. When attending a concert a person does not expect of having control over the indoor climate in such a crowded space. Perhaps he or she remembers the last concert in the same place was very hot and adapts his or her clothing according to these expectations. But when it turns out that the concert hall is cool this time the person may be displeased. When moving a company from old uncomfortable offices in the city centre with lots of cafes, restaurant and shops to a suburban, empty area it is likely that the satisfaction of the office workers will not increase even with a very new building, well-designed offices and a comfortable environment.

Constraints and expectations may play an important role in study design investigating comfort or performance and for the results gained from those studies. In a study on office performance in summer conditions Hellwig et al (2012) explained to their subjects the context of their study: working in an office in summer outside temperatures. This idea was supported by a realistic office environment providing view to the outside, sun shading and openable windows. Although none of the subject opened the window, it was not forbidden to them. The subjects were allowed for clothing adaptation during the experiments. The research group decided to not put constraints onto the subjects to keep the setting as close to a normal office environment as possible. Schweiker et al (2012) suggested a controlled test design where constraints are put onto subjects in some of the tests to restrict adaptive opportunities.

Boerstra et al (2013) failed to show a correlation between available controls and perceived control except for the case of solar shading with external shading provided higher perceived control over temperature than internal shading. Hellwig et al (2006) found combined perceived control over temperature and air movement to be significantly higher in naturally ventilated buildings (with central heating in winter) and mechanically ventilated or air-conditioned buildings.

Boerstra & Beuker (2011) distinguished between personal control which is not possible, possible but ineffective, and possible. They called this perceived effectiveness of control. Effective personal control options in offices lead to a decreased amount of complaints compared to those cases with none or ineffective personal control. In a few cases they even determined an increased chance for complaints for the group perceiving ineffective control compared to the group with no control.

In naturally ventilated spaces occupants regarded thermal discomfort as a result of their own behaviour rather than attribute discomfort to the building as in air-conditioned spaces (Kim & de Dear, 2012). The forgiveness factor (Leaman & Bordass, 2007; Deuble & de Dear, 2012) characterises the discrepancy between overall mean comfort and the mean score of a single IE variable and was shown to be higher for green buildings.

Although many studies already investigated available control and perceived control the link between the building design, building services and how occupants perceive control in these environments was not focussed on so far.

"Bicycles can exist without riders and riders without bicycles, but it is the interaction of the two that provides the unique system, or process, of bicycle riding." (Veitch & Arkkelin, 1995, p 39).

A certain design of a building's floor plan or façade will as a consequence cause certain building services systems for room conditioning. Very big office units i.e. open-plan offices cannot provide access to windows for every occupant, even the implementation of natural ventilation during occupancy is very unlikely. Because of the huge depth of such buildings heating will be provided via the ventilation system which at the same time induces that there will be less control in the space (personal ventilation is not widely used in real buildings, yet). Buildings with a very high proportion of glazed area in the façade have a potential to reduce perceived control because the occupants have to solve for conflicting goals: either having a view to the outside or let the sun heat up the space. The building's construction influences perceived control also: The effectiveness of temperature control devices is influenced by the thermal inertia of a building and its combination with a heating or cooling system.

Hellwig et al (2006) investigated perceived control in dependence of the heating and ventilation system in buildings with mechanical ventilation from the ProKlimA-study. The mean value of perceived control (combined control on temperature and air movement; scale 0-1) is 0.23 in buildings with an air heating system and 0.51 in buildings with radiators. Buildings with sealed windows have a mean value of perceived control of 0.19. The value increases up to 0.48 in mechanically ventilated buildings with openable windows.

To report from real building experience: A building with e.g. a thermo-active building system (TABS) for heating and cooling will react very slowly. It is called a passive technology but when heated once it cannot be used for cooling in the same day because of its thermal inertia. Normally there should be a dead band between heating and cooling in the operation mode of such a system. Combining, e.g. a slowly reacting activated building element with a high percentage of glazed area in the façade will result in a coincidence of heating from the ceiling and heating through a high amount of passive solar gains and lead to high temperatures even in winter at outside temperature levels far below zero. If there is a thermostat mounted and the user will try to lower the temperature in the room he will not succeed because of the high inertia of the system. A completely different picture gives a room with high thermal mass, which is not activated. In this room the heat resulting from solar gains could partly be stored in the thermal mass and the temperature will rise more slowly than in the first case. If this room was combined with radiators the occupant could adjust the thermostat or just rely on the proper functioning of the thermostat.

Finally, with regard to building automation, excellent studies were carried out and guidance was provided on how to improve the design for high usability of user interfaces of building automation (Stevenson et al 2013; Bordass et al, 2007).

6 A conceptual approach explaining perceived control as a key factor for satisfaction

The equilibrium of an environmental factor in a person differs with time, internal state, activity, and expectations. So the desirable steady state can be different. An environment which is suitable e.g. on one day or for one activity or one person could be not on or for another. Thus, an environmental stimulus can be perceived as disruptive for one person but could be perceived as to be perfect for another person. Effective behaviour as the consequence of a disruption caused by the environment could be perceived as pleasurable and hence, will cause satisfaction as long as the selected effective behaviour is consistent with the expectations (of an appropriate behaviour). The disruption can be compensated by effective behaviour and therefore cause positive feelings already before the steady state is reached again. This seems to be a strong motivator to exercise effective behaviour.

Analogy between general models of control like locus of control or self-efficacy and perceived control could be drawn. Even if the concepts of locus of control or self-efficacy are more generalised ones and perceived control in a built environmental context is more specific their impact on a person's attitudes and expectations seems to be quite similar. Kim & de Dear (2012) already draw this analogy to distinguish NV and AC buildings.

Boerstra et al (2012a) listed key attributes for feedback looped psycho-physiological models:

- "Distinction between information, heat flow and action
- Separation of physiological effects and autonomic regulation on the one side and psychological effects and behavioural regulation on the other side;
- distinction between perception, interpretation and action plan development
- inclusion of situation, habituation and adaptation effects
- inclusion of memory and expectation effects
- separation of available controls, exercised control and perceived control
- distinction between external, environmental control (e.g. adjusting thermostats, opening windows) and 'internal' control (e.g. changing clothing or metabolism)"

What is perceived control?

It is suggested that perceived control can be defined by using the generalised concept of locus of control and the complementary concept of self-efficacy and use them more specific on the level of indoor environment in buildings. Thus locus of indoor environmental control (IE control) is linked to the experiences of a person with indoor environments. A high locus of IE control means a person believes he or she can cause changes in the indoor environment. A high IE self-efficacy means a person is convinced that he or she has the capabilities or skills to cause these changes. To finally define what actual perceived control means the influence of constraints from the degree of responsiveness of the system building – HVAC – automation, the social constraints, the expectations resulting from individual weighting factors for the importance of IE variables, and the feedback (outcome realisation control) have to be considered.

Fig. 8 shows the resulting model merging aspects of the above described models. For the sake of clear arrangement it was impossible to include the huge variety of control actions and the distinction between information, heat flow and action. The model

explains how occupants perceive the built environment and how behaviour by means of control mediates the evaluation of the environment. It does not account for autonomic processes but focusses on behavioural actions. The model aims to explain the different stages of control and to show how perceived control is formed.

Satisfaction is shown to result not only from comfort but as well from pleasure. Constraints coming from the building, particularly the building's responsiveness, and the social environment reduce the variety of available controls occupants can select. Perceived control results from the person's experiences, competences or skills (self-efficacy, locus of control of indoor environment), knowledge of the building and its technical systems and the person's expectations. Together with the constraints and the success or failure in previous behavioural control actions these variables form the term perceived control.

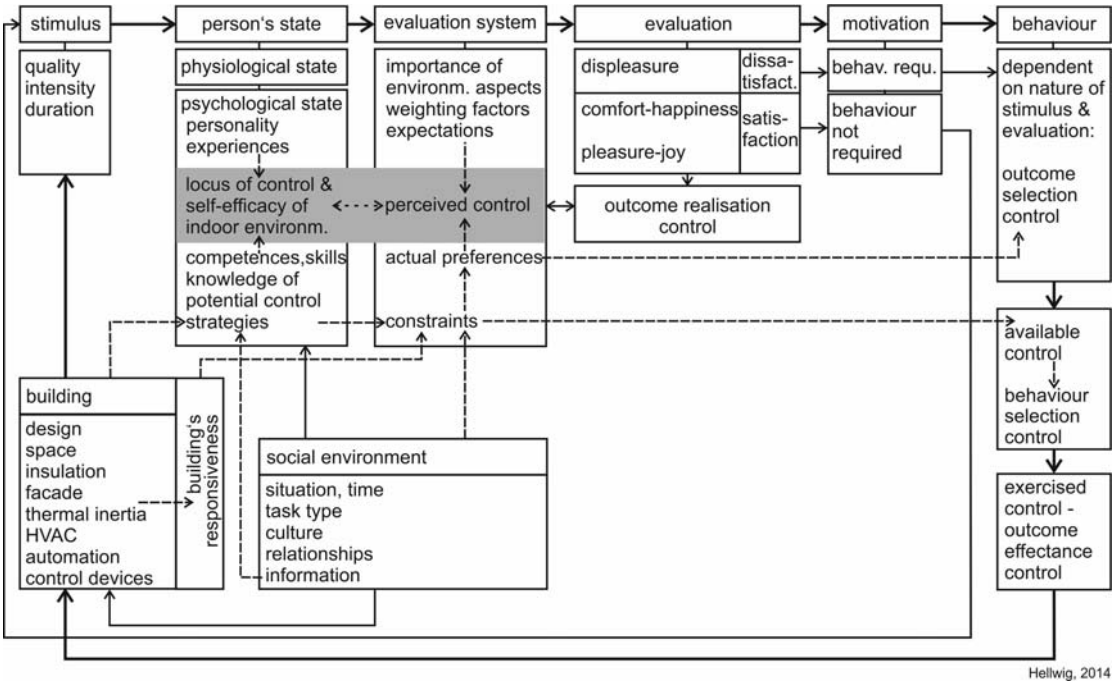

Figure 8. A conceptual approach explaining perceived control as a key factor for satisfaction.

7 Conclusions and outlook

A conceptual model was developed including psychological constructs from social learning theory and personality psychology transferred to the field of personal control of the indoor environment. Furthermore, the idea in behavioural psychology that taking a meaningful action is rewarded by joy seems also applicable to the man-indoor environment interaction. Thus, satisfaction with the indoor environment occurs in case of comfort but also immediately after a successful control action even when homeostasis has not yet reached. There are constraints from the built and social environment determine the available controls. The model should be proved in practice.

Future perceived control studies should put more emphasis onto the investigation of the effectiveness of a control action in the context of the design of the building and its interaction with the HVAC systems. In this context further research is needed to describe the required degree of responsiveness of the system building-HVAC-

automation. Furthermore, advanced knowledge is needed to better understand the impact of user information or guidance which could help to increase the perceived control in buildings.

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