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The Psychophysics of Well-being
Socio-psychological Monitoring and Benchmark Measurement in Energy-efficient Housing

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Abstract: The exploration of subjective aspects in architecture mainly concentrates on life-style preferences and on issues of aesthetical and architectural psychology. In this research it is usually taken for granted that particular physical building parameters have positive effects on residents' well-being. Empirical research on what residents actually experience however and how they evaluate their housing environment in reality is rare. Following a two-years monitoring of the residents of the VELUX energy-efficient model home in Hamburg-Wilhelmsburg, Germany, the material gained from interviews and survey questionnaires in that process was analysed in order to uncover the underlying structure of housing well-being in energy-efficient housing and develop a multi-facetted measurement instrument that can be put to an empirical test with subjects from outside the model home. The goal is to design a Housing Well-Being Inventory *(HWBI) that can serve as a standard for the measurement of the subjective quality of housing.*

Keywords: Housing well-being, psychophysics, architectural psychology, energy-efficient housing

Introduction

In view of the problems of limited fossil energy resources, air pollution and climate change, it is essential to implement collective energy-saving measures and to use renewable energy sources that will also enhance reduction in CO_2 emissions. A key area for energy-saving is the housing sector. Using renewable energies and applying energy-saving technologies in residential housing will save countless tons of CO_2. However, energy-saving is not restricted to newly build houses alone. For economic as well as social and political reasons, new buildings cannot replace large proportions of the existing housing stock. In Germany for example, much of the present housing are "settler houses" dating from the early 1950s. These houses are simple constructions that were put up hastily after WW II to replace buildings that had been destroyed during the war. Their architectural design has long ceased to meet the needs of the current third generation of occupants. The challenge ahead therefore is to develop appropriate measures to upgrade the

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energy systems to suit the needs of new groups of residents. To the extent that these needs are met, it will be possible to regenerate the settler housing stock, usually in peripheral urban locations, relieving the pressure on central inner-city areas and preventing at the same time undesirable land use in the surrounding countryside.

Renovation issues with regard to old settler houses involve different disciplines and professions. Not only architecture and engineering but also political science, psychology, sociology, urban planning, and health engineering all add important aspects that need to be taken into account. The study of these interdisciplinary aspects is only in its initial stages, both in terms of the availability of data and the development of theory. The focus of this report therefore is to examine the psycho-social domain of energy-efficient housing renovation or facets that can be treated in genuinely social-scientific terms. Our main object is the assessment of housing well-being and the person/environment interaction of housing.

The study of housing well-being must cope first with the representation of the concept of well-being as a multi-dimensional construct. In the present study, establishing such a construct has been the object of a two-years exploration phase with occupants of an experimental model home that was developed out of an old settler house. Secondly, this report outlines the methods used in the exploration of this concept and in its development. Thirdly, it presents the initial results of the exploration and allocates them to the components of the newly developed concept. Finally, using the concept thus explored and based on methods proposed recently by Wegener [1] for designing a standardized instrument for measuring well-being, it provides an overall evaluation of the measurement device.

Housing Well-being as a Multi-dimensional Construct

We propose a multi-component view of the person/environment interaction and of housing well-being conceiving it in terms of well-established psychological attitude models. If housing well-being is understood as an attitudinal phenomenon, it needs to be based on a definition of attitudes that stresses the evaluative element in attitudes [2]. Thus an attitude is understood as an individual mental evaluation of objects that is reflected in different dimensions. In the present case we employ a three-component view on attitudes originally developed by Rosenberg and Hovland [3] distinguishing between affective, cognitive, and conative reactions in attitude formation. These reactions can manifest themselves verbally as well as non-verbally. For both, measurement instruments can readily be built.

In application to housing well-being we are dealing with a mental construct that represents an evaluative judgement *over time*. Imagine that at time t_1 the residents are moving into their new home. At this point they develop a certain evaluating attitude towards their new home that we measure by means of verbal and non-verbal indicators. The judgement at t_1 however is influenced, among other things, by experiences individuals made at t_0, i.e. before they moved into

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their new home. Conversely, by t_2 time has elapsed in which the occupants have interacted with their new home affecting their evaluation anew. This dynamic interaction between the evaluation at t_0 and the various stimuli of the new home (e.g. temperature, functionality, social interaction) produces reactions in the dimensions of affect (triggering certain feelings), cognition (giving rise to certain opinions) and conation (influencing actual behaviour). These reactions can be measured at t_2, but on-going experiences may alter this evaluation again, so housing well-being is certainly a quantity that needs to be re-measured at times t_3, t_4 and so on in repetition. It can safely be assumed however that these changes level off after a while when the number of new impressions in a home decrease, giving way to a more stable well-being estimation.

Method

Since there is little relevant research to rely on, in our study the well-being of housing was carefully explored in an experimental study. The opportunity for this was provided by the VELUX LichtAktivHaus (LAH) in Hamburg-Wilhelmsburg, Germany, as part of the International Building Exhibition (IBA) and its numerous architectural, social and cultural ventures. The VELUX IBA project belongs to a series of pilot projects (“ModelHome 2020”) run by the VELUX Corporation. One of the goals of the VELUX project is to gain experience with regard to renovating existing houses according to energy-efficiency standards. During these experiments the model homes are closely monitored both in terms of physical performance and of the psycho-social functioning of the occupants.

In the Hamburg VELUX model home, a family of four—mother, father, two sons aged 5 and 8—were given the opportunity to take part in a real-life test of the building. They moved into the house by December 2011 and stayed on for more than two years (April 2014) when the experiment ended. (Actually in the end, the family decided to buy the house—post-experimentally, so to speak—and is still living there today.)

The study design for monitoring the test-family followed the sequential steps for developing standardized measurement instruments of well-being along different problem fields (as outlined by Wegener [1]). This begins with exploring the relevant dimensions of housing well-being. Several methods were used for this exploration: initial group discussions with the family members, self reports using diary methods, digital logbooks as well as a public family blog the family had fun to entertain. In addition, approximately every four weeks respondents completed an online questionnaire including both standardized and open-ended questions about the various dimensions of their well-being. About every six weeks, in-depth structured interviews were conducted with the parents in the form of video calls. Finally, extensive structured face-to-face interviews were carried out in the model home itself at the end of the yearly seasons. These different procedures led to the accumulation of a very detailed recording of the affective,

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cognitive and behaviour-related dimensions of the family's well-being in the house.

Subsequently, this material was analysed in order to uncover the underlying structure of housing well-being that would then be put to an empirical test with subjects from outside the model home, the goal being to design a measurement instrument, the Housing Well-Being Inventory (HWBI), that can serve as a standard for the measurement of the subjective quality of housing.

Patterns of Exploratory Findings

1. Affective – Feelings and Perceptions

We began by outlining the *sensory imprints* of the family in order to become familiar with the affective components of attitudes. We distinguished four sections (thermal, hygienic, acoustic and visual perception) based on the influencing factors currently used in architecture to normatively characterise levels of comfort.

The thermal aspect includes the perception of temperature, air draught and humidity. Whereas the occupants perceived the temperature in the individual LAH rooms to be neutral during the initial winter months, at the beginning of summer they tended to describe the room temperature as somewhat too warm. During exceedingly bright sunshine periods in summer, the air in the rooms was found to be uncomfortable and too hot, so that additional manual ventilation was applied. In Figure 1, subjective temperature sensations are plotted against the objectively recorded room temperature and the range of the outdoor temperature in 2012.

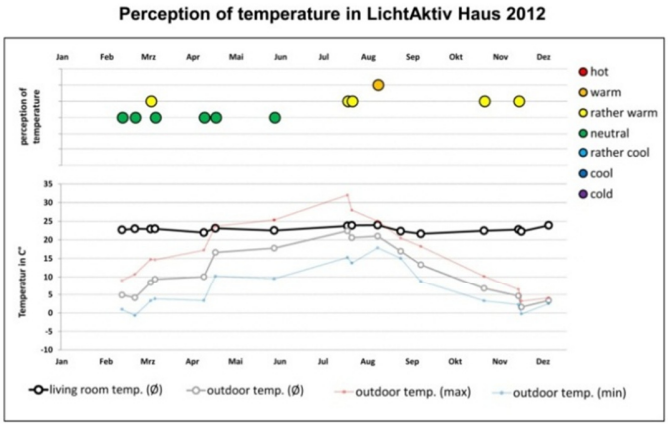

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Figure 1: Temperature and temperature perception

Regarding *hygiene* in terms of air quality, a distinction had to be made between the children's rooms in the house and the other rooms. In the case of the latter, the occupants found the air quality to be very good throughout the year with no unpleasant smells, but in the children's rooms the air quality was sometimes less than satisfactory. These rooms were stuffy, especially in the mornings. This fault was possibly due to the low ceilings of the children's rooms, the lacking possibility of transverse ventilation and the fact that the air conditioning system was routinely turned down over night.

The perception of the *acoustics* was also recorded. The respondents were asked not only about external noises, such as street noise, but also about the noise caused by the in-house equipment as well as the efficiency of soundproofing within the building. External noises that were mentioned included the nearby railway and also the nearby motorway. These noises were not considered particularly annoying as the family quickly became accustomed to them. However, the noise from appliances, or more precisely the automatic opening and closing of the windows, was perceived increasingly loud and was felt upsetting throughout.

As far as *visual perception* is concerned, it is primarily the light supply in living areas that is relevant. The occupants of the LAH were often impressed by the amount of daylight in the house and saw this as a very positive aspect. The brightness of the rooms was applauded, not only in the summer but also in the darker months, so that even in the winter it was possible to manage without artificial light for long periods of the day.

2. Cognitive – Thoughts and Values

The study revealed many illustrative findings regarding the *cognitive components* of the well-being attitudes. For example, the functionality of the technical equipment, i.e. the interaction between persons and the technical environment in the building, played an important role in the evaluation of the LAH. This is true not only regarding the general operation of the building's technical systems but also for problem-solving strategies and the practicability of standard values. Generally speaking, occupants' feedback about the technical systems was very positive. In their eyes, the equipment worked perfectly. We also observed that over time the occupants became more familiar with handling the equipment and gradually learned to use the many different settings.

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Automation is a valuable asset since it prevents incorrect ventilation, for example. However, family members did not really acknowledge the need for automatic air conditioning overnight and preferred undisturbed sleep to optimum air quality. Thus at no time did the occupants feel controlled, because they always had the sense that they could override the technology if necessary.

Since the architecture of the LAH is important for the comfort and satisfaction of the occupants, the outer appearance of the house was also included in the evaluation process. Again this was rated very positively and the occupants not only liked the external appearance of the house but also its internal layout and architecture. The occupants particularly enjoyed the size of the house and the availability of space.

Monitoring environmental awareness and the energy-consumption behaviour of family members brought to light particularly interesting aspects of the evaluation. It was assumed that moving into the LAH and the interaction with it, would lead to greater awareness and stimulate a more sustainable way of thinking. And indeed this assumption was confirmed. The occupants of the LAH grew more accustomed to energy consumption issues along the way. Obviously living in the LAH had a positive influence upon their environmental awareness.

Interviews with the family also revealed that their housing preferences had changed significantly over the course of the experiment. Whereas at the time they moved in, the extra space they gained compared with their old flat was seen as the most important feature of the new home, the longer they stayed in the model home, the more they appreciated its brightness, the garden and the energy-efficiency of the house. Initially occupants attributed this enhanced quality of living primarily to the modernity and the size of the house but within a few months they regularly referred to the brightness of the living areas as a contributory factor to their increased sense of well-being. In response to the question of what their main criteria would be when looking for a new house in the future, the family did now add brightness and energy-consumption as top priorities to their list of criteria. Obviously housing preferences are prone to changes if confronted with positive experiences.

3. Conative – Behaviour and Intentions

The third component of the attitude concept relating to housing well-being is the actual behaviour triggered by the attitudes. Managing the technical systems for controlling light, heating, air flow and energy-consumption is one of the activities within the realm of the person/environment interaction that was new to the family. But from the very start of the experiment, they were thrilled with the systems and the possibilities of controlling them. As they became more familiar with the techniques and the modification options, they also became more aware of system malfunctions and were able to identify problems quickly.

Great attention was also given to the family's *room usage* behaviour. Here, the large living area

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was identified as by far the most often used room. It was the main recreation room used for various activities throughout the year. Because of its spaciousness and brightness, it was particularly inviting for social activities and for receiving guests.

There were also changes in the social interaction within the family after they had moved into the LAH. Essentially, the new home has had a beneficial effect upon the social climate within the family. This is not only evident amongst the children, who are now considerably more relaxed and squabble a lot less than in their previous home, but also in the improvement in the occupants' overall mood ("it all seems right somehow"). Their new home also changed their contact behaviour with friends. The main reason for this seems to be the additional space and the garden, which enable them to receive guests, so that they have had more social events in their own home since moving into the LAH.

Measuring Housing Well-being

The results of the two-years long exploration efforts, examples of which were given above, were then used to design a multi-dimensional device for measuring housing well-being. The purpose of this instrument is to have a yardstick for assessing the quality of a house as it is seen through the eyes of the users. How do houses, in particular reconstructed energy-efficient houses, perform socially and psychologically? What level of subjective well-being do these houses convey? Based on the explorations in our test family, we were able to accumulate a pool of roughly 250 questionnaire items that represented the categories of well-being that had proven to be important to the family of the LAH model home. The methodological task, if confronted with such a collection of survey items, is to reduce this excess of data empirically. The standard way of doing this is to have a sample of respondents answer all of the questions in the pool on a metric scale (from "very strongly agree" to "very strongly disagree," for instance) and analyse the resulting correlation matrix statistically. Using the factor analysis method [4] it is possible to disaggregate a correlation matrix into a small number of factors that emerge when one looks at the correlations of the questionnaire items with these factors. The factors with the highest correlating items are taken to be the most meaningful factors in representing the data in the correlation matrix. Conversely, the items that exhibit the highest correlations with the individual factors can then be selected for constructing a survey questionnaire.

Table 1: HBWI factor and factor loadings (factor loadings < .50 not shown)

	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
1. I have a positive attitude toward my apartment*	.84									
2. I feel at home in my apartment	-.94									

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3.	I don't really like to be in my apartment	-.84						
4.	I have difficulties calling my apartment my home	-.96						
5.	My apartment is too small		-.90					
6.	My apartment meets my need for ample spacing		.90					
7.	I wish I had more room because everything is happening at one and the same spot		-.90					
8.	The technical equipment in my apartment satisfies my need for modernity			.80				
9.	My apartment is in need of renovation			-.66				
10.	The technical equipment in my apartment is up to date			.91				
11.	In my apartment I can make full use of the natural light				.88			
12.	In my apartment I am too much dependent on artificial light				-.90			
13.	My apartment has too many dark rooms				-.78			
14.	On sunny days I can enjoy the light in my apartment to the full				.78			
15.	I have nice neighbours					.83		
16.	I feel accepted by my neighbours					.97		
17.	My neighbours discriminate against me					-.63		
18.	The temperature in my apartment can easily be adjusted according to my needs						.73	
19.	The control of temperature levels in my apartment is satisfactory						.91	
20.	During the winter months I have to adjust the temperature in my apartment quite often						-.52	
21.	I sometimes wonder if my apartment uses up too much energy							-.77
22.	Cost for energy in my apartment is too high							-.78
23.	Compared to other apartments, the cost for energy in my apartment is low							.84
24.	My window pains often grow damp						.83	
25.	I have a problem with mould-infested rooms in my apartment						.76	
26.	Where I sleep there is too much light							-1.07
27.	The sleeping environment in my apartment gives me a restful sleep							.52

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28.	My apartment can easily be ventilated	.96
29.	I wish the temperature in my apartment could be controlled more automatically	-.65

*The reference "apartment" is replaced for "house" in appropriate applications.

The 250 well-being items of our exploratory study were presented to a sample of 60 sociology students who gave their responses that were then aggregated into a correlation matrix. The correlation matrix was factor analysed. Very much in accordance with our intuition from the exploration study, we find 10 meaningful factors based on 29 items. Each factor is marked by either two, three or four items that measure that factor. Together the 29 items form the core of the *Housing Well-Being Inventory* (HWBI) that presents the results of our study. Table 1 reports the main factor loadings (factor-item correlations) that characterise the 10 well-being factors and the item wording. They factors are named accordingly: Factor W1: *Emotional attachment*, Factor W2: *Size*, Factor W3: *Modernity*, Factor W4: *Brightness*, Factor W5: *Neighbourhood*, Factor W6: *Heating control*, Factor W7: *Energy consumption*, Factor W8: *Humidity*, Factor W9: *Sleeping comfort*, Factor W10: *Ventilation*.

The final version of the HWBI will have to include additional elements, among them are housing preferences [5], ecological awareness [6], life style inclinations [7], and engineering styles (König 2010 [8]. For most of these concepts however, there are numerous measurement instruments and survey questionnaires available on which our further research can rely. The same is true of course for the assessment of the socio-demographic information of the house users. In a modular combination therefore, the final product of the HWBI will consist of several subscales and categorizations.

Conclusion

Architects and engineers usually think that they are quite well informed about what the users of the houses they are constructing like. There are defined "ranges of comfort" with respect to temperature and light, air quality and acoustics that practitioners take for granted. Many of these standards have been implemented in formalised "social performance" guidelines—on the European level for instance in the CEN TC 350 norms *Sustainability of construction works* EN 15643-3 and EN 16309. But empirical research on what residents actually experience and how they evaluate their housing environment in reality is rare. Instead architects and lawmakers entertain a normative architectural psychology bias, stipulating future users as to what is good for them. We report here on an initial attempt to let the users have a say on what determines their well-being in the house. Following a two-years monitoring of the residents of the VELUX energy-efficient model home in Hamburg, the material gained from extensive interviews and

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survey questionnaires was analysed in order to uncover the underlying structure of housing well-being in energy-efficient housing and develop a multi-facetted measurement instrument that can be used with subjects from outside the model home. The *Housing Well-Being Inventory* (HWBI), the core of which is presented here, needs refinement and further validation, but in its final stage the hope would be to have an instrument available for the benchmark measurement of housing well-being that will assist architects in building houses worth living in.

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