Carbon neutral living in a modernised settlement house:
Living experiment combines quantitative and qualitative research methods

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ABSTRACT: The LichtAktiv Haus is a typical 1950s settlement house, transformed into a zero energy home for the IBA Hamburg international building exhibition by combining intelligent energy design with optimum liveability. Sophisticated use of daylighting provides the building with plenty of light and fresh air. At the same time, the energy required by the house is produced solely from renewables. The LichtAktiv Haus thus demonstrates that it is possible even for existing buildings to be exceptionally energy efficient. Moreover, the life cycle assessment of the house showed that the LichtAktiv Haus has less impact on the environment than a comparable building certified by the DGNB (German Sustainable Building Council). Since December 2011, a family of four has been putting the theoretical planning and calculations to the test in practice. This living experiment is accompanied by extensive scientific monitoring whose underlying concept combines both quantitative and qualitative methods of investigation for the first time. Rather than simply recording and documenting the energy usage and indoor climate, a correlation between the test family's personal comfort and wellbeing is established using supporting social research. The interdisciplinary research, carried out in this way for the first time on a zero energy home, should help to answer the fundamental question of what is really important in terms of the future quality of living, and how future demands on the energy efficiency of a building can be met while maximising the consumer's experience.
Keywords: energy efficiency; living experiment; scientific monitoring

SEARCHING FOR CONSTRUCTION AND LIFESTYLE SOLUTIONS OF THE FUTURE

Sustainable, climate-neutral construction and lifestyle are the greatest challenges currently facing the construction and real estate sectors. However, the focal point in the realisation of any energy efficient building product should always be people and their emotional need for a home in which they feel completely at ease. With its Model Home 2020 project, VELUX is looking for new ways to combine optimum liveability with optimum energy design. In six projects across Europe, the company, together with experts, has developed new ways of living and working which include pleasant indoor climates, use of natural light and optimum energy efficiency (figure 1). The aim of the experiment: to create buildings, using future-oriented planning, high quality materials and intelligent components, that make use of elements in nature to provide their occupants with plenty of natural light, fresh air and a view at any time of year while achieving optimum energy efficiency. All six of the buildings created for the VELUX Model Home 2020 experiment in Denmark, Germany, Austria, France and England cater to the respective climate, cultural and architectural conditions in the different locations. They were developed in collaboration with local architects, engineers and higher education institutions in order to reflect the typical housing and lifestyle of the respective country in the underlying architectural design of the building.

Figure 1: Locations of the six houses in the VELUX Model Home 2020 experiment

The LichtAktiv Haus – the modernisation of a 1950s settlement house in the Wilhelmsburg district of Hamburg to a zero energy home – is Germany's contribution to the VELUX Model Home 2020 experiment. It is also a project of the IBA Hamburg international building exhibition which is a city development scheme facing up to the demands of future standards of living. VELUX contributes to the climate protection project "Renewable Wilhelmsburg" through its partnership with IBA Hamburg. The joint aims: sustainability and climate protection.

FROM DESIGN TO IMPLEMENTATION: CREATING THE LICHTAKTIV HAUS

The starting point was an unimproved 1950s semi-detached house in the Wilhelmsburg district of Hamburg (figure 2). With a ground area of around 64 m² plus a small extension originally used as a shed, the building no longer met current requirements in terms of room size and height.

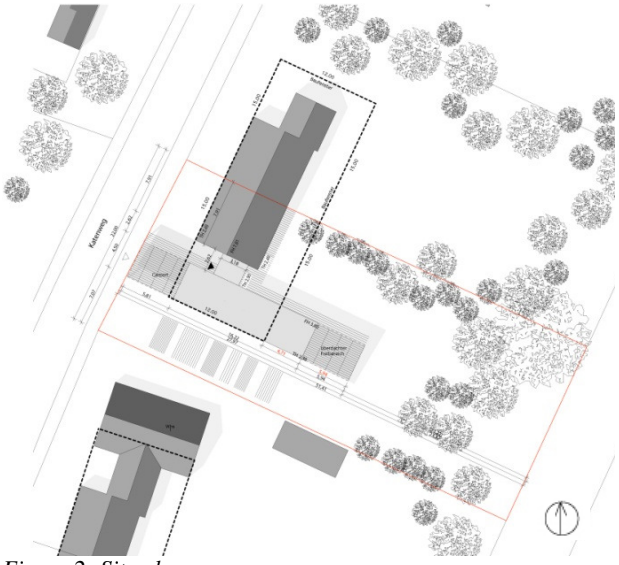

Figure 2: Site plan

In the run-up to the planning process, an ideas competition was held which saw students from Darmstadt University of Technology putting forward creative suggestions for modernising the old settlement house. At the beginning of September 2009, an expert panel awarded prizes to four of the twelve designs submitted in total. As well as energy design and measures to improve liveability, the panel also assessed the architectural creativity of the designs. The winner of the competition and the prize totalling 7,500 euro was Katharina Fey with her design "home grown" (figure 3).

Figure 3: The winning design "home grown"

The students' works served as an impetus to the draft design of the LichtAktiv Haus. VELUX's interdisciplinary team of experts supervised the planning process. The team comprised specialists in architecture and lighting design such as Professor Manfred Hegger of Darmstadt University of Technology and Professor of Lighting Design Peter Andres, of Düsseldorf University of Applied Sciences. After intensive analysis of various architectural and building ideas, the design documentation was finally completed at the end of March 2010 (figure 4). The integrated planning process continued through to the start of the structural implementation in the early summer with the ceremonial opening of the German Model Home taking place on 19 November 2010.

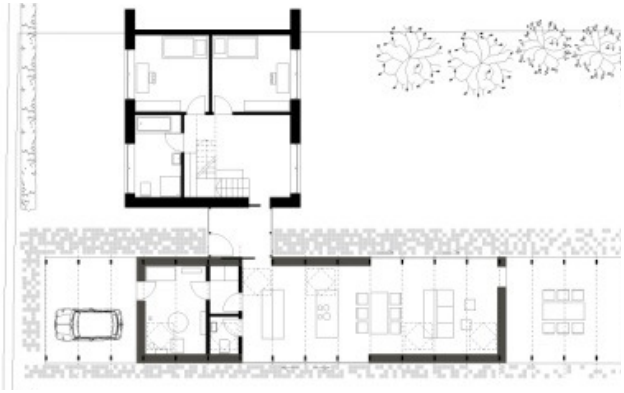

Figure 4: Ground floor LichtAktiv Haus"

FOCUS ON LIVING COMFORT AND ENERGY EFFICIENCY

In order to provide additional living space and floor area and create more freedom for individual needs, the extension was replaced by a new one and the original building was extensively modernised. This meant that the closed-off, small room structure was opened up to create generous sleeping, living and traffic areas (figure 5). As part of the restructuring and modernisation work, it was also possible to create a floorplan with an open aspect.

Figure 5: The LichtAktiv Haus before and after climate renovation

Sophisticated use of daylighting provides the building with plenty of light and fresh air, and ensures a sense of wellbeing and comfort. Solar energy inputs support heating during the heating season thanks to the large surface area of the windows. At the same time, the rooms are flooded with natural light so that even on cloudy days, there is hardly any need for artificial lighting (figure 6). Moreover, the skylights play a key role in providing ventilation for the building. The window openings in the air-tight structure of the building are controlled automatically dependant on temperature, CO_2 levels and humidity, to ensure a healthy indoor climate thanks to this natural ventilation.

Figure 6: The large amount of windows provides the building with plenty of natural light and fresh air.

A new extension building provides additional living space, and is also at the heart of the innovative energy design: together with an air-to-water heat pump, the photovoltaic modules and solar thermal collectors installed on the roof of the extension provide all the energy required for heating, domestic hot water and electricity in the modernised settlement house (figure 7).

Figure 7: Photovoltaic modules and solar thermal collectors on the roof of the extension

The heat for nearly all rooms of the building is distributed by a low temperature underfloor heating system with a very low installation height. Warm water is generated using the continuous flow principle. To reduce water consumption, the toilets, garden irrigation and washing machine use greywater which is stored in a cistern in the front garden.

LIFE CYCLE ASSESSMENT PROVES PRACTICAL RELEVANCE

A life cycle assessment carried out by Darmstadt University of Technology indicated that the environmental impact of the LichtAktiv Haus is significantly lower than that of a comparable DGNB-certified building and would be partly, or perhaps even entirely, compensated over the course of the building's life. The compensation is realized by the intelligent use of a range of renewable energies like solarthermal collectors, PV-cells and ambient heat. The assessment takes into account the whole life cycle of the modernised settlement house – from manufacture, operation and upkeep through to disposal of the building structure. The use of the existing primary structure of the building, which no longer needed to be built and therefore contributed no environmental impact to the assessment, in addition to the logical design of the new construction with a wooden frame were crucial to the environmental impact of the building structure being somewhat significantly below that of the DGNB-certified comparator.

Thus, the modernised house represents an ecological optimum and supports the assumption that extensive modernisation of an existing building can have considerable advantages compared to a conventional new construction under the given circumstances. Moreover, as existing houses in need of renovation can be considered an almost inexhaustible resource, the potential relevance of the life cycle assessment of the LichtAktiv Haus for specifiers, owners or purchasers becomes apparent.

LIVING EXPERIMENT COMBINES QUANTITATIVE AND QUALITATIVE RESEARCH METHODS

The key part of the experiment began in December 2011, when Christian and Irina Oldendorf and their two sons Lasse and Finn moved into the house. Their task as a test family is to put the VELUX LichtAktiv Haus to the test until the middle of 2014. This living experiment is accompanied by extensive scientific monitoring whose underlying concept combines both quantitative and qualitative methods of investigation for the first time. During the test period, researchers from the Institute of Building Services and Energy Design at Braunschweig University of Technology are measuring and documenting energy produced and consumed in the modernised settlement house, as well as recording quantitative data about the indoor climate such as temperature, relative humidity and CO2 levels in the air. Alongside these quantitative measurements, an interdisciplinary team of architects and sociologists from Darmstadt University of Technology and Humboldt University of Berlin continually record the experiences of the test family through interviews and on-line surveys, thus making it possible to make a direct correlation between the personal comfort and wellbeing of the test family and the quantitative data.

Figure 8: The test-family and the electric car

Since February 2013, the experiment has been further augmented by an electric car provided by Peugeot Germany (figure 8). The "i0n" seats four people and has a range of up to 150 kilometres on a fully charged battery which is plenty to comfortably allow for all normal daily journeys around town. At the same time, using energy efficient e-mobility increases the amount of solar-generated electric energy that is required for personal consumption, making the car therefore the ideal companion to the VELUX experiment to find construction and lifestyle solutions for the future.

THE LOW HEAT REQUIREMENT VALIDATES THE BUILDING DESIGN

The test family's happiness with the house and the good performance of both the building and the technology seem essentially to validate the theoretical calculations and design of the VELUX LichtAktiv Haus. So far, the renewable energy produced has exceeded expectations as follows: both the solar thermal yields and the harvest from the photovoltaic system (figure 9) are above the calculated values.

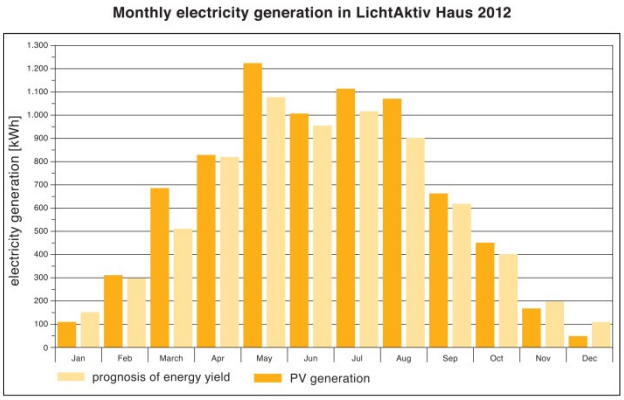

Figure 9: The yield from the PV system exceeds the calculated values

At the same time, the requirement for additional heating in the building is lower than initially calculated – even though the interior temperature in the winter averaged 22.4°C, above the values calculated based on the norm (figure 10). One reason for this is the high quality of the building envelope. The needs-oriented and controlled natural ventilation ensures best possible air-quality and at the same time avoids inadequate ventilation heat losses. In addition, solar heat gains through the skylights in the LichtAktiv Haus have a considerably greater effect than in less well insulated buildings, due to the minor overall need for heating

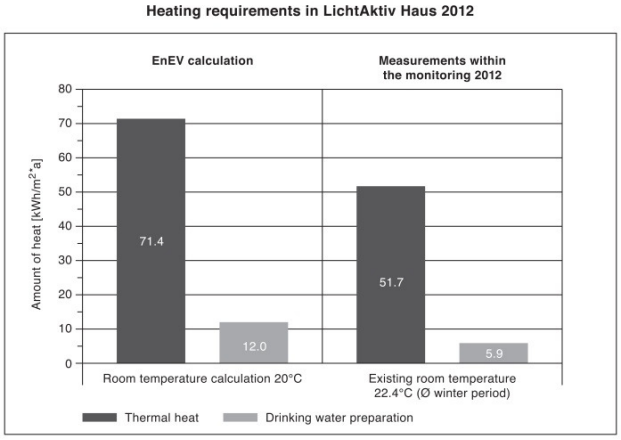

Figure 10: The requirement for additional heating in the building is lower than initially calculated

This outcome leads to the conclusion that heat loss due to ventilation with adequate natural ventilation does not lead to higher energy consumption without heat recovery. Moreover, the chimney effect of the natural transverse ventilation means that in the summer months, even if the external temperature is in the region of 40°C, the temperature inside the building

remains at 25–28°C which still feels pleasant, thanks to the storage mass of the building and the night-time ventilation.

THE SYSTEM'S HIGH CONSUMPTION OF ENERGY REQUIRES OPTIMISATION

Although the family's energy consumption, at 18 kWh per square metre per year, is comparable with other reference buildings, and is actually below the German government's criterion of 20 kWh/(m²a), the energy used by the heating system is roughly 55 per cent above the calculated values. This excess consumption by the heat pump of approx. 2,500 kWh/a matches the deficit, leading to an even or positive balance, and as a result the target of "zero energy home" was not achieved in 2012 (figure 11).

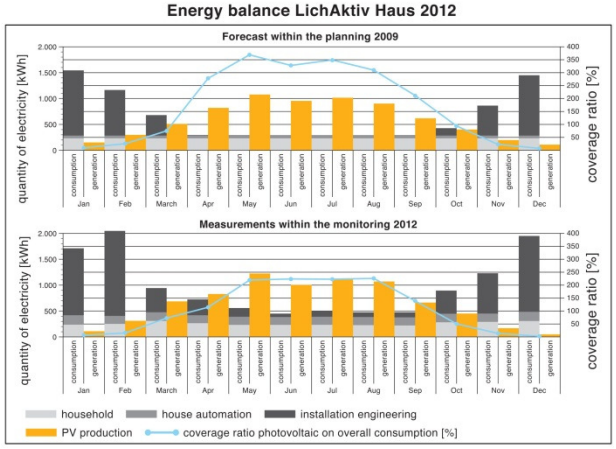

Figure 11: The energy consumption of the LichtAktiv Haus cannot be completely covered by the PV system

The cause of this lies mainly in the complexity of the entire system and the presetting of valves, pumps and controls, for example. The higher room temperature desired by the occupants in the winter months, which was 22.4° C on average and thus around two and a half degrees above the interpretation of 20° C made in accordance with the EnEV, has a minor influence. A standardisation calculation of consumption carried out by the scientists at Braunschweig University of Technology, which takes this higher temperature into account, confirms that the control of the system equipment used for heat generation requires optimisation.

Furthermore, the experiment has shown that the solar thermal energy system is too largely dimensioned for a family of four. Therefore, the yields which cannot be used or stored must be diverted to the heat pump via the external unit in summer. This “re-cooling” leads to increased power consumption of the system equipment in the summer months. To avoid this power consumption, Velux and the participating scientists have decided to add a geothermal system to the experiment. In the summer months, the surplus solar energy produced is stored in the ground soil to provide a higher temperature level in winter. This increases the solar coverage and reduces the energy consumption in winter.

RESIDENTIAL WELL-BEING AS A MULTI-DIMENSIONAL CONSTRUCT

Parallel to the physical measurements, sociologists from the Humboldt University in Berlin are investigating perceived experiences of the occupants of the LichtAktiv Haus. The objective is to gain an insight into how sustainable living impacts on the well-being of occupants and thus to establish a well-being study of living. The basic idea for the well-being study of living is a three-dimensional attitude model which distinguishes between three categories of reactions to attitudes – affective, cognitive and conative –which can be expressed verbally and non-verbally. The brightness, functionality or social environment of the modernised settlement house, for instance, trigger certain feelings in the occupants (affect), give rise to certain opinions (cognition) and influence behaviour (conation). All these reactions can be measured.

Since the attitudes, i.e. the residential well-being or the evaluation of it, change continuously due to experiences over time, the measurements must be repeated. It is, however, assumed that the number of new impressions decreases after a sufficient period of time, with the result that it is possible to make a relatively sound assessment of the liveability of a new home. Ideally, the evaluation process should allow for an estimation of the significance of the various affective, cognitive and conative components involved in forming the attitude.

THE PSYCHO-SOCIAL MONITORING OF THE VELUX LICHTAKTIV HAUS

The study design used in the living experiment in the LichtAktiv Haus consists of various instruments which make it possible to record the test family’s attitudes towards their new home, as well as possible changes over time (figure 12). This includes a detailed group discussion at the start of the experiment, as well as structured interviews carried out at the end of each season with the family on site in the LichtAktiv Haus. In addition, approximately every four weeks the residents complete an online questionnaire including both open and closed questions about the various dimensions of well-being, and approximately every four to eight weeks, more in-depth structured interviews are conducted with the parents in the form of video calls. In addition, the family records all their assessments of their living conditions in a digital logbook accessible to the monitoring team and reports on their experiences in the modernised settlement house in a public blog. The evaluation of the statements recorded in detail makes it possible for the scientists to scientifically assess the well-being of the family in the LichtAktiv Haus. In addition, the scientists can compare the sentiments and behaviour of the occupants with the findings of the quantitative evaluation and optimise the technology if necessary.

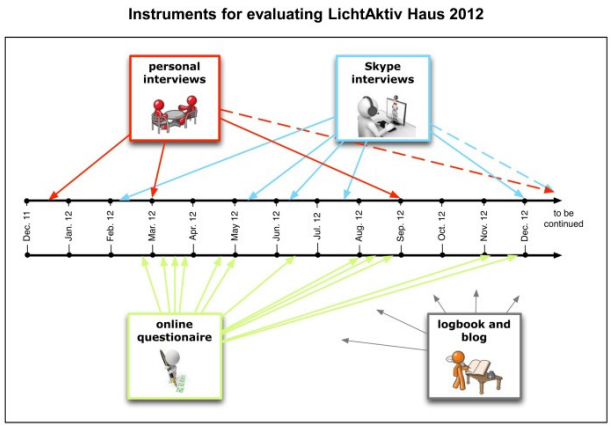

Figure 12: Overview of the use of qualitative research methods

IMPRESSIVE LIVING COMFORT AND INDOOR CLIMATE

The LichtAktiv Haus offers its occupants a very high degree of living comfort. The division of space and the interior architecture of the modernised settlement house were perceived very positively by the test family, and the interviews that have been carried out show that, despite a few small criticisms, the family feels very happy in their new home. The comfortable temperature, optimal air quality and amazing amount of light in the rooms, in particular, were rated positively time and again. The house's good indoor climate is another plus (figure 13). The values for relative humidity are between 45 and 55 per cent, making it very comfortable during the heating season. The CO2 level in the air was likewise in line with expectations.

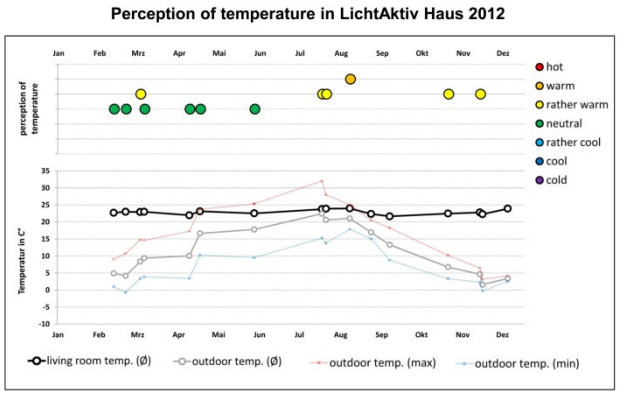

Figure 13: Temperature perception of the occupants

BUILDING TECHNOLOGY PROMOTES ENERGY-SAVING BEHAVIOUR

The functionality of the technology was rated as outstanding by the occupants, both as regards the automated operation and in terms of the customised control options. However, the noise caused by the automatic opening and closing of the windows was perceived as too loud, in particular at night. Moreover, after moving in, the family initially felt a lack of security due to the windows opening automatically while they were out. This feeling subsided with time. However, as it is possible to manually set the technology at any time, there was no point at which the test family felt imposed by it; rather, they considered the automation to be a genuine asset.

The LichtAktiv Haus also fulfils expectations in terms of sustainability. As a result of their new living environment, the occupants are demonstrating a greater awareness of the concept of saving energy, and have modified their energy consumption behaviour accordingly. This sustainability is one reason amongst others for the family identifying strongly with the Model Home project and the LichtAktiv Haus, and being proud to represent the lifestyle of the future.

CONCLUSION

Through the LichtAktiv Haus experiment, VELUX provides insight into construction and lifestyle solutions for the future. In the process, by modernising an existing house, the company has taken on a task of relevance to the whole of society: around half of the 39 million residential properties in Germany are between 30 and 60 years old and in need of modernisation in terms of energy usage. Against the background of the German government's climate protection targets, which envisage energy savings in the building sector of 19 per cent by 2020 compared to a 2005 baseline, energy efficient renovation of existing buildings will play an important role. However, this should not be at the expense of living standards or the health of the occupants. Future-oriented buildings should meet both needs: energy efficient and sparing use of natural resources, and at the same time healthy, attractive living spaces for enhancing wellbeing through plenty of natural light and fresh air.

The LichtAktiv Haus exemplifies how optimum energy efficiency and optimum liveability can be brought together to create a future-oriented solution, even as part of an ambitious modernisation project. Rather than a passive house, where the design is based on an air-tight, very well insulated building envelope with "forced ventilation" and as few "loss areas", i.e. windows, as possible, the LichtAktiv Haus follows the strategy of an active house, with automatic natural ventilation and an above-average proportion of window surface area. The result is optimum indoor air quality and generous amount of light in the rooms that significantly increase living comfort and are perceived positively by the occupants. At the same time, the house's measured heating requirement leads to the conclusion that heat loss due to ventilation with adequate natural ventilation does not lead to higher energy consumption without heat recovery.

The evaluation of the living experiment, carried out in this way for the first time, is situated at the interface between the four disciplines of architecture, engineering, sociology and psychology. The knowledge gained should help to answer the fundamental question of what is really important in terms of future quality of living, and how future demands on the energy efficiency of a building can be met while maximising the consumer's experience.