A THOUSAND EXPERT OPINIONS IN ONE EXPERIMENT – CONNECTING THE DOTS IN A EUROPEAN PROGRAMME

CONFERENCE PAPER · SEPTEMBER 2015

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Fig 1: users as pivoting point

WHICH ARE YOUR ARCHITECTURAL (R)SOLUTIONS TO THE SOCIAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES OF TODAY?

Research summary Can sustainable buildings (e)valuate and support people´s health and wellbeing?

In historical terms, the current concept of dwelling is extremely novel. During our lifespan we spend 90% indoors, sheltered from the elements, safely moored in a controlled environment for our comfort and welfare. Yet our bodies have not altered one bit since we went shopping with a spear and dozed under the open sky. In essence, we are still adapted to life outside rather than inside. The model home 2020 programme of 6 demonstration projects across Europe bases on the assumption that sustainable living can be achieved in an indoor environment that prioritises natural living conditions. One essential target is to recreate the nurturing properties of an outdoor experience without compromising the need for heat and shelter. Discoveries from the post occupancy evaluation and monitoring of the model homes confirm that access to more daylight and fresh air has a positive impact on the inhabitants' wellbeing and even a direct beneficial effect on asthma and allergies.

Keywords: *Practice work, applied research; demonstrator buildings, innovation by design; field testing*

1. Introduction

"*One experiment is better than a thousand expert assumptions*" forms the point of departure for a cross-European demonstration project programme. During 2009-2011, 6 projects were built in Denmark (Home for Life and Green Lighthouse in 2009), Austria (Sunlighthouse in 2010), Germany (LichtAktiv Haus in 2010), France (Maison Air et Lumiere in 2011) and United Kingdom (CarbonLight Homes in 2011). Local planning teams, with a common point of departure, designed the projects with a holistic approach to sustainable construction, formulated as the Active House principles of Comfort, Energy and Environment (Alliance, 2011) (fig.2). After completion the projects were inhabited by test families and subject to extensive post occupancy evaluation schemes performed by national research teams of engineers and / or scientists. The many theoretical expert assumptions were put to the testbed, to learn and deduct how theory worked in practice. The aim was to enable practice to give back to theory, and further to replicate into the building stock on a wide basis; leading by provo- and prototyping.

Fig 2: Active House radar diagram

2. Research objectives

The research evidence, reports, findings and empirical data from the Model Home 2020 experiment have been consolidated during 2014, into a unique knowledge base. Three cross-reports cover the key areas of energy, comfort and well-being aspects of the inhabitants. Ten papers were published at the World Sustainable Buildings 2014 in Barcelona, following thirteen papers published during 2011-13 on the individual projects.

The cross-reports and conclusions form the body of the empirical studies, hereto added the key learnings from the national house reports, as well as the synthesis of a questionnaire process. The point of departure for the research questions are to investigate whether comfort levels can be based on natural ventilation and use of daylight, while the buildings are zero energy or energy positive? This paper presents the main common denominators from the knowledge base.

The houses featured low-energy electric lighting, appliances and multimedia equipment – as well as photovoltaic cells integrated into the roof, solar collectors and air-to-water heat pumps. Measured energy performance of the houses are not dealt with in detail in this paper, beyond the established fact from the cross-comparison report that it is possible to build zero/plus-energy building with today's technology. (T. Wilken O. R., 2014) The objective beyond energy consumption and production is to dig deeper into the relation between comfort, health and wellbeing for the users. Can sustainable buildings meet human requirements on an eye-to-eye level? And can designers and house owners maintain a positive relationship between sustainable buildings and value of what goes on inside the buildings beyond technology (fig 3).

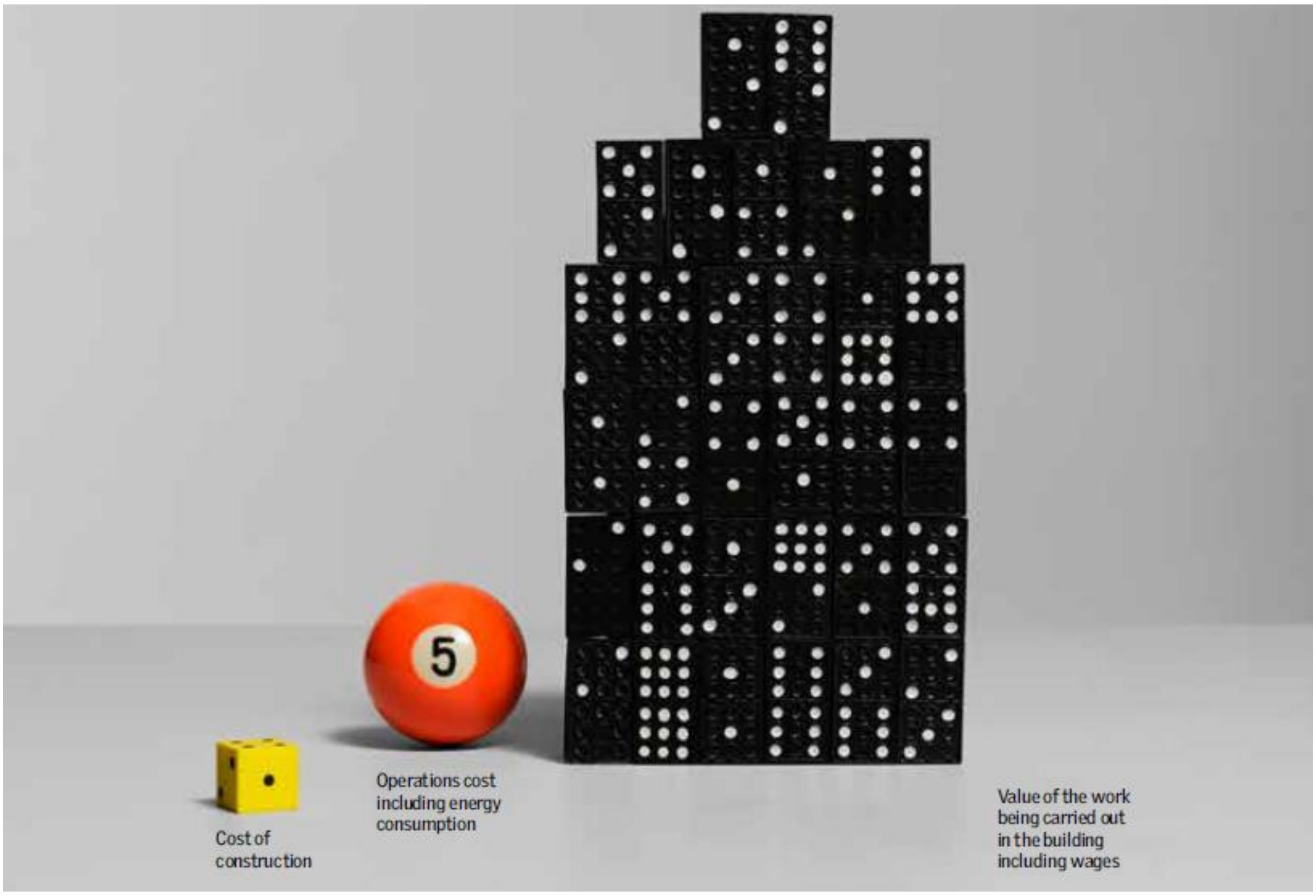

Fig 3: Construction costs is the minor cost, where people are the major value of buildings (Consulting, 2007)

3. Methods and approach applied

3.1 Physical Measurements

Measurements of Indoor Environmental Quality (IEQ) included light levels, thermal conditions, indoor air quality, occupant presence and all occupant interactions with the building installations, including all operations of windows and solar shading. All sensors were part of the building control system, so each sensor was used for both control and monitoring. The sensors for presence, temperature, CO2, relative humidity and light were standard sensors, were wired to the control system, recording of position of window and shading products was done by extracting data from the control system for these products.

Use of natural ventilation for summer comfort was based on ventilative cooling principles. Ventilative cooling refers to the use of natural or mechanical ventilation strategies to cool indoor spaces. This effective use of outside air reduces the energy consumption of cooling systems while maintaining thermal comfort. The most common technique is the use of increased ventilation airflow rates and night ventilation (Venticool, 2015). The houses used natural ventilation in the warm season. Most houses used mechanical ventilation with heat recovery during cold periods. External automatic solar shading on windows towards the south and in most cases towards east and west. Overhangs were used where appropriate.

Each room was treated as an individual zone in the control system, and were controlled individually. The sensors, for humidity, temperature, CO2, presence and lux in all main room, were used for both control and data recording. The building occupants could override the automatic controls, including ventilation and solar shading at any time. The recorded temperature data was evaluated according to the Active House specification (Active House, 2011), which is based on the adaptive approach of EN 15251 standardisation (Standardisation, 2007). The data from sensors, and controls was recorded. IEQ data was recorded pr individual zone as an event log, where a new event was recorded when the value of a parameter changed beyond a specified increment from the previously recorded value. The event log files were automatically converted into data files with fixed, 15-minute time steps, and used for the data analysis.

3.2 Post Occupancy Evaluation Survey

As part of the evaluation, a Post Occupancy Evaluation (POE) survey was carried out seasonally, during the test year, to allow variations on a seasonal basis, with approximately three months in-between surveys. The intent, with four replies per house, is twofold: firstly, to identify if the occupants experienced perception changes during their stay, for instance – was their perception of indoor environment, expression, comfort or automation changed throughout their stay? The second aspect to the seasonal distribution was to explore if seasonal changes in weather (e.g. outdoor temperatures, daylight) influenced occupant experience.

The questionnaire was translated into the occupants' native language and contained questions on satisfaction/dissatisfaction with energy consumption and production, indoor climate and air quality, daylight and electric lighting, house automation, and sustainability. Also addressed was the frequency of occupant interaction with elements of the house, and if the house fulfilled the expectations of the occupants (Hammershøj Olesen, 2014). In total, 18 responses were made.

The questions about satisfaction were made as sets of Likert-scales, categorised as very satisfied, satisfied, neither satisfied nor unsatisfied, unsatisfied, and very unsatisfied. Questions about how comfortable the subjects were in their indoor environments are categorised on a five-point rating scale by: very rarely, rarely, occasionally, frequently, and very frequently. Finally, the questions about energy, environment and sustainability were made as sets of statements and categorised as a three-point scale yes, very, yes to some extent, no normally not, or as sets of five-point scales from strongly agree to strongly disagree, and very good to very bad.

For each project a sociologist performed monitoring, respecting the national and cultural particularities. A cross report summarizes the results, where the following instruments were used: face--to--face interviews, telephone interviews, questionnaires and logbooks. Results are summed up in a cross report (Fedkenheuer, 2014) The overall purpose of both cross POE evaluation methods was to get indications on how successful the houses were, if there were challenges or problems, and what could be learned and improved, for future theory and practices.

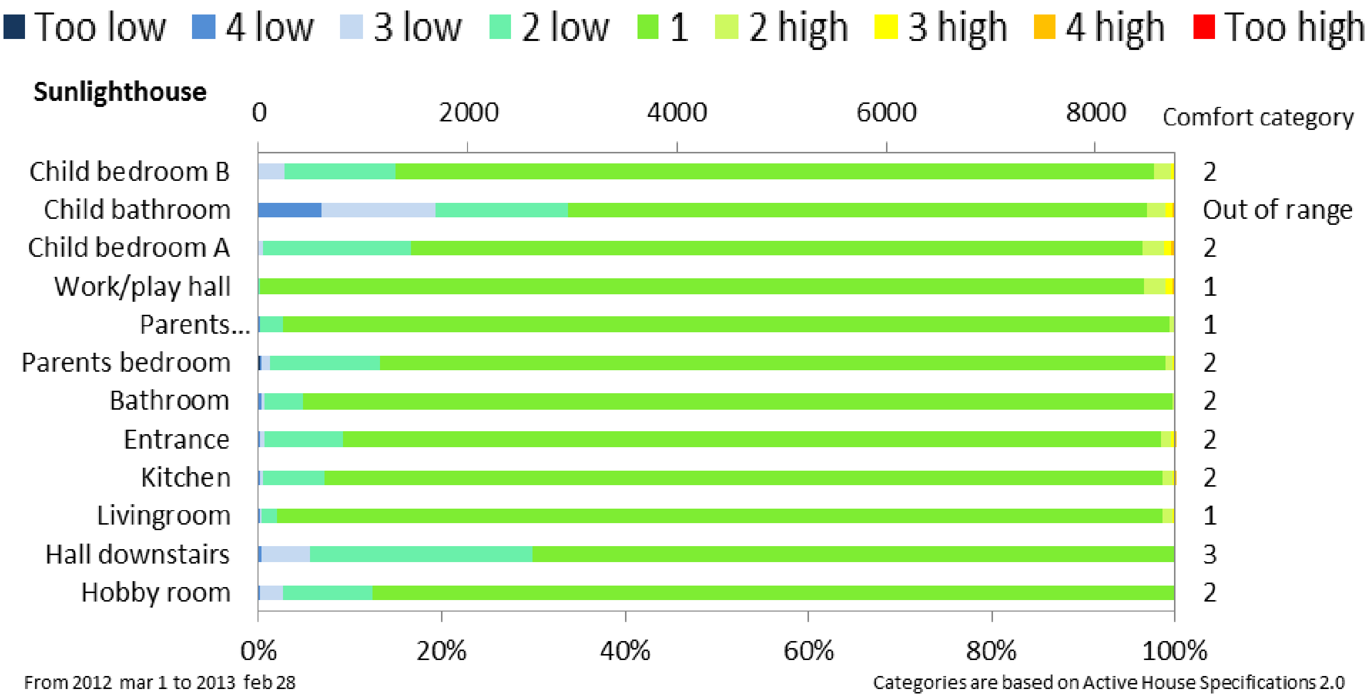

Fig 4: ***Thermal comfort of Sunlighthouse.*** *Thermal comfort for each room evaluated according to Active House specification (based on adaptive method of EN 15251). Criteria differentiated between high and low temp..*

4. Results and design potential

4.1 Improved sleep & reduced no of sick days

Within the last decade, increased knowledge has identified the importance of appropriate light during the day and darkness at night, as playing key roles in the regulation of the sleep/wake cycle (Veitch, 2012). Also, the room temperature when falling asleep has an influence on sleep quality and research suggests that it is preferable to have a lower room temperature during times of sleep than when awake. In the Model Homes 2020, the bedrooms had blackout blinds installed and the house control system allowed the possibility of remote window-opening. In the POE survey, the families were asked if they experienced their sleep quality as being "better, almost the same or worse" compared to their former home. They stated that they subjectively experienced sleep quality as being "better" (50%) or "almost the same" (39%), and when rating their children's sleep quality, the tendency was a bit higher ("better" 56%; "almost the same" 44%). Furthermore, they experienced "less" sick days (83%) than in their former homes and they stated that their general health, all in all, was "good" or "very good".

Across all the houses, the residents are either "very satisfied" or "satisfied" with the temperature conditions in general (90%) and the three rooms in focus (>85% state "very satisfied" or "satisfied"). Most of the times, the temperature conditions is assessed as about right, but separated into the different season of the year, the winter and the spring/autumn is stated as time of the year when temperature is sometimes evaluate as varying, while few state temperature as too hot, even in the summer.

4.2 Ventilative cooling prevents overheating. Night cooling important.

A particular element of the present study is that the actual position of windows and the level of solar shading have been included in the data recording, which provided detailed insights into the role of those components. The use of window opening followed the seasons; during spring and autumn windows were used on most days for approx. 50% of the time during daytime. During summer, windows were used more systematically during daytime hours, and also during the night. There is a correlation between use of windows and hours without overheating. This indicates that window openings have played an important role in maintaining good thermal comfort.

Open windows during the night (night cooling) cools down the rooms from a temperature at the upper range of the comfort range to a temperature at the lower end of the comfort range, e.g. from 26°C in the evening to 20°C in the morning. The temperature can then rise during the day, in many cases without becoming uncomfortably hot at the end of the day. This underlines the importance of night cooling (fig 4).

The results are supported by tracer gas measurements which were used to investigate the airflow generated by ventilative cooling, and how large a temperature reduction ventilative cooling provided. The results showed that airflow rates of 10-20 air changes per hour could be achieved, and that the indoor temperature could be maintained 5°C lower than if ventilative cooling had not been applied (Favre, 2013).

4.3 Solar shading helps prevent overheating

The position of solar shading was recorded separately by extracting data from the control system. Awning blinds were the preferred type of external shading used on the houses, and the results showed that the awning blinds had a role in providing good thermal comfort. The awning blinds were used the most during the summer, but also during spring and autumn. There is a correlation between the use of awning blinds and the hours without overheating.

4.4 Automation important

Automated control of window openings, solar shading and mechanical ventilation were used in all the investigated buildings. The results show that the automated solar shading and window openings were used frequently during work-hours on weekdays, and during the night, e.g. at times when the families cannot be expected to be able to operate the products themselves. The same use of products could not have been achieved with only manual products.

The families responded in the POE survey that they were generally “very satisfied” or “satisfied” (>85%) with the way the automated house system operated the facade and roof windows, the indoor temperature, internal and external screen, and ventilation system (one house used natural ventilation only). They had a clear feeling that the way the control unit operated the house supported their needs, and it was “easy” or “very easy” to use. The survey also showed that they “rarely” or “occasionally” used the control system to manually operate the facade and roof windows to regulate the internal temperature, but more frequently used the control system to manually operate the screening.

4.5 Satisfying CO2-levels during summer

Generally, the indoor climate was rated as “very important” and the residents stated that most of the time it was “good” or “very good” (>90% state “good” or “very good”). When the residents were asked to choose three conditions they would like to change to make the indoor climate more comfortable to live in, they reported less noise from the window opening systems, less peeping inside (privacy) and better electric lighting (Hammershøj Olesen, 2014). The CO_2 levels were low during the spring, summer and autumn seasons, typically below 900 ppm. Natural ventilation was used in this period as the only means of ventilation, and the results clearly show that the stack effect created by temperature and height differences with even a limited temperature difference, still made it possible to reach a reasonable CO_2 level. During summer there was no electricity consumption for mechanical ventilation and no heat loss, so high ventilation rates and excellent indoor air quality can be achieved without any use of energy (Holzer, 2014). The most challenging rooms were the bedrooms, as these were small rooms where approximately eight hours were spent each night, often two persons together in the same room. This is longer than the time spent in any other room in the home. Still, the CO_2-levels were maintained at a reasonable level in the bedrooms. The POE survey indicated that the perceived indoor air quality was good, as it was rated as "very acceptable" (78%) or "acceptable" (22%), and the families stated that they did not experience any problems at all. Most houses used hybrid ventilation, so that mechanical ventilation with heat recovery was used during the winter to save energy. The mechanical ventilation systems were designed and commissioned to provide the ventilation rates required by the building codes, and they fulfilled this requirement flawlessly. However, when the winter CO_2-levels were evaluated according to the Active House specification, particular bedrooms only achieve a category 2 or 3.

4.4 Effect on mindset – behavioural effects

All test families praised the houses for improving their mood and their state of health so the recreational value of the buildings can be seen as very high. The experiment could display that well designed modern homes are able to alleviate, or even resolve, health problems, such as asthma or allergies. Furthermore the energy-saving concept of the houses not only reduced the families overall energy consumption but also sensitised the residents to their behaviour. It proved to be a stimulator for the environmental consciousness and energy saving behaviour. Living in low--- energy houses encouraged the residents' responsibility and made them more aware of their ecological footprint (Fedkenheuer, 2014).

"*Not needing to take any medication, you can't put a price on that.*" MAL test family (Fedkenheuer, 2014)

5. Future implementation

The collective results form a platform for discussion, definition and suggestion of a recommendation catalogue of conclusions for learnings transferred to the wider building stock, new as well as existing. Rule of thumb # 1 is that with good daylight conditions (Daylight Factor > 5% in main rooms), use of electric light is avoided between sunrise and sunset. # 2 is that good daylight conditions do not cause overheating, when automated solar shading and window openings are included in the building design. # 3 rule is that night cooling is a particularly important aspect to implement for summer comfort. Through high ventilation rates during summer utilizing the stack effect by ventilation through open windows, even if limited temperature differences between in- and outside during the warmer period. As rule # 4, use of ventilative cooling during summer means with high ventilation rates, with low measured CO_2-levels, with few issues for improvement (Fedkenheuer, 2014).

6. Conclusions

The families generally stated that they were very satisfied with the indoor environment; that their expectations were often fulfilled, and that house automation was acceptable. Furthermore, combining excellent indoor environment with high quality homes resulted in the residents experiencing better health and better sleep quality, as well as having less sick days, than when living in their former homes. All in all, the results support the notion that beneficial outdoor properties can be put into effect inside a modern home without compromising the principles on which the future of sustainable building relies. It is possible to achieve 2020 standards with today's products, techniques and competence; the decisive parameter is the holistic approach, and the paramount principle is user-centric.

7. Acknowledgments

We thank all the involved planners, designers, engineers and researchers profoundly for contributing to this unique experiment. The dots were particularly connected in the cross reports, written by Thomas Wilken and Oliver Rosebrock from Technical University of Braunschweig (energy), Peter Holzer from Institute of Building Research & Innovation, Vienna (the comfort deductions and analysis), and not least Bernd Wegener and Moritz Fedkenheuer from Humboldt University, Berlin on their unique work on social monitoring for users wellbeing and derived connection and effect on sustainable mindset changes.

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