Livability across Europe:
Common denominators in five active houses

LONE FEIFER[1], TIM WESTPHAL[2], PETER FOLDBJERG[1]
[1]VELUX Group, Hørsholm, Denmark
[2]Verlagshaus DETAIL, Munich, Germany

ABSTRACT: What are the common denominators in five active houses tested in post-occupancy evaluations? The five houses vary in size, architecture, cultural and contextual approach, as well as differentiated social segmentation; the post-occupancy evaluation results offer a view of tomorrow´s living, as well as the need of integration of socio-cultural and regional characteristics for sustainable buildings. By means of Active House radar diagrammes, the learnings and experiences from the livability indicators are shown and discussed. The analysis reports the theoretic programming and actual performance, documenting and discussing in parallel the aspect of livability for the inhabitants.
Keywords: Livability; Climate Renovation; Active House; EPBD; Comfort

INTRODUCTION

From 2009-2011, five active houses were built as demonstration buildings in Denmark, Austria, Germany, France and United Kingdom. All houses are residential buildings, based on the Active House principles [1], with a holistic approach to comfort, energy and environment. The houses are programmed to have excellent indoor comfort levels, a low use of energy and focus on the environmental impact. All houses are tested and monitored in use, followed by national research teams and Active House Alliance partners.

The houses are designed by local architects and engineers, and base on a common point of departure; generous daylight conditions and natural ventilation as key components to optimal livability. All houses respond to the target of the Energy Performance of Buildings Directive (EPBD), that new buildings in the EU should be `nearly zero´ energy, and basing mainly on renewable energy sources [2]. Furthermore, the houses reflect the predicted building regulations by 2020 as per country, encompassing the specific country compliance tools and calculation engines. The approach to optimise livability whilst minimising environmental impact is applied to 3 new single family houses (Denmark, Austria and France), one semi detached double house (United Kingdom) and a climate renovation of a 1954 Settler´s House (Germany); all designs aim to adapt to current requirements of modern family living, interpreted into a healthier and more comfortable life for the occupants, without having a negative impact on the climate.

With this paper, we assess some of the common denominators and take a closer look at how theory performed in practice, with a specific focus on the indoor comfort aspects.

METHODOLOGY

Firstly, a comparative overview describes the five designs in facts and figures typical for daily design practices. This overview displays common denominators as well as the local specifics. Secondly, two houses – new built Home for Life in Denmark, and climate renovation, LichtAktiv Haus in Germany, – are analysed via an Active House radar diagram, which categorises the principles of *Comfort*, *Energy* and *Environment* (Fig. 1) in four levels, 1 being the highest level; all parameters are interdependent and the diagram gives an overview of goals and priorities of a sustainable project. Here the diagram is used to display measured and calculated values, analysing with the aim to share experiences for design practitioners on ventilation principles in residential buildings**.**

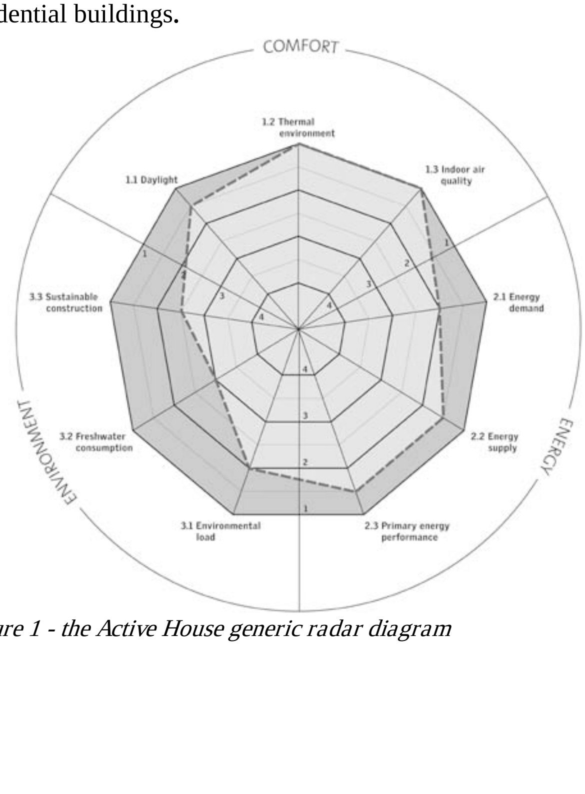

Figure 1 - the Active House generic radar diagram

RESULTS

Each housing project is designed in a vernacular architecture tradition. There are variations in space demand, in cultural habitat, as well as in energy requirements and sustainable focus (Table 1). 3 houses are one family houses (OFH), the GB houses are built as double house (DFH) (table shows the smallest house), and the climate renovation in Germany is half a double house (DFH/R).

Table 1 - facts and calculations on the 5 active houses

Cases	Home for Life **HFL**	Sunlight -house **SLH**	Maison Air et Lumiere **MAL**	Carbon-Light Homes **CLH**	Licht-Aktiv Haus **LAH**
Country City	DK Aarhus	A Vienna	F Paris	GB Kettering	D Hamburg
Storeys	1,5	2,5	1,5	3	3
m^2 ISO 9836	190	304	233	117	189
Type	OFH	OFH	OFH	DFH	DFH/R
Window area m2	85	101	46	32	92
Occupants (o)	4	4	4	4	4
Energy demand kWh/m^2/y	37	43	45	87	94
Energy production kWh/m2/y	63	63	65	87	108
Orientation by ridge	E-W	NW-SE	SW-NE	N-S	N-S/ E-W
u-value ext. walls	.1	.13	.12	.11	.16
u-value windows	1	.76	1.2	1.6	1.1
g-value windows	.57	.46	.6	.57	.49

The houses span from a footprint pr occupant of approx. $75m^2$/o to $30m^2$/o, all being inhabited in the test phase by a four-person household.

Figure 2 – the five active houses, top left: LAH, Hamburg; HFL, Aarhus; SLH, Vienna; CLH, Kettering; MAL, Paris

Daylight requirements for all houses were average 5% daylight factor in living rooms; the window area covers a range from approx. 20% to 50% of the total area, and there is a large difference in compactness between the houses.

Figure 3 – interior of the five houses, top left clockwise: HFL, Aarhus, LAH, Hamburg; MAL, Paris; CLH, Kettering; SLH, Vienna

Each house has a main sustainable characteristic: HFL sources daylight from all four facades; SLH aims to demonstrate energy efficiency even on a shaded and sloped plot; MAL focuses particularly on how to establish summer comfort based on natural ventilation; CLH demonstrates low footprint and generous daylight; LAH uses natural ventilation principle only, where all other houses base on hybrid ventilation systems. The building fabric is of high quality with low u-values for walls and windows. The energy balance for windows is based on a whole year perspective, where heat loss (u-value) as well as solar gain (g-value) is reflected in the calculations and specification of components. Each house is conceived as an experiment, designed as a prototype on the architect´s drawing board and in the engineer´s calculator. Proof is collected by research teams during the occupancy phase, where reality meets theory.

The first experiment to report was HFL, year 2 of occupancy. The performance was scored according to the Danish national building codes, where voluntary classes for 2015 and 2020 have been defined (Fig.4).

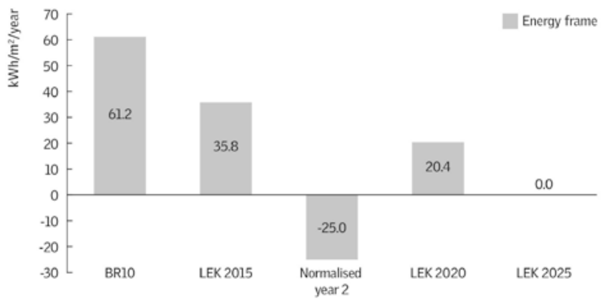

Figure 4 – Energy consumption for HFL year two compared to Danish Building Code actual (BR10) and voluntary future classes(LEK 2015 and LEK 2020).

HFL meets the future requirements, exceeding the zero energy by +25 kWh/m2/y. This figure is normalised to match preconditions of the compliance engine, +6 kWh/m2/y without normalisation.

Reviewing the performance indicators in the Active House radar diagram gives an overview of the sustainable parameters, as well as a comparison between the calculated and measured performance (Fig. 5).

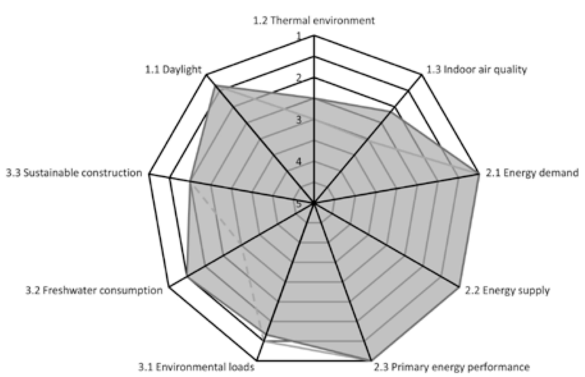

Figure 5 - Home for Life radar diagram calculated (light grey solid & punctured line) and measured (dark grey fill)

The comfort indicators are the key to assessing livability. Daylight conditions are typically a design given constant, whereas the thermal environment and indoor air quality are strongly determined and influenced through user preferences, behaviour and to some extent also the changing outdoor conditions. Both indicators are assessed through the principle method of EN 15251 [3], where parameters for a.o. indoor air quality and thermal environment are regarded on an adaptive basis, rather than on absolute figures.

The ventilation system is hybrid, i.e. natural ventilation is used during summertime, mechanical ventilation with heat recovery during wintertime, while hybrid ventilation is used spring and fall; there is external automatic solar shading on all windows facing south, adjusted based on external solar radiation. There are sensors for humidity, temperature, CO2 and presence in each room. The building occupants can override the automatic controls, including ventilation and solar shading at any time, and were recorded to use solar shading motivated on individual preferences – avoid glare, privacy, sense of security etc.

The score of the thermal environment represents an average of all habitable rooms in the house. Half of the rooms fall in category 2 and the other half in category 4. The hours out of category 1 are mainly hours with undercooling, while overheating is rare. If undercooling is disregarded, the primary rooms of the house achieve category 1. The episodes with undercooling are explained by comfort demands, window airings during mechanical ventilation, and occupant preferences [4].
An exemplification of the adaptive principle is the thermal comfort for the main living room with kitchen and multi-purpose area, where the family spends a great deal of their time at home. The indoor temperature is evaluated according to the European standard EN 15251, which defines four comfort categories from I (best) to IV (unacceptable). The figure 6 shows the distribution of categories for each month and for the entire year.

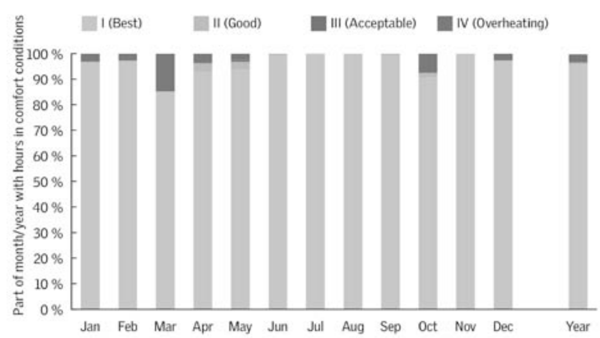

Figure 6 - Home for Life - Measured thermal indoor climate kitchen and multi-purpose area year 2

More than 95 % of the hours of the year are in category I, which means that the room is categorised as category I as far as indoor temperature according to EN 15251 is concerned.

The methodology used to assess HFL was also used on the LAH, a climate renovation designed to be carbon-neutral in operations, with renewable energy production from windows, solar collectors and photovoltaic panels, controlled by a solar based heat pump with an outdoor unit. The house is based on automated natural ventilation as key principle for air exchange throughout the year. The natural ventilation as key principle was chosen specifically based on the assumption, that a modular model for climate renovation should assign solutions with minimum level of technology and easy installations; thus enabling the house owner to invest into qualitative modernisation design which delivers instant payback on livability such as health and well-being.

The house is inhabited by a test family for two years, and the first year is reported in calculated and measured performance (Fig. 7).

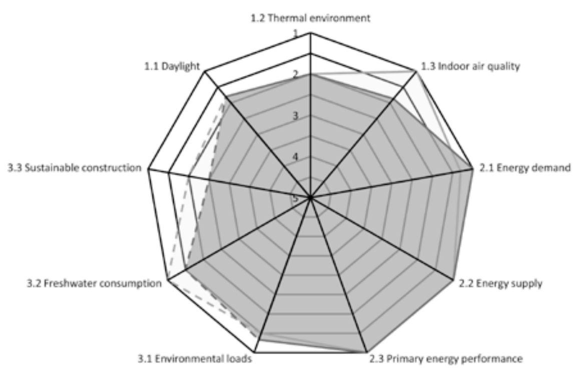

Figure 7 - LichtAktiv Haus radar diagram calculated (light grey solid and punctured line) and measured (dark grey fill)

The thermal environment is performing according to expectations, with an average score of 2 for all habitable rooms of the house. The sociological research team following the test family reports that the family finds the heating to work perfectly, and the occupants rated the general room temperature as essentially satisfactory over the entire year [5]. Looking into the livability indicator to evaluate indoor air quality, particular interest is paid to the comfort levels of the winter time.

Again using the Active House radar to evaluate levels for Indoor Air Quality, which are based on the EN 15251 adaptive comfort levels, the performance of the first year for the main living room is recorded (Fig. 8). The room is a category 2, considering the whole year. During the winter time, the occupants overrule the window openings manually, typically to avoid the cold draught; despite this, the quality of the indoor comfort level is good.

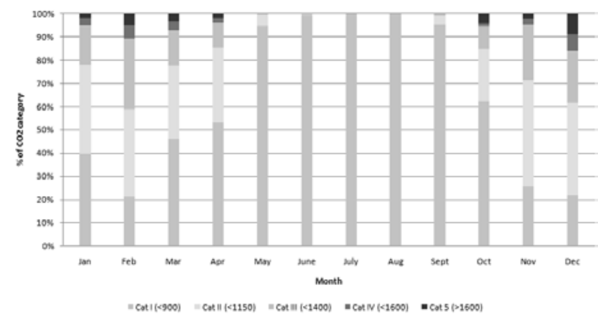

Figure 8 - LAH kitchen / living room, yearly results for CO2 (measured in ppm, based on principles of EN 15251

Looking at the measured energy performance of LAH and comparing this to the German compliance tool EnEV (EnergieEinsparVerordnung), the results for the first year show a lower consumption than calculated, even with a higher comfort level (22.4) for indoor temperature (Fig. 9).

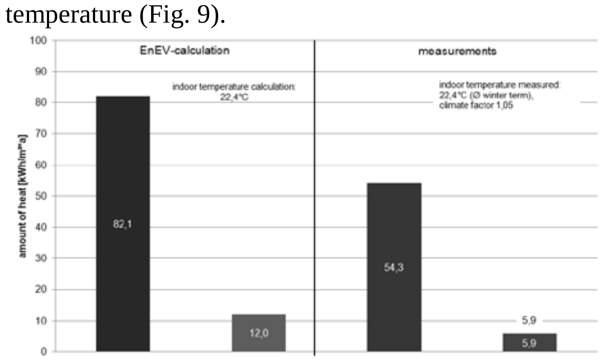

Figure 9 – the measured energy performance compared to the German compliance programme EnEV calculation. Black is heating, grey warm water consumption

This means firstly that the building envelope is performing as expected, and secondly that the calculated heat losses caused by natural ventilation do not lead to inflated heating consumption [6].

DISCUSSION

Seen from afar, the five active houses differ on a large number of aspects; they are geographically spread, from latitude 55 in Denmark to latitude 48 in Austria; placed in different climates – temperate, continental and oceanic. The houses are very different in size, compactness, footprint, materials, and particularly on the design aspects plugging into vernacular architectural approaches, as well as cultural responses of typical middle-class family life. However taking a glance inside-out, the houses share a substantial common baggage with generous amounts of daylight, coming from several sky angles, and the use of fresh air for user comfort and sensoric experience of open windows during summer and outside the heating season.

From an environmental engineering overall perspective, the houses have several common denominators: use of automated natural ventilation, use of ventilative cooling, an automated control of indoor environment quality with a system operating window openings, heat controls pr room, CO_2 rates, humidity sensors, daylight controls, dynamic external solar shading, all linked to a weather station detecting the wind speed, solar radiation, etc. Taking a more detailed look, there are differences within heat pump types, comfort levels in compliance data, u-values in the envelope, and different systems, brands, materials and system diagrammes. This makes each house different in the execution, at the same time staying true to the overall goals.

Common for all is that the users can override the system and take manual control of their indoor environment. Window openings are used very actively in the houses. This was particularly interesting in the naturally ventilated LAH, where windows are used all year for air exchange and to maintain a good indoor air quality. The test family closes the windows whenever they find that it gives a draught or discomfort, however this did not appear to influence the air quality in a negative direction.

\`The proof of the pudding lies in the eating´ goes an old proverb. This applies particularly for sustainable buildings, especially when conceived as prototypes for a new model and a more holistic approach to sustainability in buildings, taking the human factor into account.

Analysing the first findings from these five active houses, the first question was whether they can live up to 2020 requirements, the so-called nZEB (nearly Zero Energy Buildings). Having established that this is possible not only in calculations, but also in measured status, the next essential question is whether the occupants well-being is granted, in this case reviewed through the indoor comfort and the indoor air quality. Both indicators are vital to the occupant´s well-being and also the most volatile and vulnerable indicators amongst the nine in the Active House radar diagram.

The results of the monitoring raises key questions as for practice of national compliance engines; firstly, the typical comfort level demanded by the users is 2-3 degrees higher than standard settings in compliance engines; secondly, the typical compliance figures focus mainly on demand for heating, however in modern sustainable houses being very energy-efficient, the indoor comfort is influenced by several other aspects; thirdly, the compliance data do not include the livability aspects of thermal comfort, which are paramount to users feeling of wellbeing.

The concept of Active House is more than a technical standard, rather a planning strategy for how to design a house, which takes advantage of the immediate surroundings, plugs into the possibilities for direct harvesting of renewable energies, and how to be flexible in design of climate envelope and use of the building by different user types; an important aspect about the quality and value of an active house is the personal relation, expression and individuality of the design [7]. The five active houses used as case studies in this paper are all local interpretations of a goal for optimal livability with a minimal of impact on the environment.

CONCLUSION

It is possible to achieve the demands of zero energy in 2020, in new built as in a climate renovation. From the two example detail investigations presented, it can be concluded, that it is possible to achieve a good thermal performance and high daylight levels in a building while in use. The good performance is achieved with automatic control of window openings and external solar shading, where the effect of ventilative cooling from open windows is especially important.

Furthermore, it is possible to achieve good thermal comfort with the use of natural ventilation and solar energy produced on site. This means that it is possible to initiate climate renovations without heat recovery, and sourced directly from the site.

Energy consumption is only a requirement to meet in a sustainable building; however livability is a key success parameter. Compliance data and - engines try to give a picture on the sustainability of a house, but typically the energy demand will differ to theory, as most users demand a higher comfort level than the compliance engines assume in standard. Environmental engineers should be aware of this factor, when programming capacity and adaptability of the systems.

Providing energy for a four-person household will mean that the hot water demand will be a constant, regardless of the size of the house. In a small house, the share of this consumption seems relatively bigger in total energy consumption than in a large house. Reviewing energy demand should also reflect footprint, i.e. assess energy demand pr occupant, as space demand is also an aspect of sustainable construction.

Using the adaptive comfort principle means that the user comfort is programmed relative to the outdoor temperature. As opposed to this principle is an absolute approach, where rigid numbers must not be exceeded, regardless of actual weather conditions. It is possible to avoid overheating through building design, rather than technological measures. Undercooling is accepted by occupants under the condition that they have direct influence on indoor temperatures and knowledge of the related heating consumption.

There can be a wide range of differences in fenestration area, orientation, size, compactness, without a risk to the sustainable proposition. Sustainability in a building is not depending on national conditions, whereas cultural reflections and vernacular characteristics play a role as in any architectural work. The architectural quality is the first priority, and the sustainable programming must submit suitable solutions to support this. The good news is that the solutions are available today.

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