SELF-EVALUATED THERMAL COMFORT COMPARED TO MEASURED TEMPERATURES DURING SUMMER IN THREE ACTIVE HOUSES WHERE VENTILATIVE COOLING IS APPLIED

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ABSTRACT

The thermal comfort of the residential buildings Sunlighthouse in Austria and LichtAktiv Haus in Germany are investigated with a particular focus on the summer situation and the role of solar shading and natural ventilation. The houses have generous daylight conditions, and are designed to be CO_2 neutral with a good indoor environment. The thermal environment is evaluated according to the Active House specification (based on the adaptive method of EN 15251), and it is found that the houses achieve category 1 for the summer situation. It is found that ventilative cooling through window openings play a particularly important role in maintaining thermal comfort in the houses and that both window openings and external solar shading is used frequently. The occupants have reported their thermal sensation daily during most of a one-year period. The thermal sensation votes show good correlation with the thermal comfort category.

KEYWORDS

Thermal comfort; ventilative cooling; residential buildings; solar shading, Post Occupancy Evaluation

1 INTRODUCTION

Five single-family houses in five European countries were built between 2009 and 2011 as a result of the Model Home 2020 project. Sunlighthouse (SLH) in Austria and LichtAktiv Haus (LAH) in Germany were both completed in 2011. The houses were occupied by test families in a one-year period (SLH) and a two-year period (LAH), and measurements were made during the period in both houses (Foldbjerg, 2013). The present paper focuses on the occupant’s evaluation of the thermal comfort.

The houses follow the Active House principles (Eriksen, 2011), which mean that a balanced priority of energy use, indoor environment and connection to the external environment must be made. The design has particularly focused on excellent indoor environment and a very low use of energy. There is a particular focus on good daylight conditions and fresh air from natural ventilation.

Measurements of IEQ include light, thermal conditions, indoor air quality, occupant presence and all occupant interactions with the building installations, including all operations of windows and solar shading. Use of natural ventilation for summer comfort is based on ventilative cooling principles (Venticool, 2014).

The presented results focus on thermal conditions, and the occupant's evaluation of the thermal environment. Some demonstration houses in Scandinavia have experienced problems with overheating, often due to insufficient solar shading and use of natural ventilation (Isaksson, 2006 and Larsen, 2012). Two British government reports similarly find that both new and refurbished low energy residential buildings have an increased risk of overheating (AECOM, 2012 and Carmichael, 2011).

The houses use natural ventilation in the warm part of the year to prevent overheating. Additionally there is external automatic solar shading on all windows towards south, east and west.


Figure 1. Photos of Sunlighthouse (left) and LichtAktiv Haus (right) by Adam Mørk.

Each room is an individual zone in the control system, and each room is controlled individually. There are sensors for humidity, temperature, CO_2 and presence in each room. The building occupants can override the automatic controls, including ventilation and solar shading at any time. Override buttons are installed in each room, and no restrictions have been given to the occupants. As house owners they have reported a motivation to minimise energy use on an overall level, and to maximise IEQ on a day-to-day basis.

The recorded temperature data is evaluated according to the Active House specification (Eriksen, 2011), which is based on the adaptive approach of EN 15251 (CEN, 2007). The results presented here are based on the measurements and analyses for the period in which test family have occupied the house, i.e. from March 1, 2012 to February 28, 2013.

The occupants responded to a questionnaire every day, where they reported their thermal sensation on a simplified 5-step version of the ISO 7730 (ISO, 2005) thermal sensation scale (as used in the present paper: hot, warm, neutral, cool, cold). They were asked to provide a response that represented the entire day.

2 RESULTS

Figure 2 shows thermal comfort categories for the two houses. Sunlighthouse experiences temperatures in category 1 for 85% of the year or more for most main rooms. The temperatures outside category 1 are mainly in category 2 (low), i.e. between 20°C and 21°C. Temperatures above category 1 are very limited, and all main rooms achieve category 1 when temperatures below category 1 are disregarded.

LichtAktiv Haus shows very similar performance for the summer situation, with very few hours above category 1 for the main rooms. The “Hall” and “Technique” rooms are secondary rooms and not used for occupancy.

Given the large glazed areas of both houses, the practically non-existing overheating in both houses is remarkable.

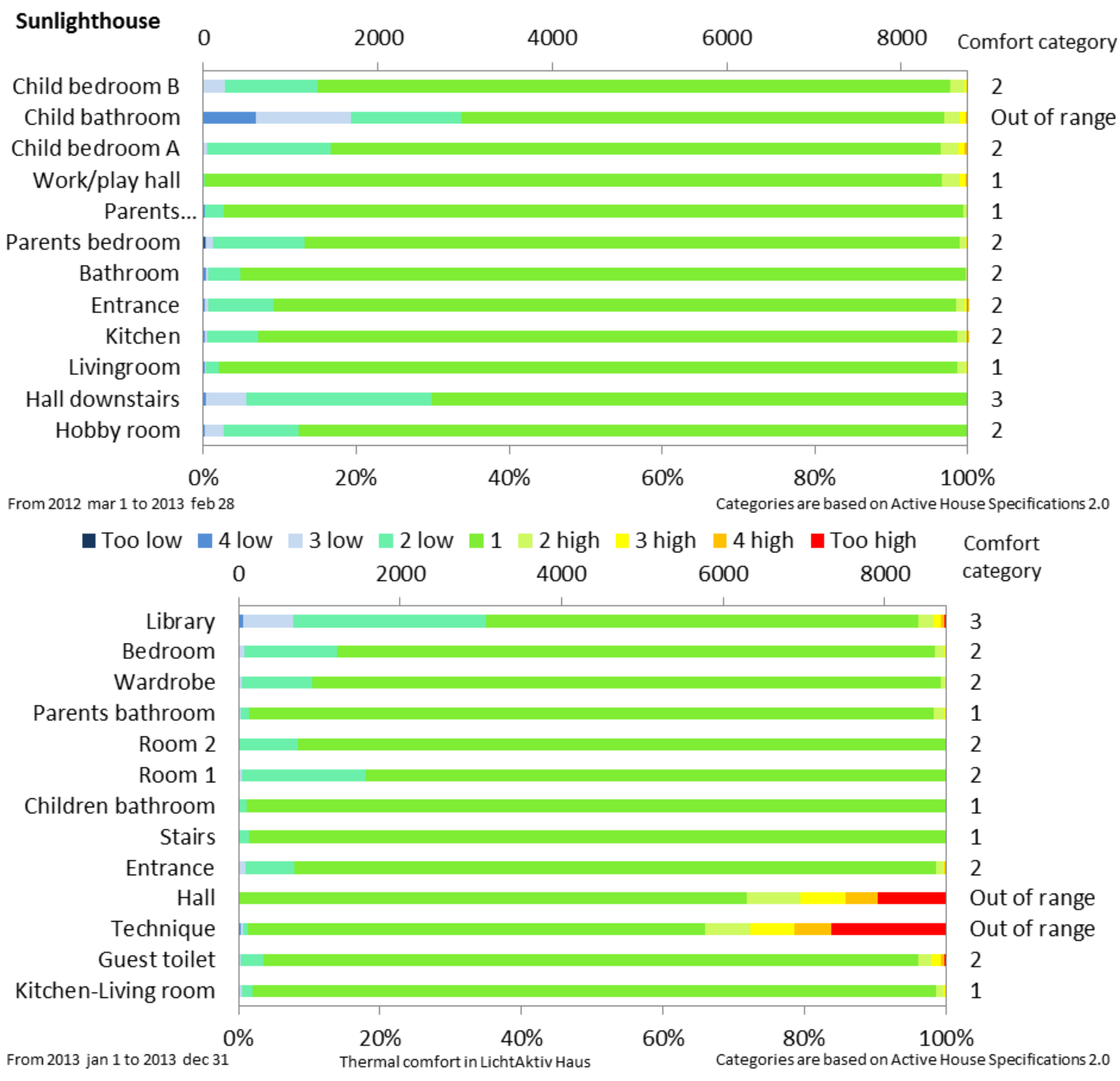


Figure 2. Sunlighthouse (above) and LichtAktiv Haus (below). Thermal comfort for each of the rooms evaluated according to Active House specification (based on adaptive method of EN 15251). Criteria are differentiated between high and low temperatures.

The results in Figure 2 sum up the rooms’ performance as regards thermal summer comfort over the stretch of one year. The variation over time-of-day and time-of-year is further investigated in

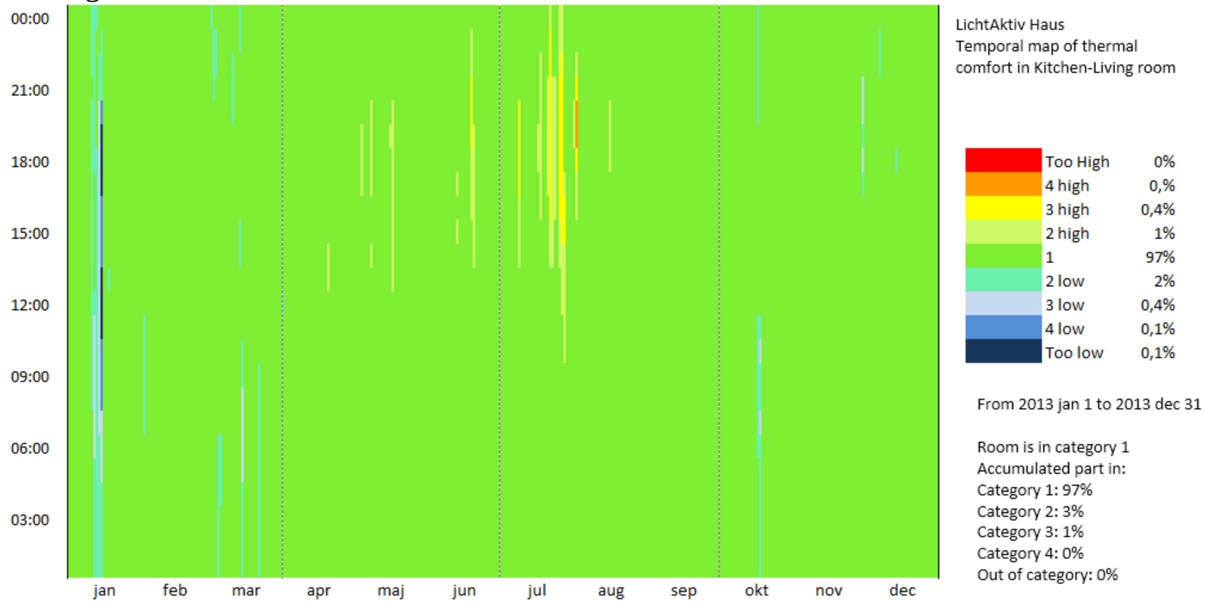
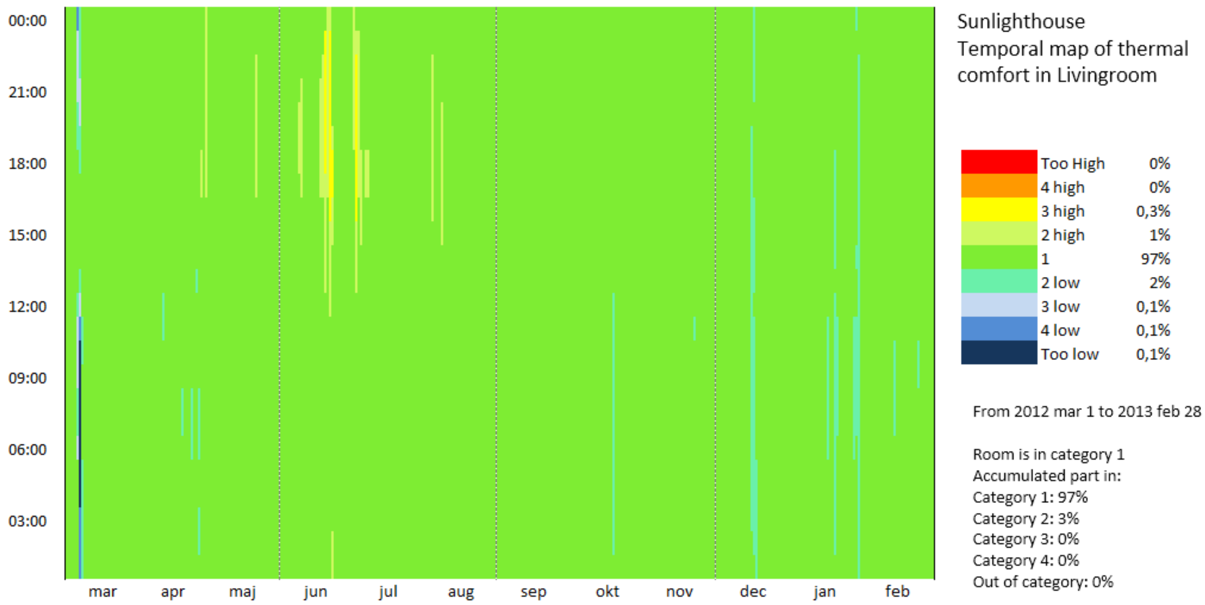


Figure 3, which is using temporal maps (carpet plots), indicating each hour of the year according to its position in the day-of-year (horizontal axis) and time-of-day (vertical axis). The figure focuses on the kitchen-living room in each house, as both of these rooms have particularly large glazed areas and therefore an increased risk of overheating.

For Sunlighthouse, three to five episodes with temperatures below category 1 are seen, each lasting a day or two. In June, a few episodes with temperatures that reach category 2 are observed between 16:00 and 23:00. These episodes last for 2-3 days. LichtAktiv Haus experience similar results.



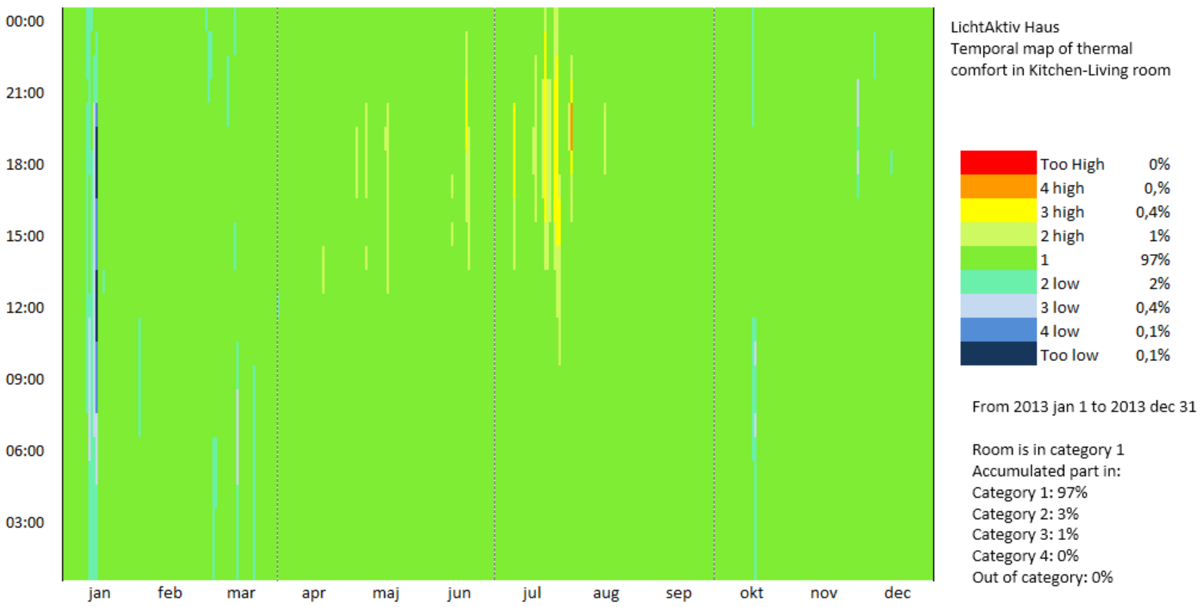
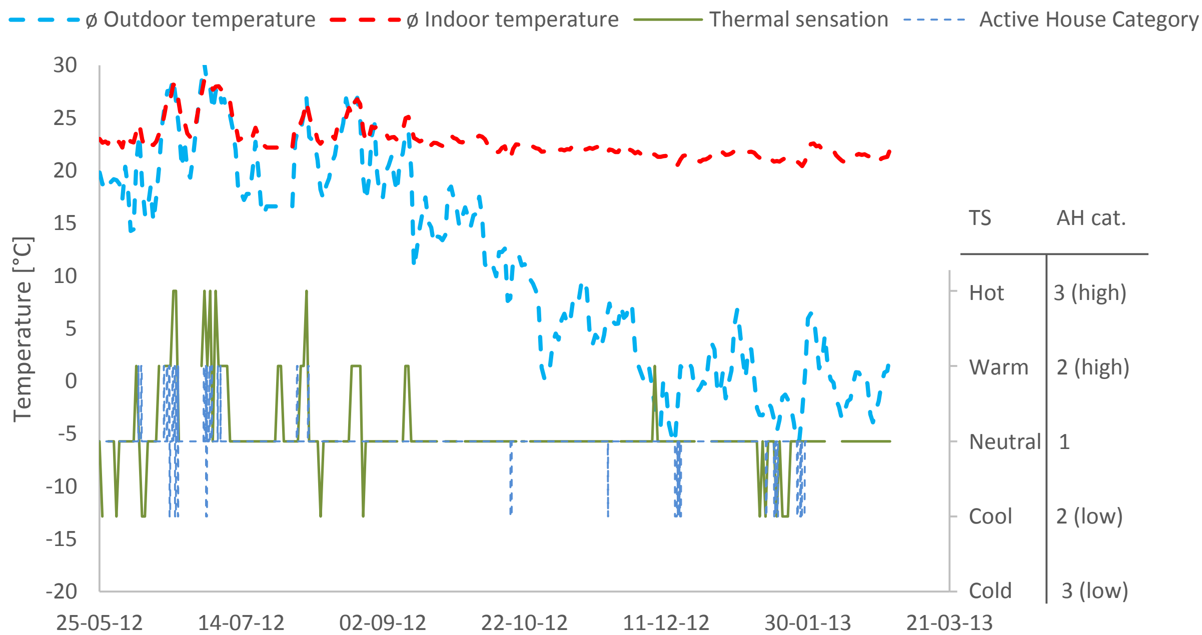


Figure 3. The comfort category for the kitchen-living room of each hour of the year is plotted as a temporal map. Sunlighthouse (above) and LichtAktiv Haus (below). Evaluated according to Active House specification (based on adaptive method of EN 15251). Criteria are differentiated between high and low temperatures.

The important role of window openings and solar shading in maintaining thermal comfort has been reported previously (Foldbjerg, 2013).



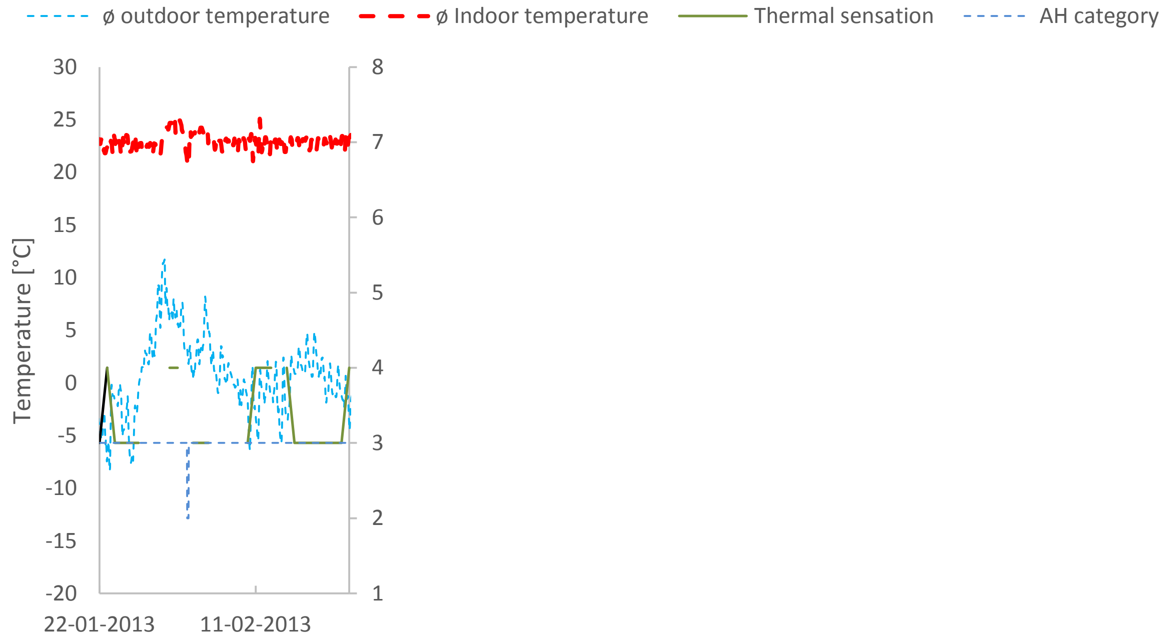
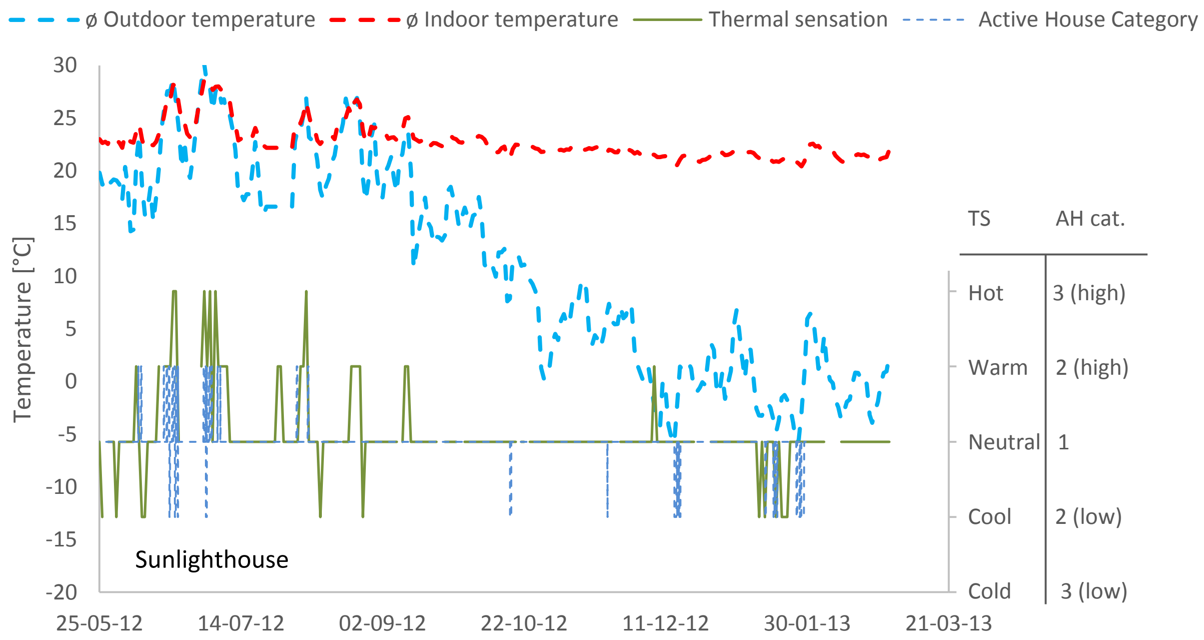


Figure 4 shows measured temperatures, thermal comfort category, and occupant-reported thermal sensation in the two houses. During the very warm period in Austria at the end of June and beginning of July, the outdoor temperature reached 30°C. The peak indoor temperatures in Sunlighthouse are 1 to 2°C lower during these warm periods, which means that the cooling potential of the outdoor air is used to a high degree. The indoor temperature does rise above category 1, but not higher than category 2.

In the summer period the occupants of SLH rate their thermal sensation as “warm” or “hot”. The same correlation is seen in the beginning of August. During the last weeks of January 2013, the indoor temperature drops slightly below 20°C, which corresponds to category 2 (low). On these days the occupants reported their thermal sensation as cool.



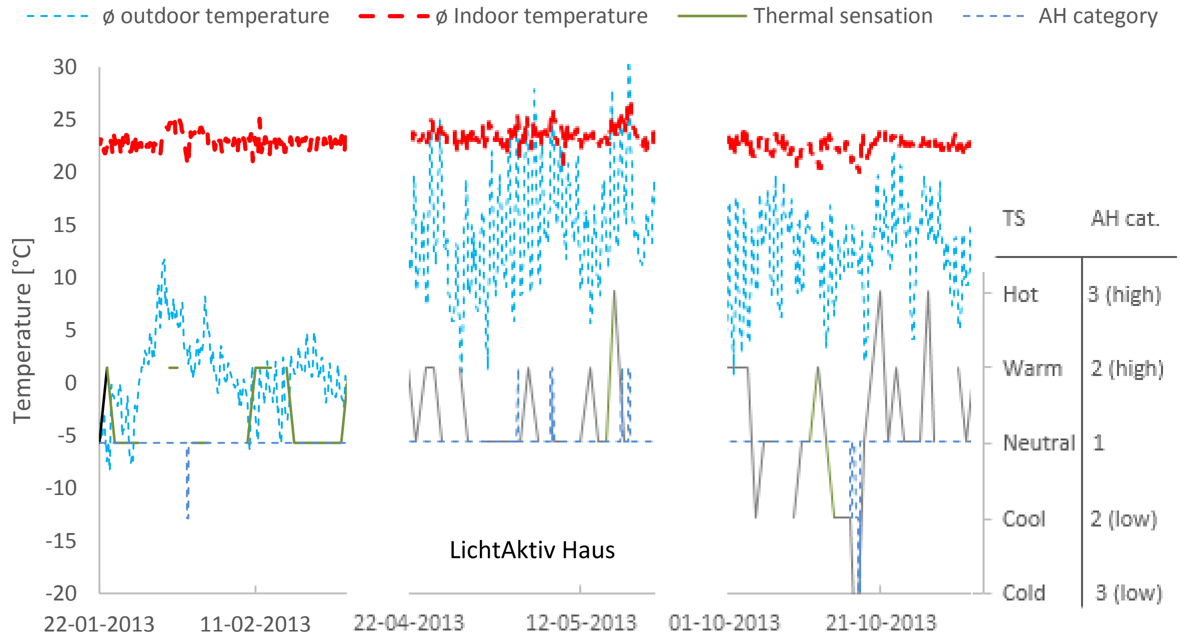


Figure 4 The dotted lines show measured indoor and outdoor temperatures in the living room of the two houses. The dotted grey line shows the thermal comfort category According to the Active House category. The solid grey line show the reported thermal sensation by the occupants. In SLH both occupants responded, for LAH, the responses of the father in the family are shown. In LAH the occupants responded during winter, spring/summer and autumn with in-between periods without responses.

In some episodes the occupants of SLH rate the thermal environment as warmer than the comfort category indicates (late July and late august). In other episodes the occupants rate the thermal environment as cooler than the comfort category (mid and late August). In general there is good correspondence between the occupant's thermal sensation vote and the thermal comfort category based on measured data.

In LAH the winter period January to February is characterised by stable indoor temperatures and more frequent votes of "warm" than "cool". The thermal comfort category is steadily 1 in this period. During the warm spring period in April to May, the outdoor temperature peaks between 25°C and 30°C. On the days with peak outdoor temperatures, the indoor temperature is generally maintained 3-5°C lower. The occupant often respond with "warm". The thermal comfort category changes from 1 to 2 on three days in this period; there is a delay between category and thermal sensation, typically only of one day.

In the autumn period from October to November the thermal sensation of the occupant of LAH varies between "cool" and "hot". The votes occur on the same days as the indoor temperatures increase or decrease, but the absolute variations in indoor temperatures are small, as indicated by the comfort category, which is 1 through the period with the exception of one day where it drops to 3.

3 CONCLUSIONS

The houses are evaluated according to the Active House specification, which uses the same methodology and criteria as the adaptive approach for naturally ventilated buildings in EN 15251 with regards to thermal comfort.

Despite high daylight levels, the houses experience very little overheating, and less than reported for other low energy houses. All main rooms of the houses achieve category 1 regarding overheating. Due to some hours with temperatures below 21°C during winter (by occupant preference), most main rooms achieve category 2.

Dynamic external solar shading and ventilative cooling by natural ventilation are key measures that have been used to achieve the very satisfying thermal conditions during summer.

The occupants rated the thermal environment on a 5-level thermal sensation scale. In Sunlighthouse, the ratings were made through almost a year, while in LichtAktiv Haus the ratings were made for three 30-day periods during winter, spring/summer and autumn. The thermal sensation votes are compared to the comfort category. There is good correspondence between thermal sensation votes and comfort category.

The results indicate that the adaptive approach of EN 15251 is reasonably accurate at predicting the actual thermal sensation of the occupants.

4 REFERENCES

AECOM (2012). *Investigation into overheating in homes: Literature review*. For the UK Department of Communities and Local Government

Carmichael, K , Anderson, M, Murray, V. (2011). *Overheating and health: a review into the physiological response to heat and identification of indoor heat thresholds*. UK Health Protection Agency

CEN (2007). CEN Standard EN 15251:2007. *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics*. European Committee for Standardisation.

Eriksen, K.E. et al (2011). *Active House – Specification*. Active House Alliance. 2011.

Foldbjerg, P., Rasmussen, C. and Asmussen, T. (2013). Thermal Comfort in two European Active Houses: Analysis of the Effects of Solar Shading and Ventilative Cooling. *Proceedings af Clima 2013*, Prague.

Isaksson, C. and Karlsson, F. (2006) Indoor Climate in low-energy houses – an interdisciplinary investigation. *Building and Environment*, Volume 41, Issue 12, December 2006

ISO 7730: 2005. (2005). *Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort*. ISO.

Larsen, T.S. and Jensen, R.L (2012). *The Comfort Houses - Measurements and analysis of the indoor environment and energy consumption in 8 passive houses 2008-2011*. Aalborg University.

Venticool, the International platform for ventilative cooling. Published by Venticool. Last accessed May 2014. http://venticool.eu/faqs/.