# Subjective and Objective Measurements of Thermal Comfort in an Austrian Active House: Occupant-reported Thermal Sensation and Measured Temperatures during a one-year Period

**Speakers:**
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***Abstract:*** *The thermal comfort of the residential building Sunlighthouse in Austria is investigated with a particular focus on the summer situation and the role of solar shading and natural ventilation. The house has generous daylight conditions, and is 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 house reach 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 all three houses and that both window openings and external solar shading is used frequently.The occupants have reported their thermal sensation daily during most of the one-year measurement period. The thermal sensation votes show good correlation with the thermal comfort category.*

*Keywords:* ***Thermal comfort; ventilative cooling; residential buildings; natural ventilation; solar shading, Post Occupancy Evaluation***

## 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 was completed in 2011. The house has been occupied by a test familiy in a one-year period, and measurements have been made during the period [1]. This paper focuses on the occupants evaluation of the thermal comfort.

The houses follow the Active House principles [2] 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 [3].

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 [4, 5]. Two British govenrment reports similarly find that both new and refurbished low energy residential buildings have an increased risk of overheating [6, 7].

The house uses natural ventilation in the warm part of the year, and mechanical ventilation with heat recovery during cold periods. There is external automatic solar shading on all windows towards South.

*Figure 3 Photo of Sunlighthouse 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 [2], which is based on the adaptive approach of EN 15251 [8]. 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 [9] thermal sensation scale (as used in the present paper: hot, warm, neutral, cool, cold).**

Results

Figure 4 shows thermal comfort categories. The house 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.

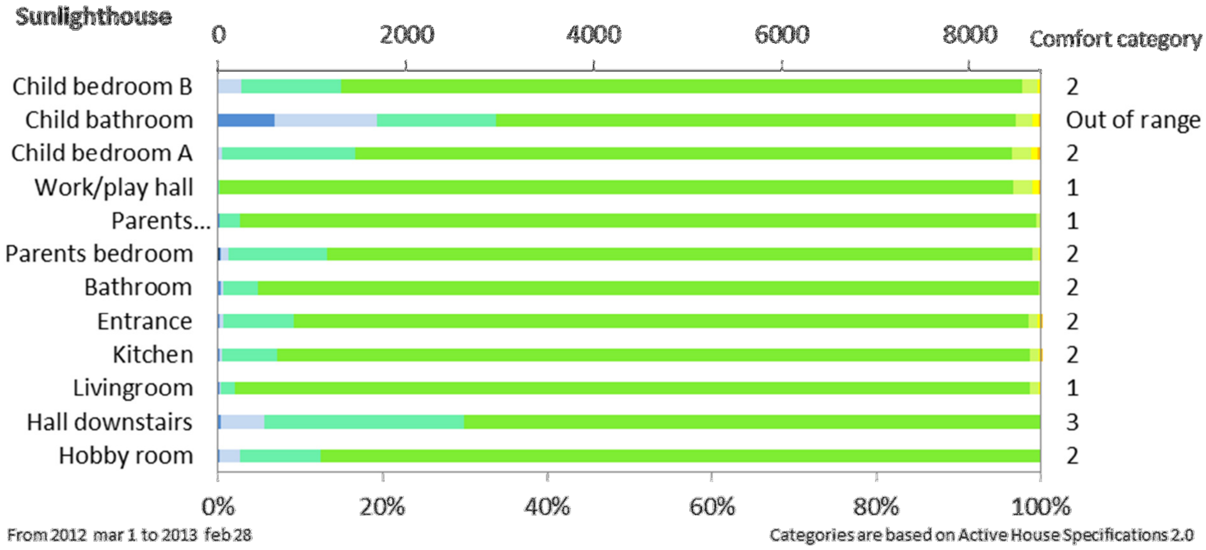


*Figure 4. Thermal comfort for each of the rooms evaluated according to Active House specification (based on adaptive method of EN 15251). Criteria are differentiated between high and low temperatures.*

The results in Figure 4 sum up the rooms' performance as regards thermal summer comfort over the stretch of one year. The following analyses will focus in detail on the specific thermal performance of two exemplary rooms in each house, the master bedroom and the kitchen/dining room. The kitchen/dining room in each house has large glazed areas, which provides a risk of overheating, and therefore these rooms are investigated further. The Master bedroom is analysed as the thermal environment at bedtime has an influence on the sleep quality.

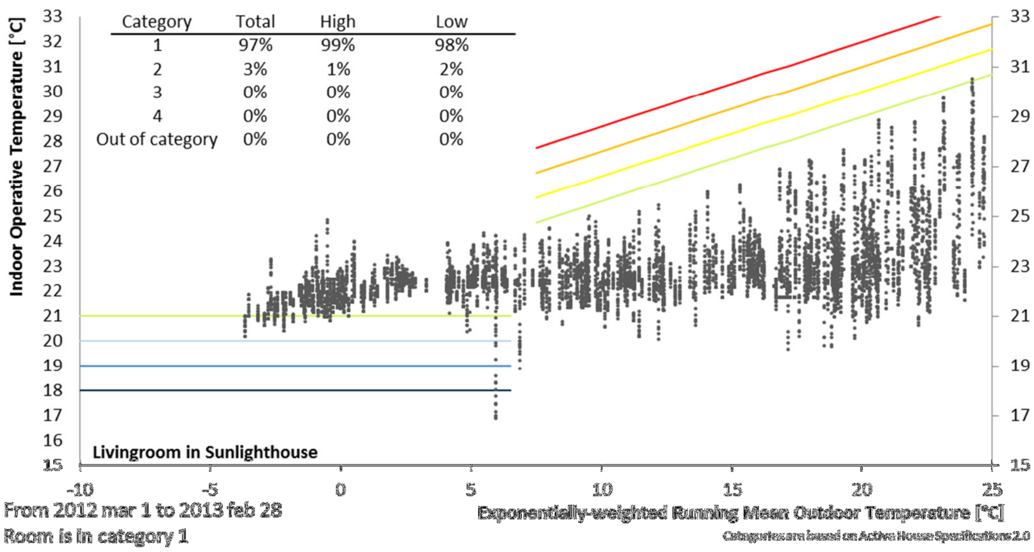


*Figure 5. Indoor temperatures in the living room plotted against running mean temperature for each hour of the year including the Active House category limits. The percentage of time the room is in a specific category is shown. The column "High" disregards temperatures below category 1, and therefore represents "overheating". The column "Low" disregards temperatures above category 1 and therefore represents "undercooling".*

Figure 5 shows the indoor temperature in the kitchen/dining room at each hour of the year plotted against the running mean outdoor temperature as defined in EN 15251 and used in Active House Specification.

Figure 5 clearly shows that the maximum temperatures increase with the outdoor running temperature, following thecategory 1 line. In the same period (running mean outdoor temperatures above 5°C), the minimum temperature in the living room does not increase with the outdoor temperature, but remains somewhat constant at approximately 20°C.

The variation over time-of-day and time-of-year is further investigated in Figure 6, 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). 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.

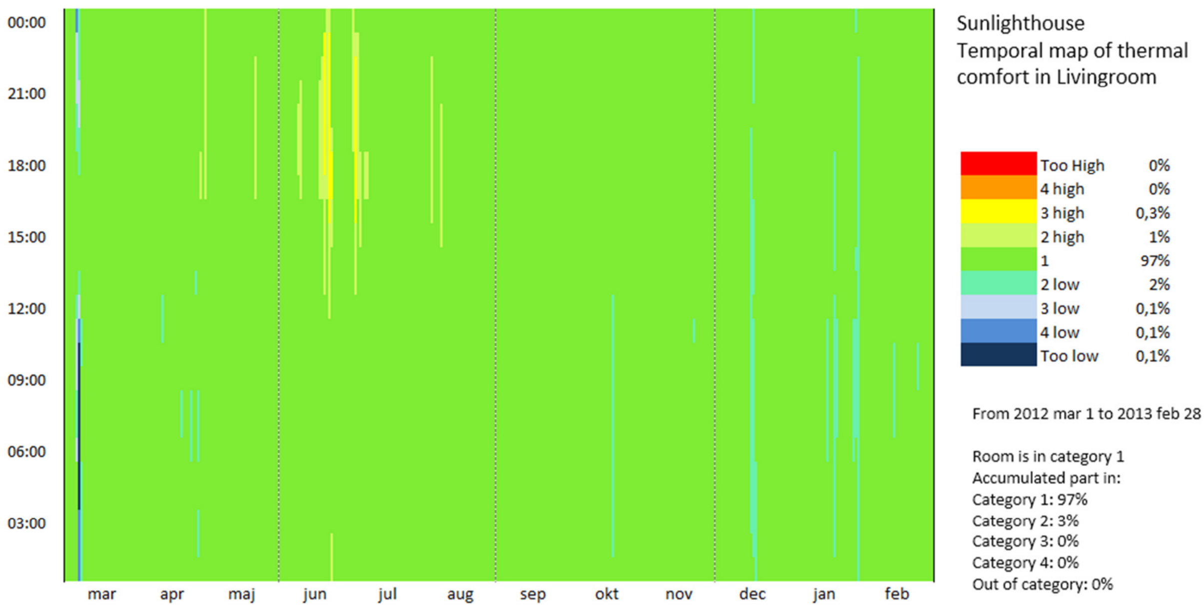


*Figure 6. The comfort category of each hour of the year is plotted as a temporal map*

To investigate the role of window openings in maintaining comfort, Figure 7 is used. A simplified comfort definition is imposed for the sake of the analysis, so that category 1 or 2 are combined, and also category 3 and 4. The figure shows if any windows where active during each hour.

Figure 7 shows that windows are used in the daytime during the transition period from March until May. From May until October windows are used also during the night for night cooling. The figure indicates that windows have played an important role in preventing summertime overheating.

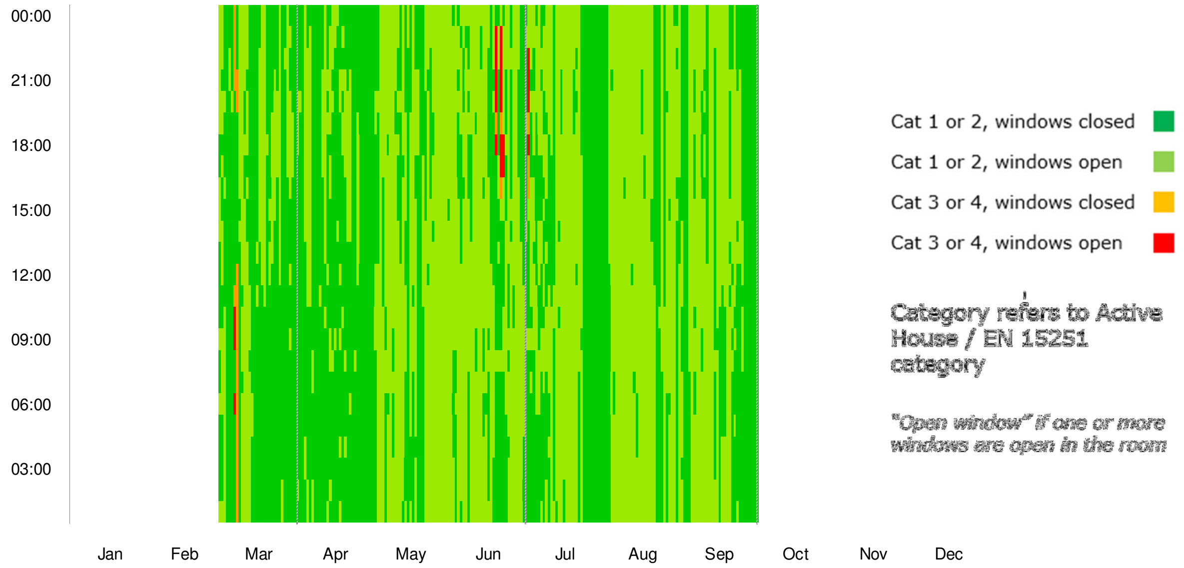


*Figure 7. Temporal map of living room showing comfort or discomfort and if windows were open or closed (active or not active).Data from October and forward were not available at the time of the data analysis.*

Figure 8 shows measured temperatures, thermal comfort category, and occupant-reported thermal sensation. During the very warm period at the end of June and beginning of July, the outdoor temperature reached 30°C. The peak indoor temperatures 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 this period the occupants rate their thermal sensation as "warm" or "hot". The same correlation is seen in the beginning of August.

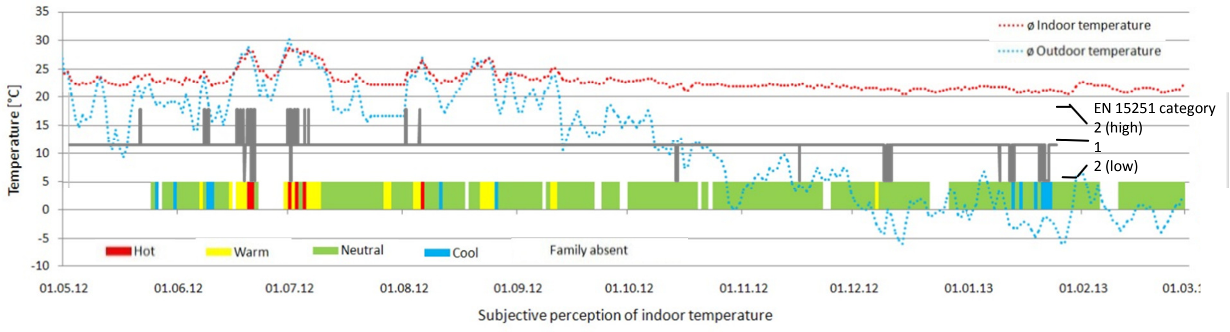


*Figure 8 The dotted lines show measured indoor and outdoor temperatures in the living room. The grey line shows the thermal comfort category (1 or 2; can be high or low). The red, yellow, green, blue bars show the reported thermal sensation by the occupants.*

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.

In some episodes the occupants 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 correspondance between the occupant's thermal sensation vote and the thermal comfort category based on measured data.

The accumulated days with a reporting of each of the thermal sensation scores are shown in Table 4. It is clear that the occupants report the majority (75%) of the days as neutral. 28 days are reported warmer or hot, and 12 days are cool.

*Table 4 Number of days with a specific thermal sensation score during the period from May 1 2012 to February 26 2013.*

| Thermal sensation | Days | % of days |
|---|---|---|
| Hot | 6 | 2 % |
| Warm | 22 | 8 % |
| Neutral | 211 | 75 % |
| Cool | 12 | 4 % |
| Cold | 0 | 0 % |
| Family absent | 29 | 10 % |

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 house 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 achive the very satisfying thermal conidtions during summer.

The occupants rated the thermal environment every day through almost a year on a 5-level thermal sensation scale. The thermal sensation votes are compared to the comfort category. There is good correspondance 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.

References

1. 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.

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

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

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

5. 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.

6. AECOM (2012). *Investigation into overheating in homes: Literature review*. For the UK Department of Communities and Local Government
7. 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

8. 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.

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