VENTILATIVE COOLING OF RESIDENTIAL BUILDINGS: STRATEGIES, MEASUREMENT RESULTS AND LESSONS-LEARNED FROM THREE ACTIVE HOUSES IN AUSTRIA, GERMANY AND DENMARK

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ABSTRACT

The thermal comfort of the residential buildings Home for Life in Denmark, LichtAktiv Haus in Germnay and Sunlighthouse in Austria is investigated with a particular focus on the strategies used to achieve good thermal comfort, and the role of solar shading and natural ventilation. The houses are three of six buildings in the Model Home 2020 project. They have generous daylight conditions, and are designed to be energy efficient and CO_2 neutral with a good indoor environment. The living rooms in all three houses have high daylight levels and have been selected for the detailed analyses for this reason. 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. Some undercooling occurs in Sunlighthouse and Home for Life during winter, which is caused by occupant preferences or incomplete commissioning. 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.

KEYWORDS

Thermal comfort; ventilative cooling; residential buildings; natural ventilation; solar shading

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. Home for Life, Denmark, was completed in spring 2009, followed by Sunlighthouse (SLH) in Austria and LichtAktiv Haus (LAH) in Germany in 2011. Home for Life and Sunlighthouse are new buildings while LichtAktiv Haus is a refurbishment and extension of an existing house. The three houses have been occupied by test families in one-year periods, and measurements have been made during the period (Foldbjerg 2012, 2013). This paper focuses on the consolidated learnings from the three houses.

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. The present deals with thermal comfort, particularly the natural ventilation system and the solar shading. Use of natural ventilation for summer comfort is based on ventilative cooling principles (venticool, 2013).

The presented results focus on thermal conditions, effectiveness and experience with the applied strategies. 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).

All three houses use natural ventilation in the warm part of the year. Home for Life and Sunlighthouse use mechanical HRV during cold periods, while LichtAktiv Haus is using natural ventilation all year. There is external automatic solar shading on all windows towards South, and overhangs are used where appropriate.

Figure 1. Home for Life (left). Sunlighthouse (middle). LichtAktiv Haus (right)

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 families have occupied the houses. For Sunlighthouse and LichtAktiv Haus data collection for this paper stopped in October 2012.

2 RESULTS

Figure 2 shows thermal comfort categories for the three houses. Home for Life experiences low temperatures (undercooling) in most rooms, but no overheating except for the bedroom. All rooms except the bedroom achieve category 1 when overheating is disregarded. LichtAktiv Haus experiences undercooling in the top-floor library, possibly in periods when the room is not used. The kitchen-living room and bedroom does not experience much undercooling. The children’s rooms (Room 1 and Room 2) experience undercooling for more than 5% of the investigated period. No main rooms experience overheating for more than 5% of the time, and therefore achieve category 1 with regards to overheating.

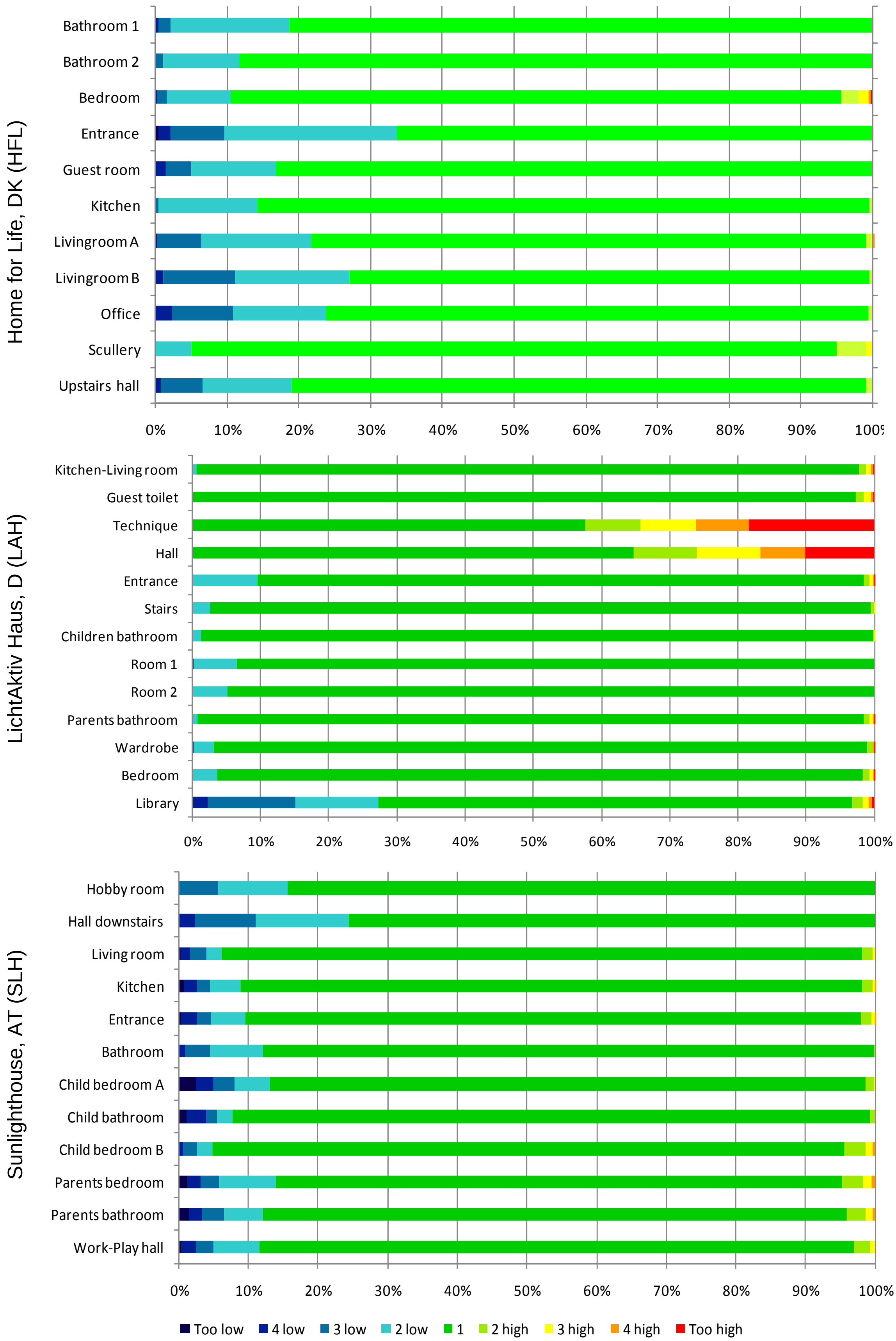

Figure 2. Home for Life, LichtAktiv Haus and Sunlighthouse. Thermal comfort for each of the rooms evaluated according to Active House specification (based on adaptive method of EN 15251). Criteria are differentiated between high and low temperatures.

Sunlighthouse experiences substantial undercooling in all main rooms for 5-15% of the investigated period. Overheating is limited, and all main rooms achieve category 1 with regards to overheating.

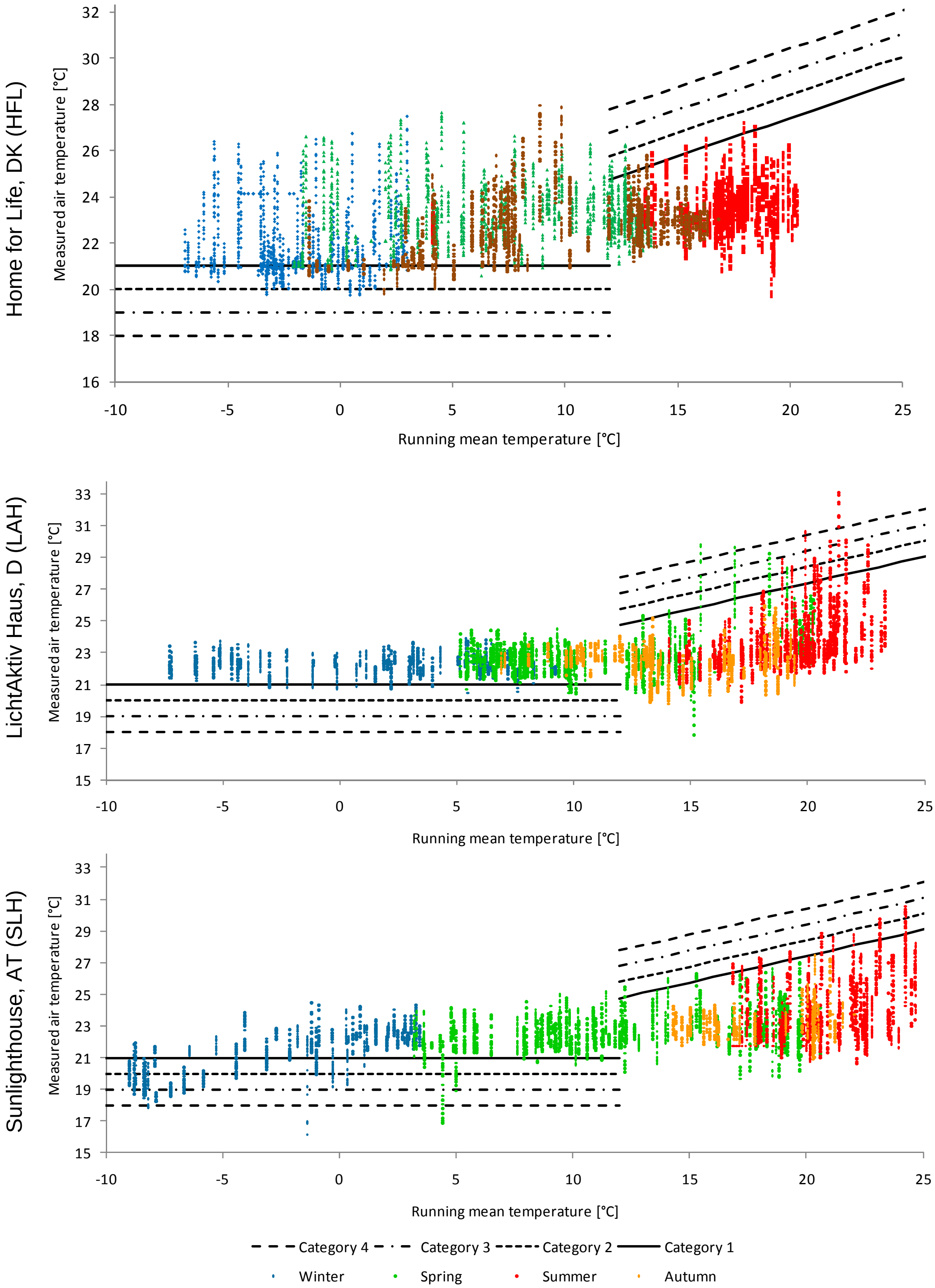

Figure 3. Livingroom in HFL, LAH and SLH. Indoor temperatures in the living room plotted against running mean temperature for each hour of the year including the Active House category limits. The dots are coloured to represent a season.

The focus of the present paper is on the performance related to ventilative cooling and potential overheating. The further analyses will focus on the performance of the combined living and dining room, which have large glazed areas in each of the three houses, and therefore these rooms are investigated further. Figure 3 shows the indoor temperature at each hour of the year plotted against the running mean outdoor temperature as defined in EN 15251.

For Home for Life the temperatures during cold periods drop below the category 1 limit (21 °C) for a substantial part of the time, but with only a few hours below the category 2 limit (20 °C). During transition periods, only few hours below category 1 are seen. For LichtAktiv Haus it is seen that temperatures below the category 1 limit (21 °C) occur both in winter and in the transition periods. The occupants have reported discomfort due to undercooling during airings at outdoor temperatures below 0 °C. For Sunlighthouse more pronounced undercooling is observed, particularly during the coldest part of the year.

In Home for Life, high temperatures are seen more in the transition periods than during the warmer summer period. This is expected to be caused by the control system, which maximises solar gains in “spring” mode, while it prioritizes thermal comfort in “summer” mode by minimizing solar gains. For Sunlighthouse, no episodes with temperatures above 26 °C are seen during winter or in the transition periods. For LichtAktiv Haus, no overheating was seen in winter, but three episodes of spring overheating (light green dots are seen). This happens when the outdoor temperature is below 26 °C, and the most likely cause is the same control system phenomena as was seen for Home for Life. Some summertime overheating is observed for LichtAktiv Haus, with some episodes where category 3 is exceeded. Only few episodes with summertime overheating are observed for Sunlighthouse.

Relatively low temperatures are observed for all three houses during summer, with episodes with temperature drops below 21 °C. This is suspected to be caused by night cooling, where the temperature decreases during the night to reduce overheating the following day, which in some situations lead to temperatures in the morning between 20 °C and 21 °C.

The variation over time-of-day and time-of-year is further investigated in Figure 4, which is using temporal maps to plot each hour of the year according to day-of-year and time-of-day. For Home for Life it is seen that the episodes during winter with temperatures below category 1 can last for several days during the winter, but that in many of the episodes, the temperature reaches category 1 between 12:00 and 20:00, possibly due to solar gains. During summer, only few episodes with temperatures beyond category 1 are observed. For LichAktiv Haus, no wintertime undercooling of importance is seen. The episodes with summertime overheating are short with a span of 2-3 days. The overheating occurs during the afternoon between 12:00 and 22:00 with temperatures reaching even category 4. For Sunlighthouse, substantial undercooling occurs mainly during one week at the end of January, during which the house was not yet occupied by the family, and in a period when the heat pump system was not functioning properly. In June, a few episodes with overheating where temperatures reach category 3 are observed between 16:00 and 23:00. These episodes last for 2-3 days.

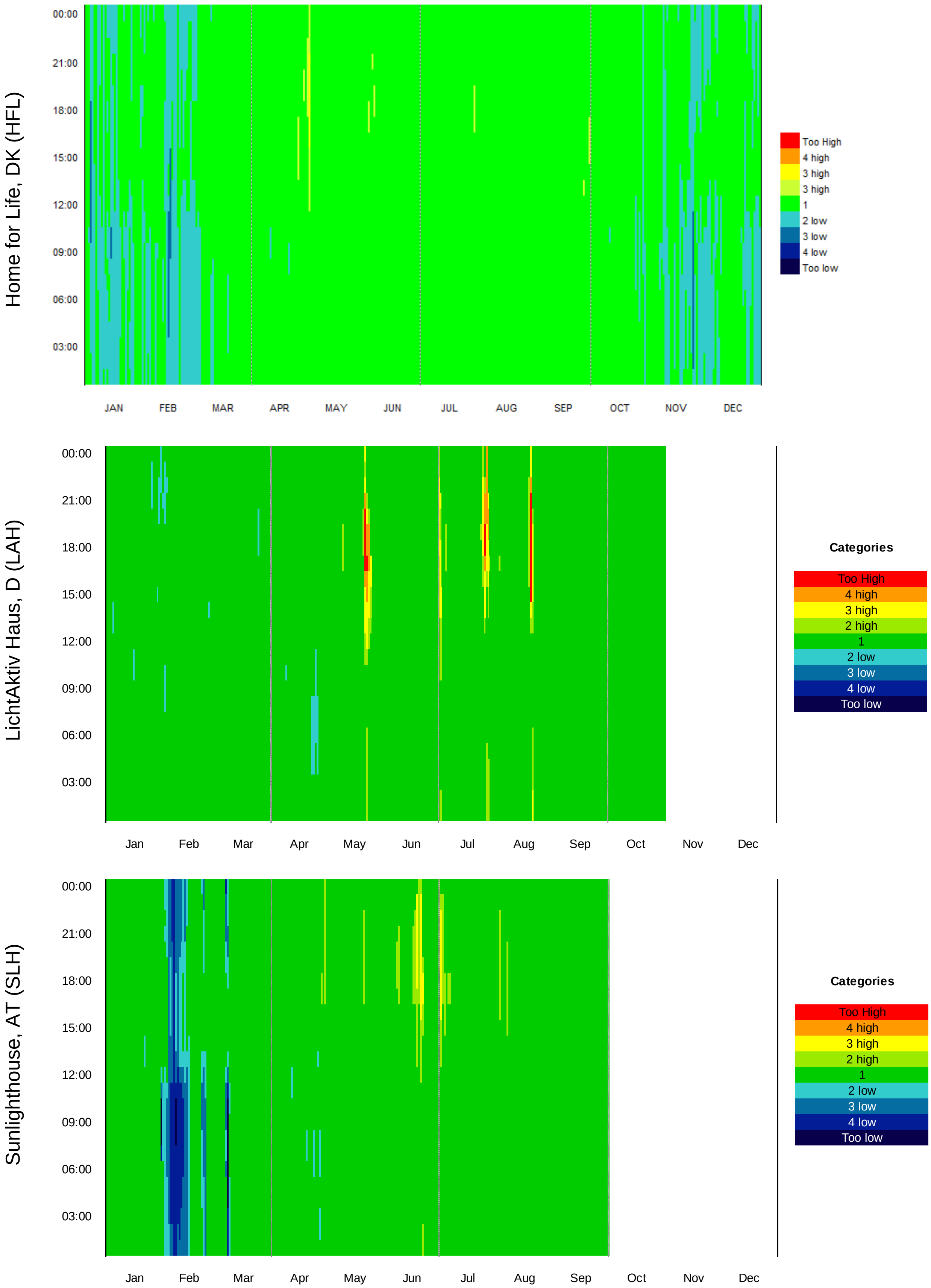

Figure 4.Living room in HFL, LAH and SLH. The comfort category of each hour of the year is plotted as a temporal map

To investigate the role of window openings in maintaining comfort, Figure 5 is used. A simplified comfort definition is imposed for the sake of the analysis, so that category 1 or 2 is considered “Comfort” while categories 3 and 4 are considered “Discomfort”. The figure shows if any windows where active during each hour.

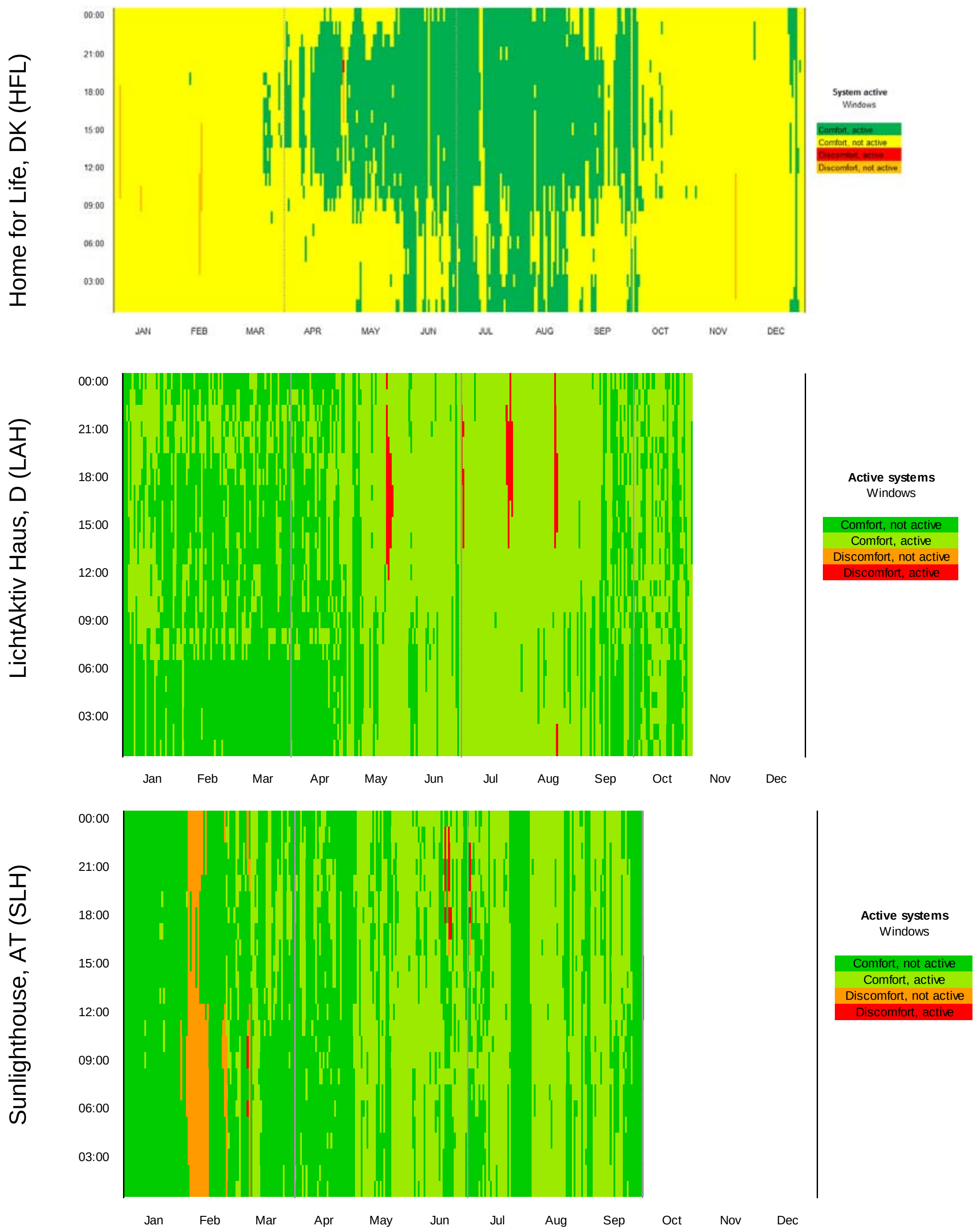

Figure 5. Living room in HFL, LAH and SLH. Temporal map showing comfort or discomfort and if windows were open or closed (active or not active).

Figure 5 shows that in LichtAktiv Haus windows are used for airings on most days in the winter at 6:00 to 8:00 and in the evening between 20:00 and 22:00, which can be expected, as the house is based on natural ventilation all year. Home for Life and Sunlighthouse use mechanical ventilation during winter, and in these houses windows were not open during the winter episodes with temperatures below category 1, indicating that these episodes were not caused by window airings. In interviews, the occupants of Home for Life have reported that they decided to have a room temperature of 20-21 ^{o}C to reduce heating consumption. The episodes with winter temperatures below category 1 can thus be attributed to user preferences.

A few episodes with red colour are seen during summer for all three houses in the late afternoon, indicating that overheating occurred and that windows were opened, but that this was not sufficient to maintain category 1 or 2.

Figure 5 further shows that during the summer, windows are almost permanently open and that category 1 or 2 is maintained during these hours. This tendency applies to daytime as well as night-time, and indicates that windows are used for automatic night cooling and that the occupants are not closing the windows by overriding the control system.

Also in the transition periods (March to May and September to October) windows are used to a large extent. In Home for Life and LichtAktiv Haus the windows are mainly used during daytime, while they are used in 24-hour cycles in Sunlighthouse.

3 CONCLUSIONS

The houses are evaluated according to the Active House specification, which uses the same methodology and criteria as EN 15251 with regards to thermal comfort. For all three houses, there is more undercooling than overheating, but not to a large extent, and most main rooms end in category 2 or 3. The undercooling has simple explanations. In HFL it is an active choice of the occupants to have a temperature between 20°C and 21°C. In SLH the undercooling occurs during a week here the house was not yet commissioned and occupied, and where the heat pump was not yet in proper operation. LAH experiences practically no undercooling which means that natural ventilation is applied without adverse effect on thermal comfort, as the occupants could have decided to close windows. The conclusions in the following refer to the combined dining and living room, which is exposed to the most solar gains.

In all three houses, the minimum indoor temperature does not increase with outdoor temperature during summer. This is most likely caused by night cooling, which cools down the building to reduce the maximum temperature on the following day. The occupants could have deactivated the night cooling if they were uncomfortable with it, which indicates that in these buildings the occupants accept lower summer temperatures than suggested by the adaptive approach.

In LAH (Germany) and HFL (Denmark), some episodes with temperatures above 26°C are seen on days during the transition periods. This is explained by the different priorities of the control system, which priorities energy in “Spring/autumn” mode, and thermal comfort in “summer” mode.

All three houses have generous daylight conditions, which could have caused overheating. However, little overheating is seen, which is attributed to the active use of ventilative cooling by solar shading and natural ventilation. The role of windows is investigated, and in all three houses, window openings occurred at the same time as acceptable thermal comfort during the summer period. This indicates that window openings have contributed to achieving and maintaining good thermal conditions.

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