Articles

Using ventilative cooling and solar shading to achieve good thermal environment in a Danish Active House

Figure 1. "Home for Life". South and east facades.

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The thermal comfort of the residential building Home for Life is presented with a particular focus on the strategies used to achieve good thermal comfort, and the role of solar shading and ventilative cooling with natural ventilation. Home for Life was completed in 2009 as one of six buildings in the Model Home 2020 project. It has generous daylight conditions, and is designed to be energy neutral with a good indoor environment.

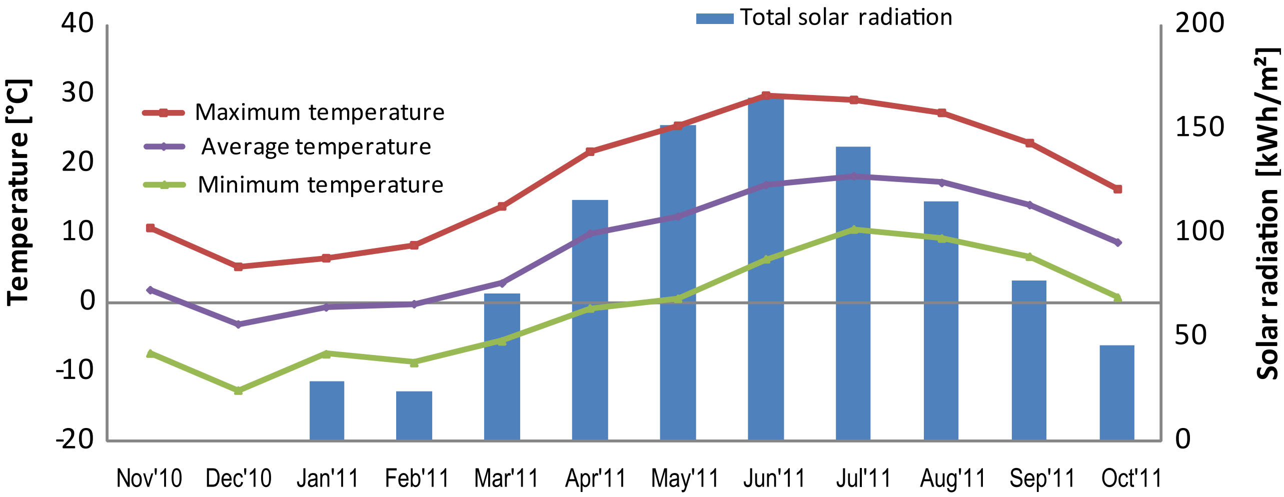

Figure 2. Outdoor conditions during the measurement period. The pyranometer was installed in January 2011, and therefore data is not available for November and December.

The thermal environment is evaluated according to the Active House specification (see article by Eriksen, Rode and Gillet in this issue of REHVA Journal), and it is found that the house reaches level 1 for the summer situation. Some undercooling occurs during winter, which is due to the occupants' preferred balance between indoor temperatures and heating consumption.

It is found that ventilative cooling through window openings play a particularly important role in maintaining thermal comfort.

Introduction

Five single-family houses in five European countries were built between 2009 to 2011 as a result of the Model Home 2020 project. The first house (Home for Life, Denmark), was completed in spring 2009 and has been occupied by two different families, of which the last family has bought the house. Measurements were performed for two years during the occupancy of two families. Home for Life is a 1½-storey house with a total floor area of 190 m². Basic climatic data are presented in **Figure 2**.

The six houses follow the Active House (www.activehouse.info) principles which mean that a balanced priority of energy use, indoor environment and connection to the external environment must be made. In practice this means that the houses should have both an 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. Most main rooms have daylight factors above 5%.

The ventilation system is hybrid, i.e. natural ventilation is used during the summertime and mechanical ventilation with heat recovery during the wintertime, while hybrid ventilation is used spring and fall. The switch between mechanical and natural ventilation is controlled based on the outdoor temperature. The setpoint is 12.5°C with a 0.5°C hysteresis. Below the setpoint the ventilation is in mechanical mode, above the setpoint the ventilation is in natural mode. In both natural and mechanical mode, the ventilation rate is demand-controlled. CO_2 is used as indicator for the Indoor Air Quality, and a setpoint of 850 ppm CO_2 is used. Besides that, relative humidity is also used as indicator. When RH is 60% or higher, ventilation is increased step-wise to maximum ventilation, which is used when RH is 80% or higher.

There is external automatic solar shading on all windows towards South, and overhangs are used where appropriate.

Results

Figure 4 shows that five rooms achieve Active House level 2, while six rooms achieve level 4. It is clear from the figure that the majority of the hours in level 2, 3 and 4 are caused by low temperatures, i.e. undercooling rather than overheating. When undercooling is disregarded, all rooms except bedroom and scullery achieve level 1.

The focus of this article is on the performance related to ventilative cooling and potential overheating. The further analyses will focus on the performance of the kitchen, which is a combined kitchen and dining room with a large south-facing window section, **Figure 1**.

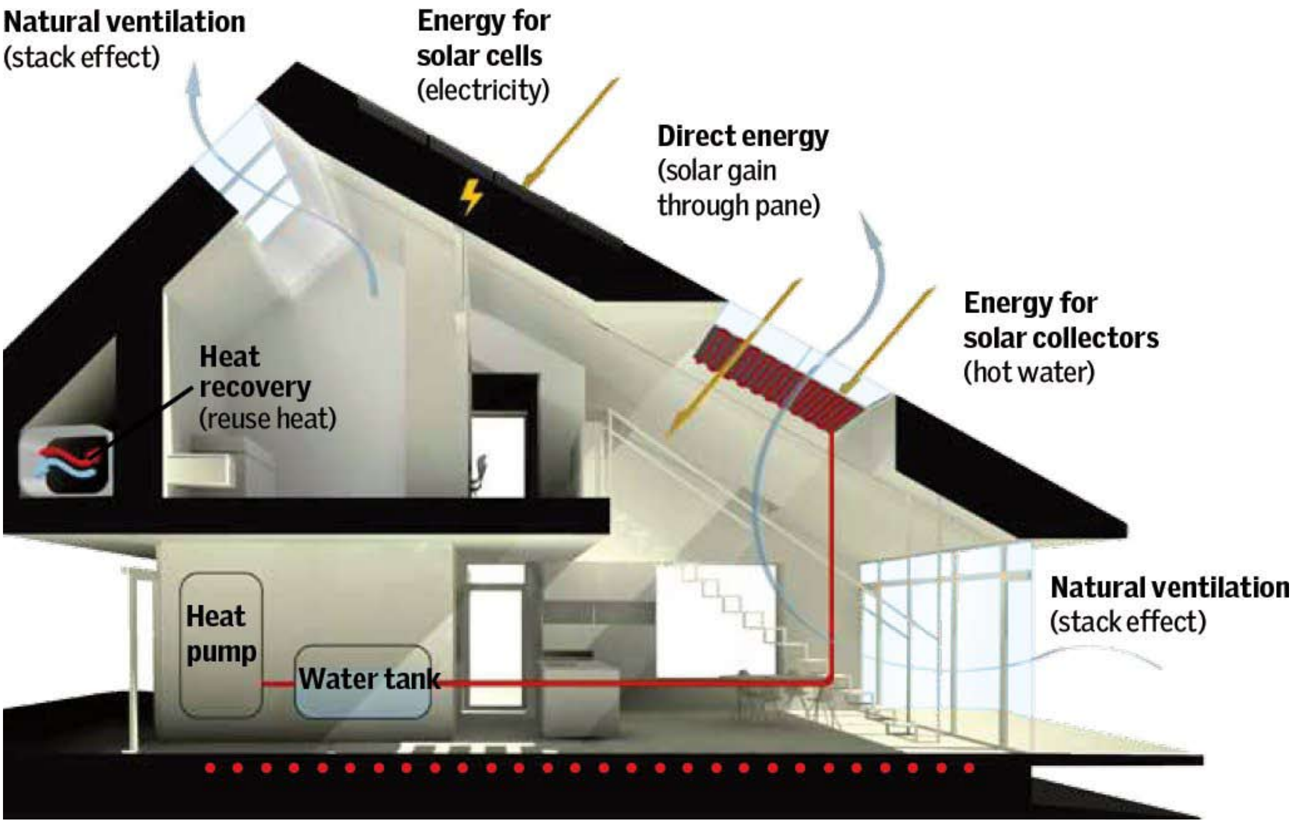

Figure 3. "Home for Life". Concept for daylight, ventilation and energy.

The distribution of categoeries between months are seen at **Figure 5**. As expected from **Figure 4**, the undercooling is an issue in 4 winter months from November to February. From April to October, level 1 is achieved.

Figure 6 shows the indoor temperature at each hour of the year plotted against the running mean outdoor temperature as defined in EN 15251. It is seen that temperatures below the level 1 limit (21°C) occur both in winter and in the transition periods, but only with a few hours below the level 2 limit (20°C). It is suspected that the episodes with temperatures below 21°C are caused by either manual or automatic airings, or more simply by user preference. The occupants have not reported discomfort due to undercooling in their diaries.

Some episodes with temperatures above 26°C are also seen during winter and in the transition periods, auggesting large variations in temperature during short periods of time. This is suspected to be due to solar gains. The automatic control of window openings and solar shading is setup to prevent overheating, but especially

Table 1. Thermal comfort scores as defined in the Active House specification, section 1.2 for naturally ventilated buildings.

The maximum indoor temperature limits apply in periods with an outside T_{rm} of 12°C or more. T_{rm} is the Running Mean outdoor temperature as defined in 'chapter 3.11 External temperature, running mean of EN 15251:2007'. The limits apply to living rooms, kitchens, study rooms, bedrooms etc. in dwellings without mechanical air conditioning and with adequate opportunities for natural (cross or stack) ventilation.

The maximum indoor operative temperatures are:
1. $T_{i,o} < 0.33 \times T_{rm} + 20.8$°C, for T_{rm} of 12°C or more
2. $T_{i,o} < 0.33 \times T_{rm} + 21.8$°C, for T_{rm} of 12°C or more
3. $T_{i,o} < 0.33 \times T_{rm} + 22.8$°C, for T_{rm} of 12°C or more
4. $T_{i,o} < 0.33 \times T_{rm} + 23.8$°C, for T_{rm} of 12°C or more

"Too high" used in this paper applies to $T_{i,o} > 0.33 \times T_{rm} + 23.8$°C, for T_{rm} of 12°C or more

The minimum operative temperatures are:
1. $T_{i,o} > 21$°C, for T_{rm} of 12°C or less
2. $T_{i,o} > 20$°C, for T_{rm} of 12°C or less
3. $T_{i,o} > 19$°C, for T_{rm} of 12°C or less
4. $T_{i,o} > 18$°C, for T_{rm} of 12°C or less

"Too low" used in this paper applies to $T_{i,o} < 18$°C, for T_{rm} of 12°C or less

Further information can be found in the specification at www.activehouse.info.

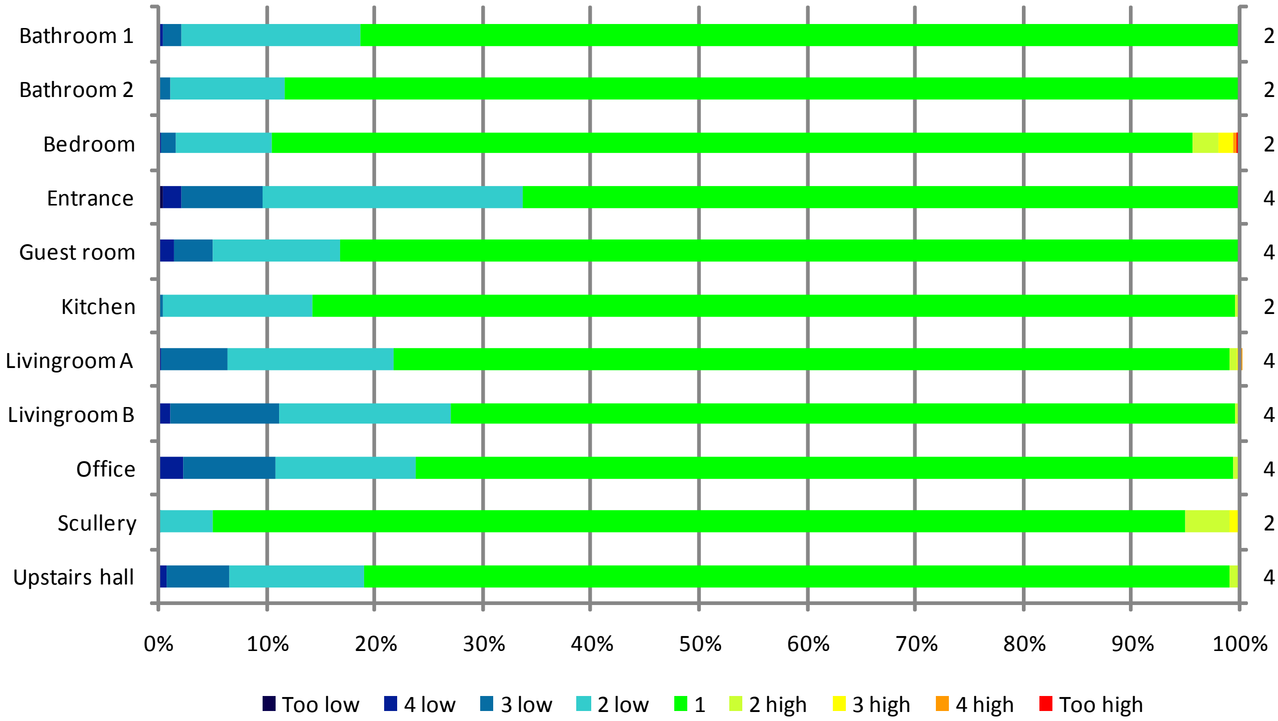

Figure 4. Thermal comfort for each of the rooms evaluated according to Active House specification section 1.2 (see Table 1 for explanation). The levels are differentiated between high and low temperatures. The number at the right side of the diagram indicates the level for each room (1 to 4). To achieve a score of e.g. "2", at least 95% of the time must be at that level or better, as defined in EN 15251.

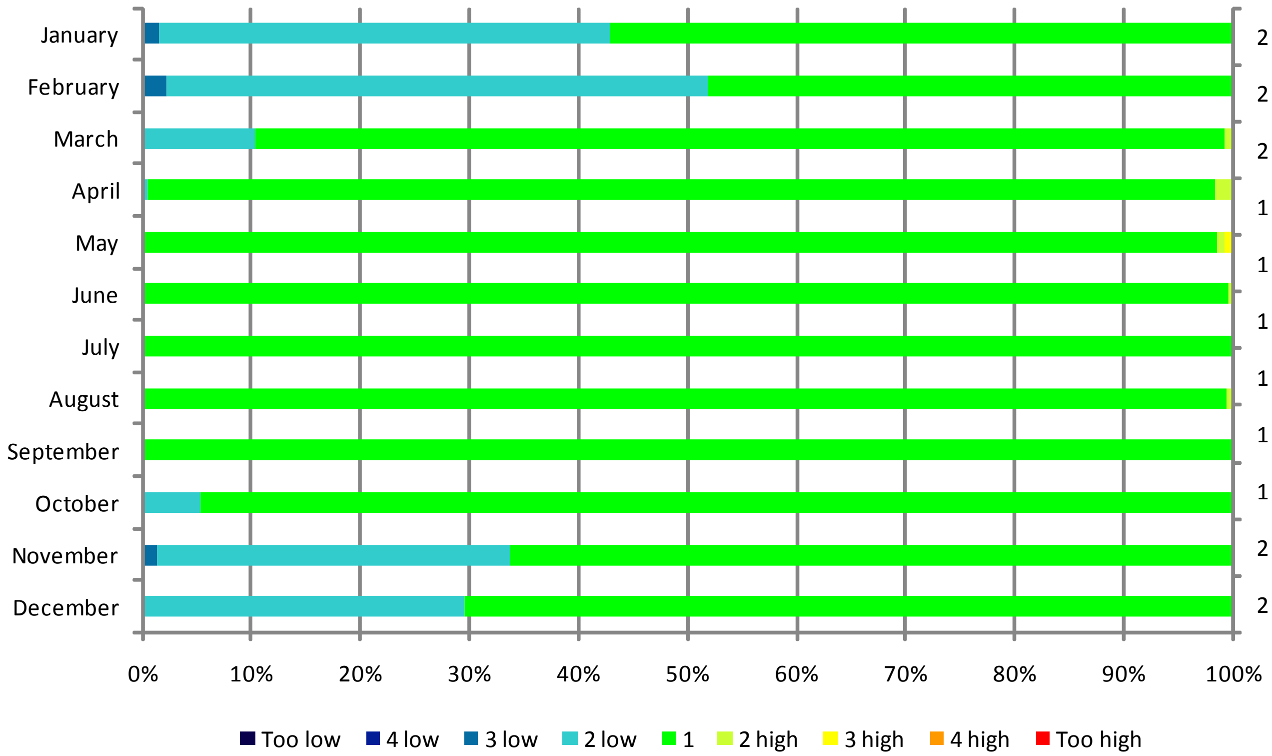

Figure 5. Thermal comfort categories for each month of the year for the kitchen and dining room. The number at the right side of the diagram indicates the score for each month (1 to 4). To achieve a score of e.g. "2", at least 95% of the time must be at that level or better, as defined in EN 15251. (see Table 1 for explanations)

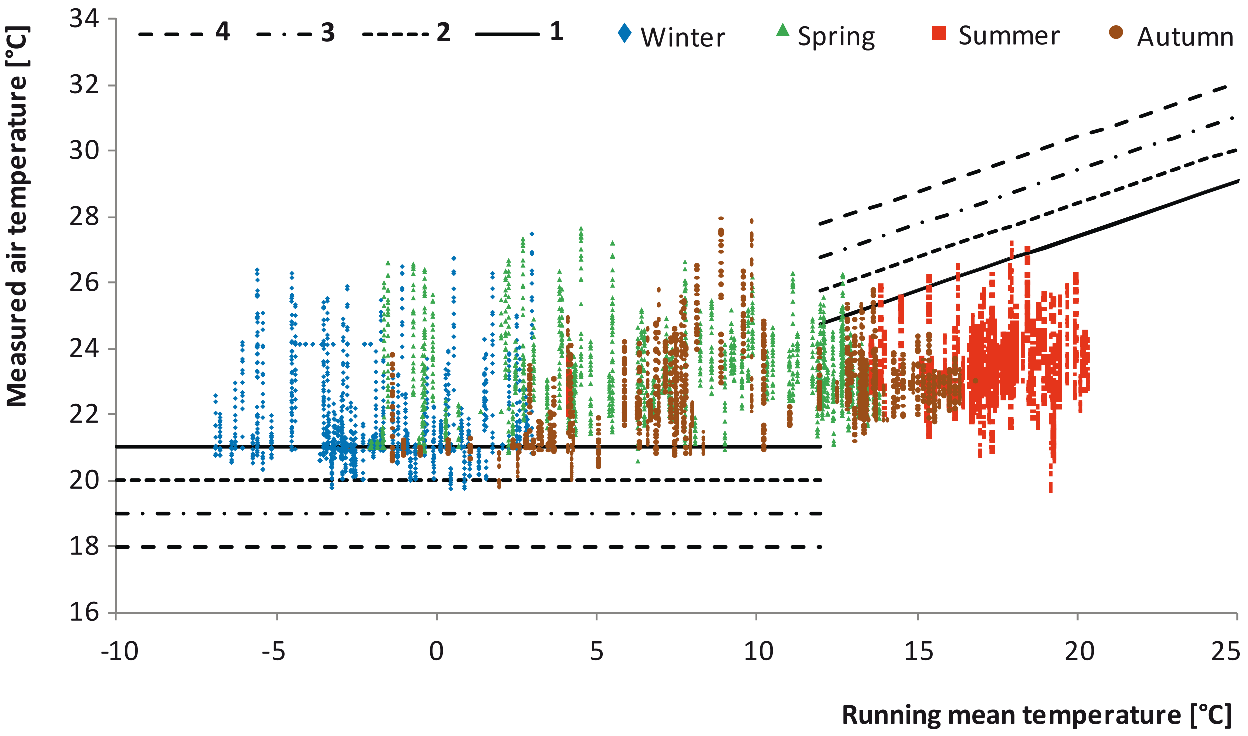

Figure 6. Indoor temperatures in the kitchen plotted against running mean temperature for each hour of the year including the Active House limits. The dots are coloured to represent a season.

during winter the system will accept high solar gains to reduce the heating demand.

During summer the system prioritizes to maintain thermal comfort, and **Figure 6** shows very limited overheating during summer, with only a few episodes with temperatures above level 1. Relatively low temperatures are observed 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 7**. It is seen that the episodes during winter with temperatures below level 1 can last for several days during the winter, but that in many of the episodes, the temperature reaches level 1 between 12:00 and 20:00, possibly due to solar gains.

During summer, only few episodes with temperatures beyond level 1 are observed.

To investigate the role of window openings in maintaining comfort, **Figure 8** is used. A rather strict comfort definition is imposed for the sake of the analysis (level 2 was the design target), where only level 1 is considered comfort. The figure also shows if windows where active during each hour.

Figure 8 shows that windows were not open during the winter episodes with temperatures below level 1 (orange), indicating that these episodes were not caused by airings. The heating system during winter is controlled in such a way that the supply temperature for the floor heating system is set at the heat pump control. The lower the supply temperature, the better the system efficiency. The occupants have reported that they set the supply temperature so that the room temperature would reach 20-21°C to reduce heating consumption. The episodes with winter temperatures below level 1 can thus be attributed to user preferences.

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

Figure 8 further shows that during the summer, windows are almost permanently open between 9:00 and 22:00 and that level 1 is maintained during these hours

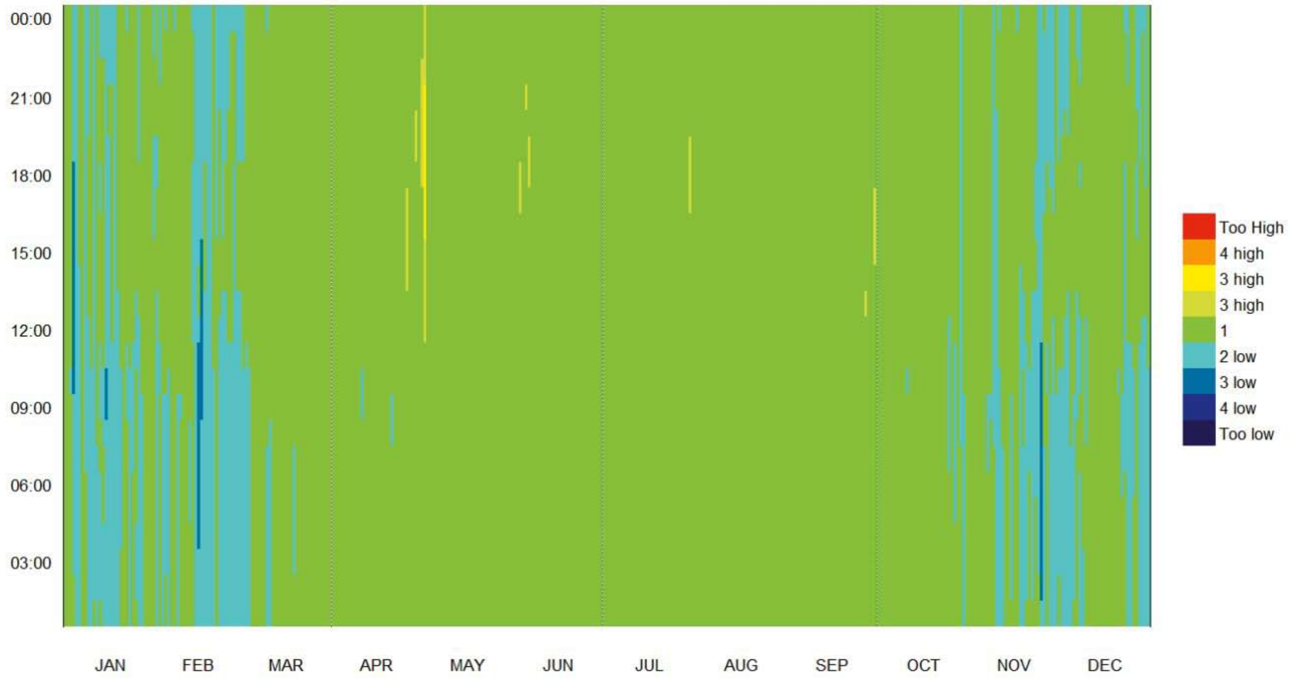

Figure 7. The comfort level of each hour of the year is plotted as a temporal map (kitchen and dining room).

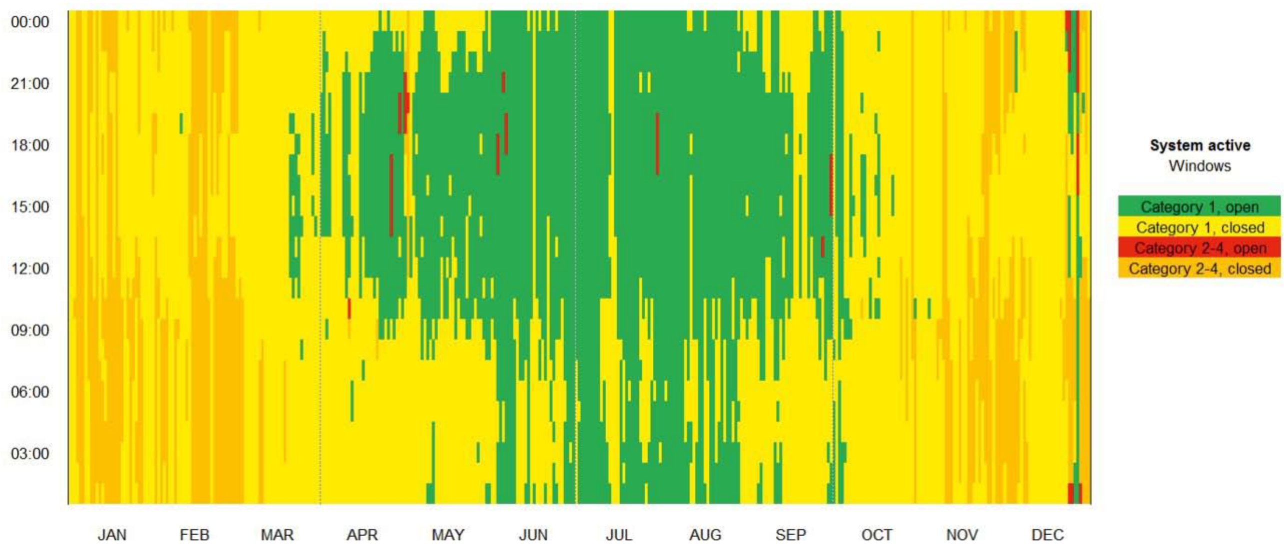

Figure 8. Temporal map showing comfort or discomfort (discomfort is here temperatures in level 2, 3 or 4) and if windows were open or closed (active or not active). Figure shows the combined kitchen and dining room.

(green). The figure shows many episodes with open windows between 22:00 and 9:00 (green), which can be assumed to be caused by automatic window opening for night cooling. Also in the transition periods (March to May and September to October) windows are used to a large extent, with openings between 12:00 and 18:00 as a typical episode (green).

The occurrence of windows in relation to outdoor temperature is further investigated at **Figure 9**. It is seen that windows are generally closed (red dots) when the running mean temperature is below 10°C. When the running mean temperature is above 12°C, windows are generally opened when the indoor temperature exceeds 22 -23°C, which is in accordance with the control strategy.

Discussion

For the rooms in Home for Life, half fall in level 2 and the other half in level 4 with regards to thermal conditions,

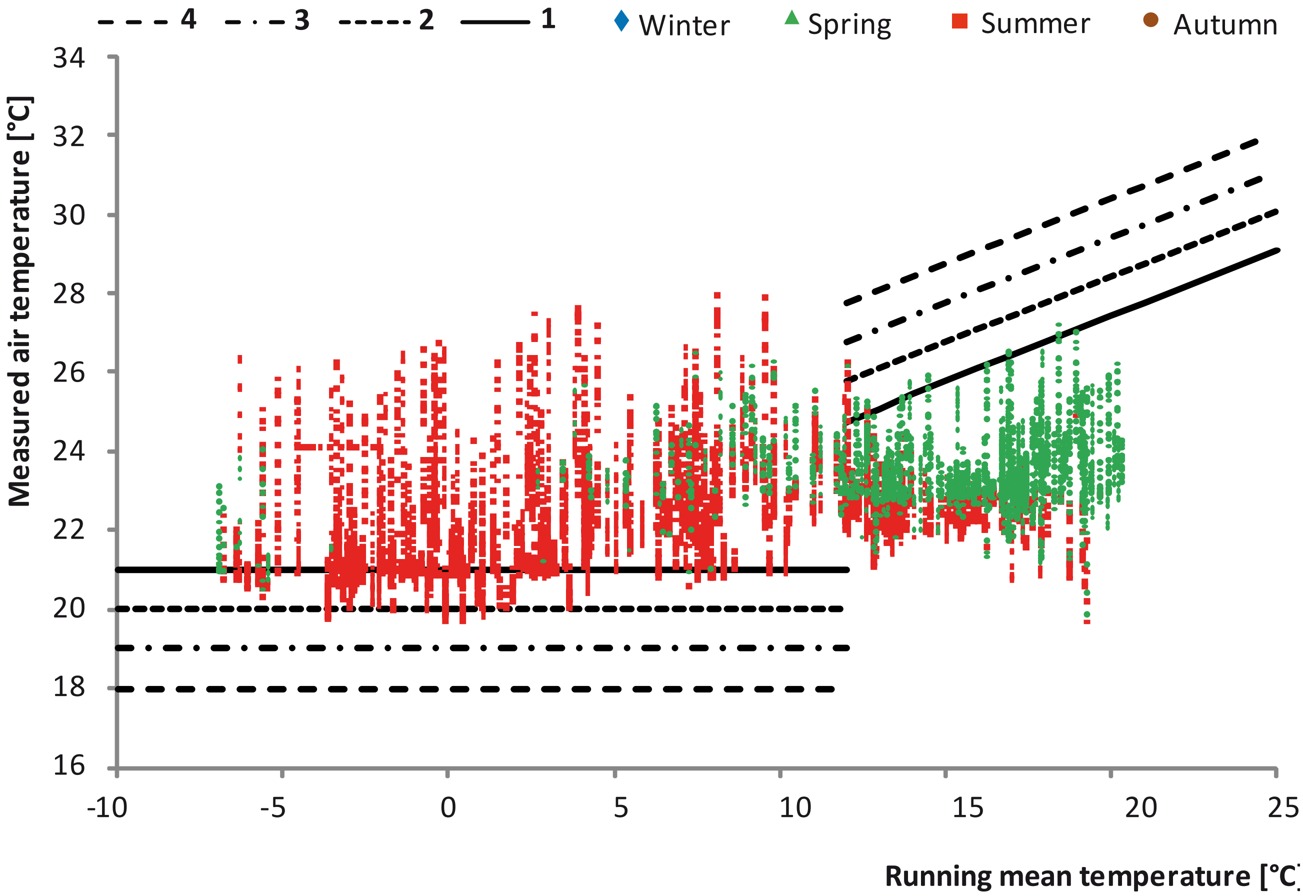

Figure 9. Indoor temperature vs. running mean outdoor temperature. The colour indicates if windows were open (green) or closed (red) for each hour (kitchen and dining room).

when evaluated according to the Active House specification, which uses the same methodology and criteria as EN 15251 with regards to thermal comfort. The hours not in level 1 are mainly hours with undercooling, while overheating is rare. If undercooling is disregarded, the primary rooms of the house achieve level 1. For low energy houses, overheating should be prevented by the building design, as overheating may require substantial measures if handled after completion. Home for Life thus meets the level 1 with regards to overheating, which is very satisfactory, given the generous daylight conditions.

The episodes with undercooling could be caused by insufficient heating capacity, window airings, poor building airtightness or occupant preferences. It was found that there was no correlation between window openings and undercooling. The airtightness has been verified by a blowerdoor test. The heating system is known to have a sufficient capacity, but the supply temperature was actively reduced by the occupants to reduce the heating consumption. Undercooling in Home for Life is therefore explained by occupant preferences.

In the kitchen/dining room, a correlation between window openings and the combination of high indoor and outdoor temperatures was found. Further, a clear correlation between window openings and acceptable thermal comfort was found. This indicates that window openings have contributed to achieving and maintaining good thermal conditions.

No clear correlation between use of external solar shading and temperature. Users may often have used the override function to deactivate the automatic control of solar shading, which could explain the missing correlation between use of shading and the combination of high indoor and outdoor temperatures.

In conclusion, Home for Life achieves a good thermal performance in real use, which should be seen in connection to the high daylight levels of the building. The good performance is achieved with automatic control of window openings and solar shading, where especially the ventilative cooling from open windows was important. ■