STRATEGIES FOR CONTROLLING THERMAL COMFORT IN A DANISH LOW ENERGY BUILDING: SYSTEM CONFIGURATION AND RESULTS FROM 2 YEARS OF MEASUREMENTS

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ABSTRACT

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

The kitchen/dining room has a large south-facing window area and is selected for the detailed analyses. 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 reaches category 1 for the summer situation. Some undercooling occurs during winter, causing the room to achieve category 2 if the entire year is considered. The undercooling 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.

KEYWORDS

Thermal comfort, ventilative cooling, residential buildings, natural ventilation, solar shading.

INTRODUCTION

Background

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 a full year during the occupancy of the two families. The results from year one have been reported already and compared to simulations [1, 2].

The six houses follow the Active House [3] 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. The calculated daylight factors are seen at Figure 1.

Figure 1. Calculated daylight factors in "Home for Life". Ground floor on the left, and upper floor on the right. The dotted rectangle indicates the kitchen and dining room which will be investigated in details.

Measurements of IEQ include light, thermal conditions, indoor air quality, occupant presence and all ocupant interactions with the building installations, including all operations of windows and solar shading. Further, an anthropological study of the family's experiences in the house was performed. Measurements of energy performance include space heating, domestic hot water and electricity for appliances, lighting and technical installations. The occupants also reported their own observations in a diary, and an anthropologist has followed the project and made structured interviews with the family.

The present paper describes the design and setup of the systems that have an influence on the summer, winter and intermediate situations, particularly the natural ventilation system and the solar shading.

The presented results focus on thermal conditions, effectiveness and experience with the applied strategies. Recent examples of demonstration houses in Scandinavia have experienced problems with overheating, often due to insufficient solar shading, [4], [5].

Technical systems

Home for Life is an experiment and the hypothesis is that a synergy between a low CO_2 emission and a good IEQ can be achieved through optimal window layout (40% of façade area) distributed towards all orientations and the roof for both good daylight conditions (daylight from all orientations) and good natural ventilation performance, through hybrid ventilation and through automatic control of solar shading, heating and ventilation. It is a 1½-storey house with a total floor area of 190 m².

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 ^{o}C with a 0,5 ^{o}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. The solar shading was initially controlled based on the indoor temperature. But based on the responses from the occupants, this control stategy seemed to react too slowly to prevent overheating, and the control was changed so that external solar radiation was used instead. On the con side, using solar radiation can cause unnecessary use of solar shading in the winter period, leading to an increased heating demand.

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 solar shading is controlled by external solar radiation for each facade, and not at room level.

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.

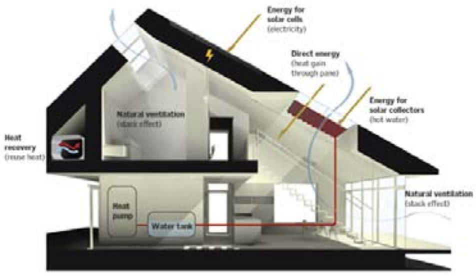

Figure 2. “Home for Life”. South and east facades (left). Concept for daylight, ventilation and energy (right)

Data recording

The data from the sensors that are used for the controls of the house is recorded. The IEQ data is recorded for each individual zone as an event log, where a new event is recorded when the value of a parameter has changed beyond a specified increment from the previously recorded value. The event log files are automatically converted to data files with fixed 15-minute time steps, which are used for the data analysis.

Data analyses

The recorded temperature data is evalueted according to the Active House specification[3], which is based on the adaptive approach of EN 15251 [6].

RESULTS

The results presented here are based on the measurements and analyses for the second year of occupancy. The main part of commissioning and adjustment of all systems took place during the first year occupancy, and year two is for that reason considered the most representative. Figure 3 shows the outdoor conditions during the reported period.

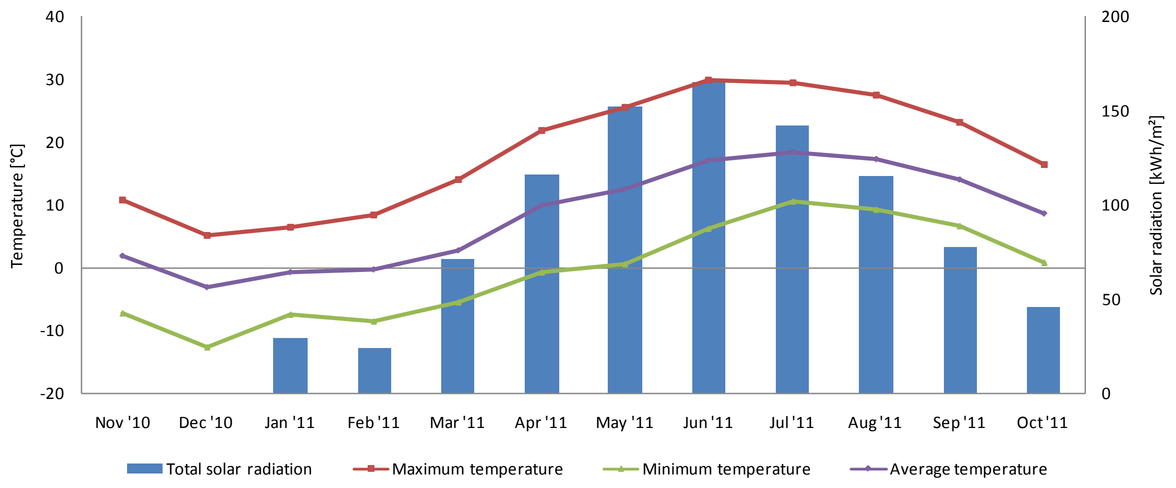

Figure 3. Outdoor conditions during the measurement period. The pyranometer was installed in January 2011, and therefore data is not available for the previous months.

Figure 4 shows that five rooms achieve catogory 2, while six rooms achieve category 4. It is clear from the figure that the majority of the hours in category 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 category 1.

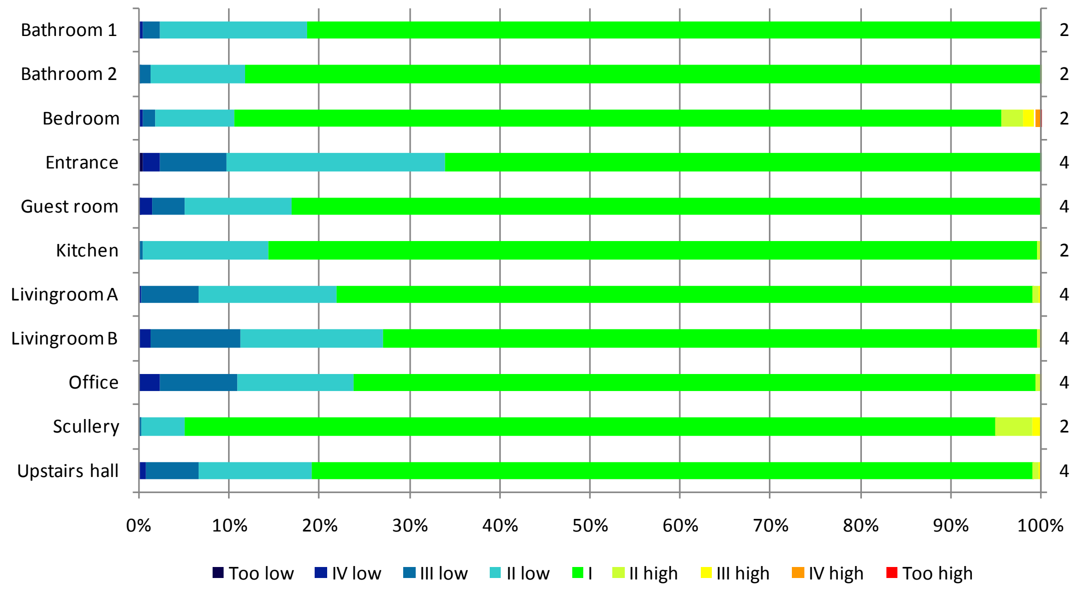

Figure 4. Thermal comfort for each of the rooms evaluated according to Active House specification (based on adaptive method of EN 15251). Criteria are differentiated between high and low temperatures. The number at the right side of the diagram indicates the score for each room (1 to 4).

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 kitchen, which is a combined kitchen and dining room with a large south-facing window section, Figure 2.

The distribution of categeories 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, category 1 is achieved.

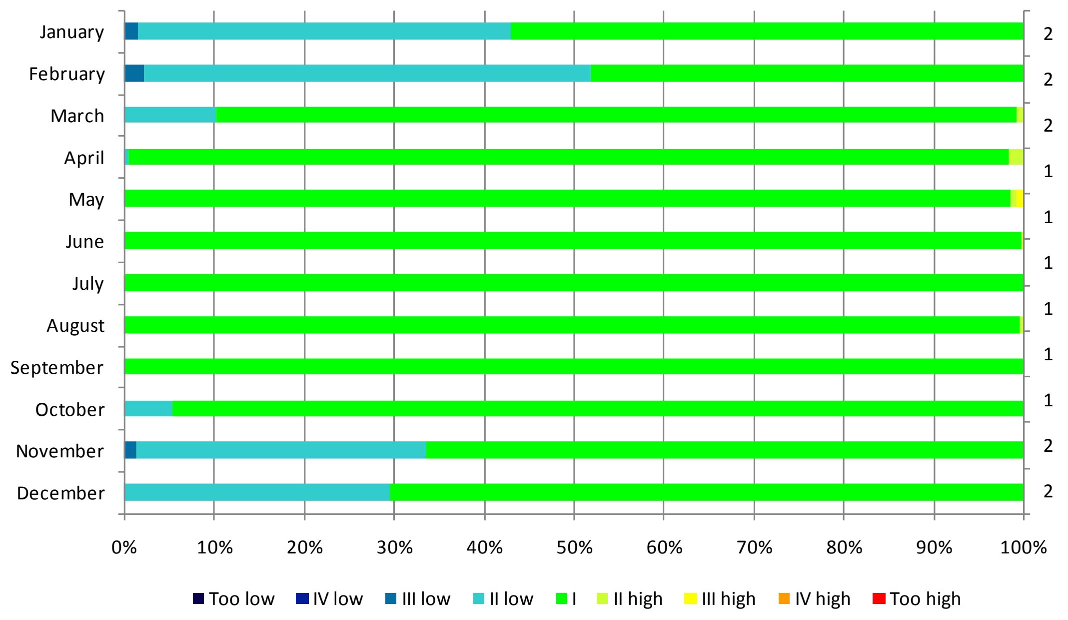

Figure 5. Thermal comfort categories for each month of the year for the kitchen and dining room. The number at the right side of the diagram indicates the score for each month (1 to 4).

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 category 1 limit (21 ^{o}C) occur both in winter and in the transition periods, but only with a few hours below the category 2 limit (20 ^{o}C). It is suspected that the episodes with temperatures below 21 ^{o}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 ^{o}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 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 category 1. Relatively low temperatures are observed during summer, with episodes with temperature drops below 21 ^{o}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 ^{o}C and 21 ^{o}C.

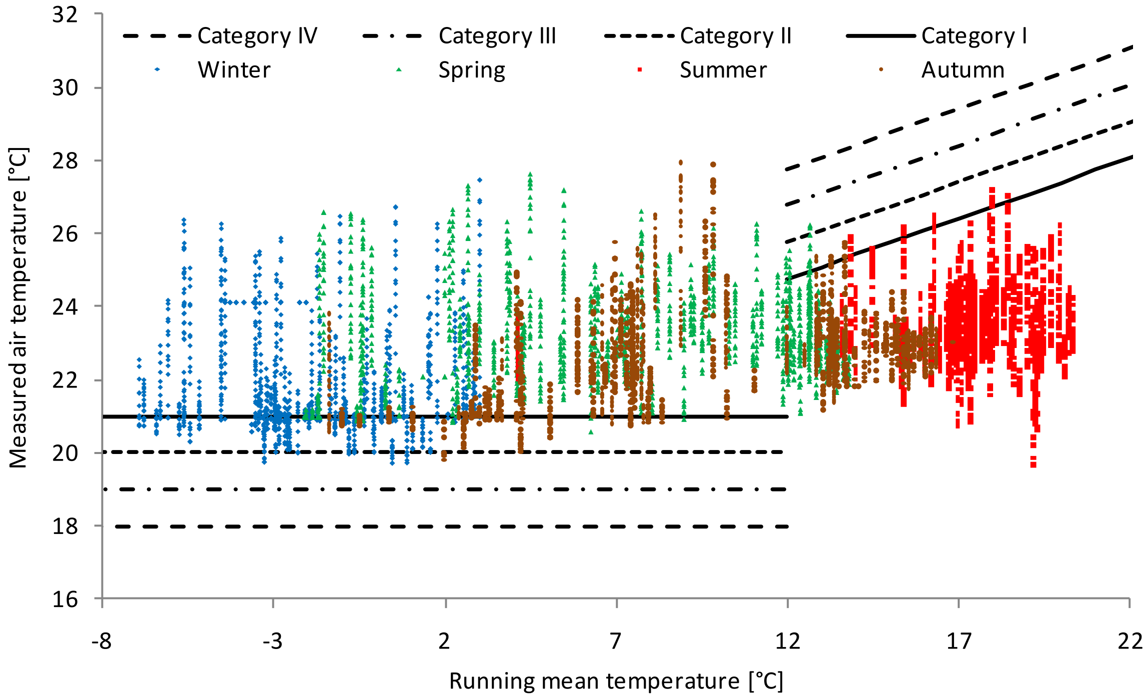

Figure 6. Indoor temperatures in the kitchen plotted against running mean temperature for each hour of the year including the Active House category limits. The dots are coloured to represent a season.

The 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 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.

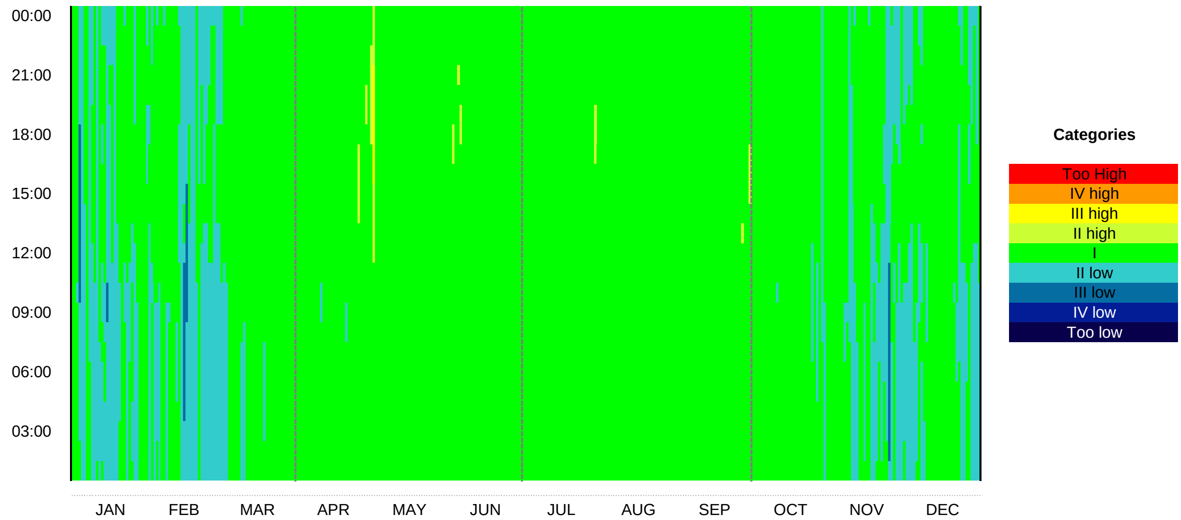

Figure 7. The comfort category of each hour of the year is plotted as a temporal map (kitchen and dining room)

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 (category 2 was the design target), where only category 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 category 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 category 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 category 1.

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

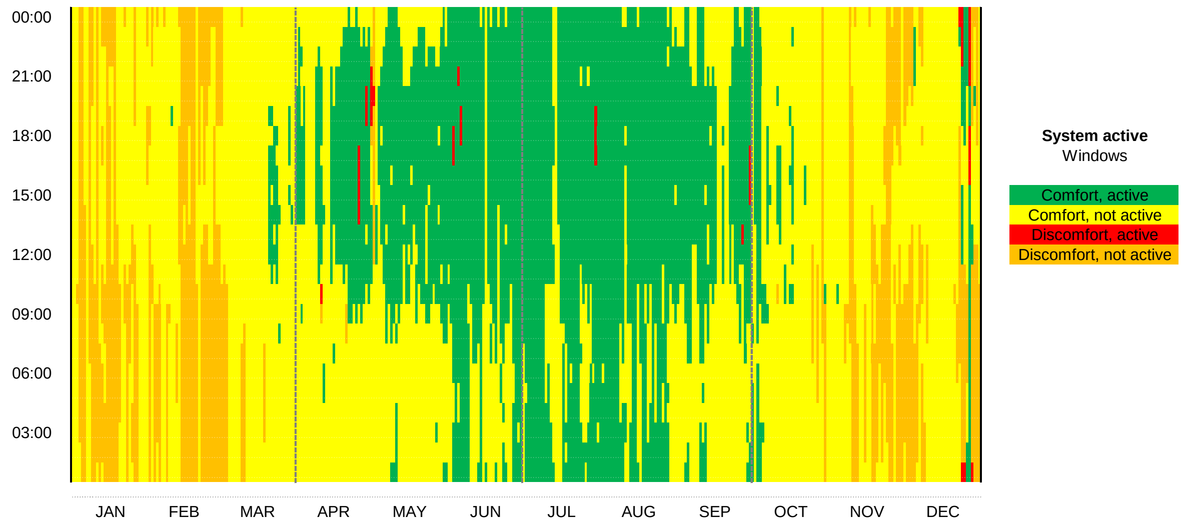

Figure 8. Temporal map showing comfort or discomfort (discomfort is here temperatures in category 2, 3 or 4) and if windows were open or closed (active or not active). Figure shows kitchen and dining room.

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 ºC. When the running mean temperature is above 12 ºC, windows are generally opened when the indoor temperature exceeds 22-23 ºC, which is in accordance with the control strategy.

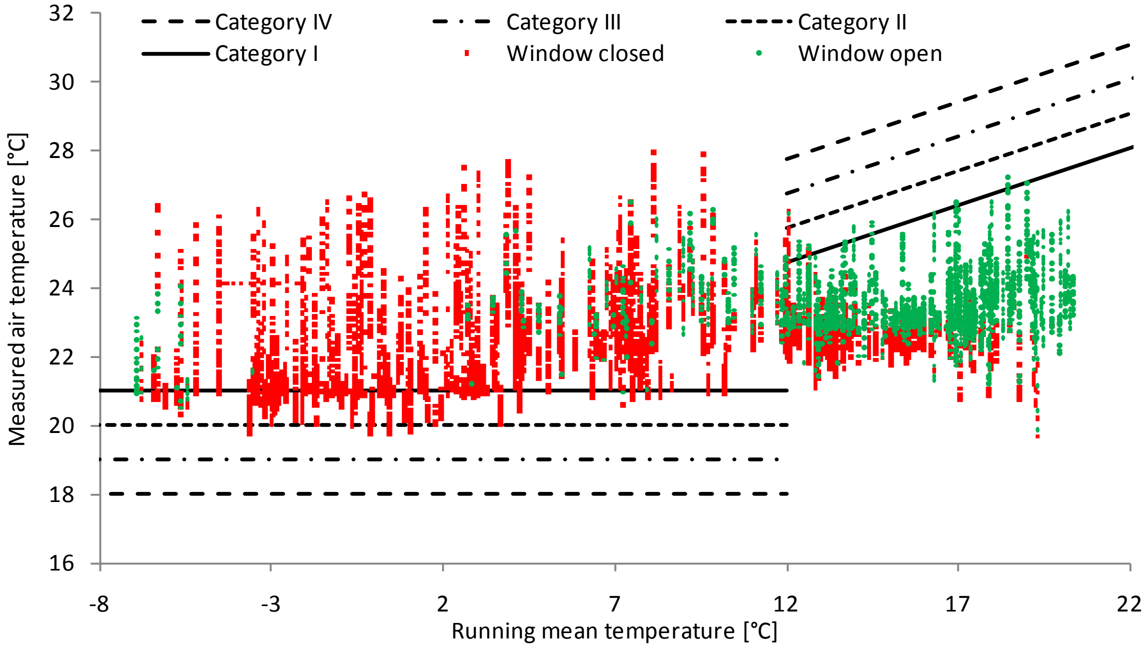

Figure 9. Indoor temperature vs. running mean outdoor temperature. The colour indicates if windows were open (green) or closed (red) for each hour (kitchen and dining room)

The role of the external solar shading is investigated at Figure 10. The figure shows no clear correlation between use of shading and indoor temperature nor running mean temperature. The external shading is activated when the external solar radiation exceeds a threshold and so is not controlled by temperatures, but some relation between temperature and use of shading could have been expected, as was the case for window openings. A further explanation is that solar shading can also be activated if glare is experienced, and also for privacy.

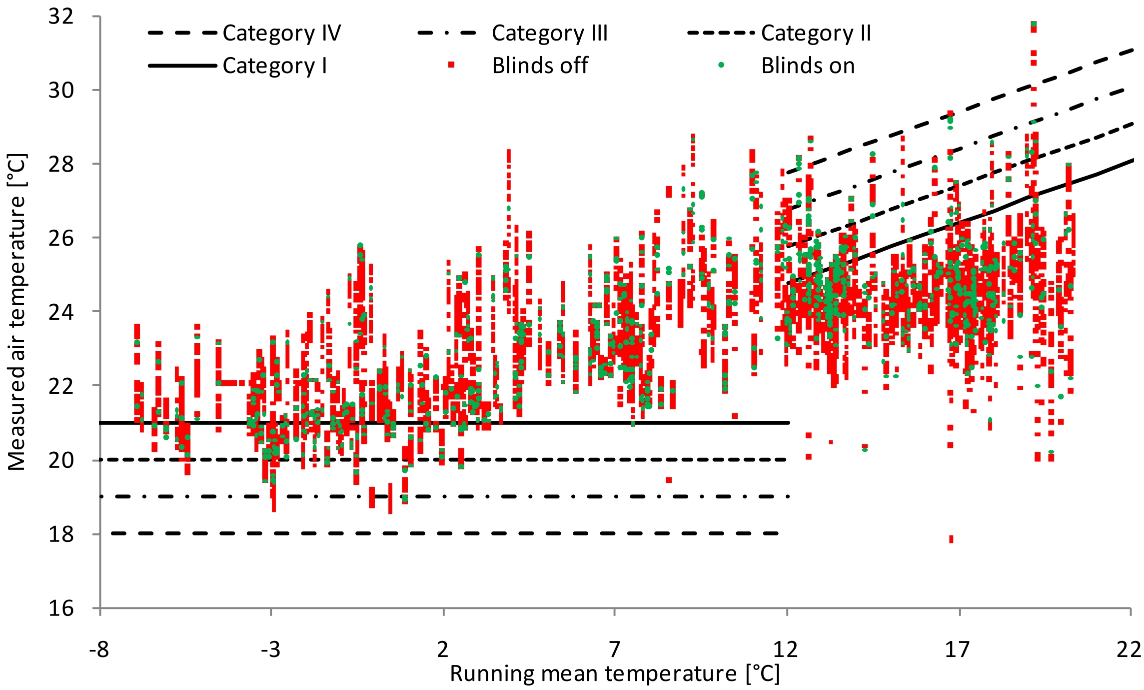

Figure 10. Indoor temperature vs. running mean outdoor temperature. The colour indicates if external solar shading was active (green) or inactive (red) for each hour (kitchen and dining room).

To further investigate the temporal use of shading, the use of shading is plotted at Figure 11, where colour codes indicates the use of shading and the comfort categories. The use of shading is increased during summer (green dots). The use appears to be distributed evenly over the day, due to the control being based on external radiance. The consistent use of shading during an hour in the morning and the late afternoon/evening has been investigated, but no clear explanation is found. It is not suspected to be caused by user controls, but rather as a result of the automatic control algorithms.

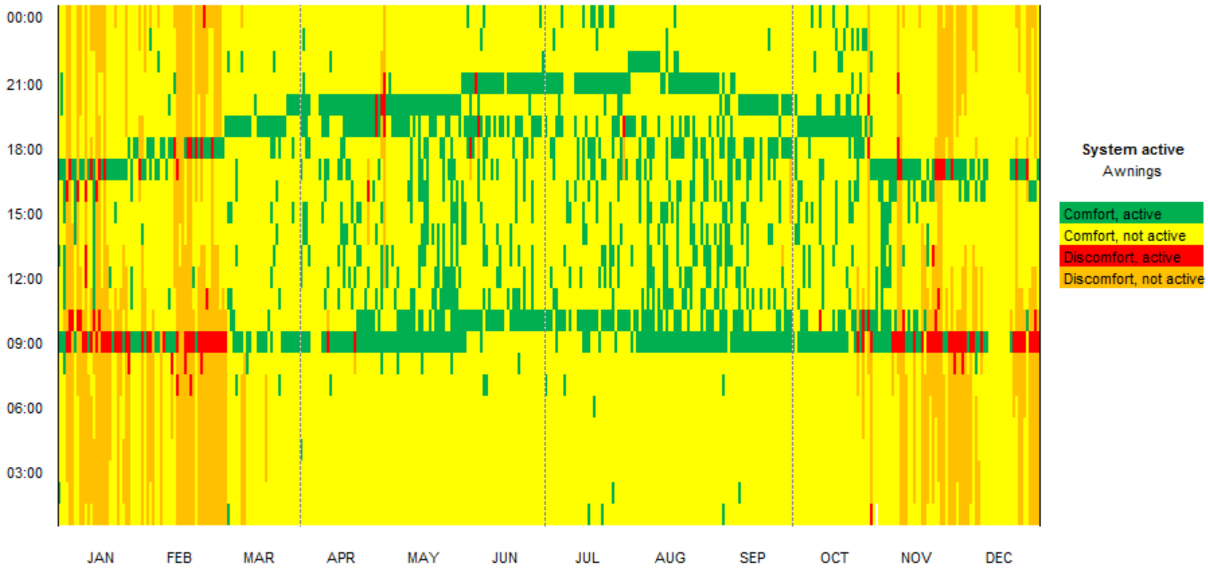

Figure 11. Temporal map showing “comfort” or “discomfort” (discomfort is here temperatures in category 2, 3 or 4) and if shading was active or not active (kitchen and dining room).

DISCUSSION

For the rooms in Home for Life, half fall in category 2 and the other half in category 4 with regards to thermal conditions, 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 category 1 are mainly hours with undercooling, while overheating is rare. If undercooling is disregarded, the primary rooms of the house achieve category 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 category 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.

ACKNOWLEDGEMENTS

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