Indoor Environment in Arctic Dwellings and Possible Improvements
– With Special Focus on Overheating

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A large proportion of newly build Arctic dwellings suffers from overheating due to well insulated and air tight envelopes, low air change, and large windows. According to the WHO, temperatures above 24°C may cause thermal discomfort. In buildings above the Arctic Circle this is becoming more and more common, even though the outside temperatures are low. Interviews, indoor environment measurements and computer simulations were performed in four new homes in Sisimiut, Greenland to analyse the magnitude of the overheating phenomenon. Based on the results, a sensitivity analysis was carried out to find suitable solutions to improve the indoor climate.

Keywords: indoor climate; overheating; extreme climates; ventilation; dynamic simulation; arctic dwellings; CO_2 concentration; solar shading

Current situation with indoor climate in Greenlandic dwellings

In the Arctic the buildings are exposed to extreme climates with extremely low temperatures, high wind speeds and solar radiation distributed unevenly throughout the year (unavailable in winter and very high during summer). In Sisimiut for example the winter average temperatures lay at –16.6°C while the maximum summer temperature rarely exceeds +10°C. The windspeeds often exceed 20 m/s. The snow cover stays until late May and the solar radiation of the low spring sun combined with large albedo effect results in potentially large solar gains. (Schrot et al., 2019).

For economic reasons and lack of experience, balanced ventilation systems are often avoided entirely or not designed to the Arctic demands. It is also not uncommon that buildings are only equipped with mechanical exhaust and natural ventilation intakes on the facade. The natural vents are often sealed by the occupants to reduce the cold draught and thermal discomfort. All in all, the ventilation rates are frequently reduced below recommended levels (Kotol et al., 2014).

The combination of 1) modern building techniques with highly insulated and airtight envelopes and thus low heat loss despite the harsh climate; 2) reduced ventilation rates and 3) large solar gains; naturally increases the risk of overheating.

Many of the overheating mitigation strategies from milder climates such as window opening, external passive or active shading cannot be used successfully due to extreme weather conditions. However, other solutions can help to mitigate overheating, such as increased air change using ventilation system, interior or in-glass integrated shading or reduced solar heat gain coefficient of windows (Mavrogianni et al., 2014; Yu et al., 2023). The behaviour of the occupants and correct heating system design and control can also have a great effect as found in (Andersen et al., 2009; Haas et al., 1998).

Our investigation aimed to study the indoor climate in four recently built homes in Sisimiut, Greenland and to compare it with traditional houses from previous studies and standard requirements. Furthermore, by means of simulations we studied possible overheating mitigation strategies.

Characteristics of the studied buildings

The study was performed in 4 single family homes built between 2015 and 2017. They are three-bedroom houses with a heated floor area of 104 m². The houses are wooden structures on concrete strip foundations. The wooden frame is insulated with glass wool insulation and average U-value of the external walls is 0.12 W/(m²·K). The windows are triple glazed with argon providing a Ug-value of 1.1 W/(m²·K) and g-value of 0.59. The houses are heated with water-based floor heating system supplied by individual oil boiler. The floor heating is controlled individually in each room via room thermostat. Ventilation units contain a cross flow plate heat exchanger with 75% efficiency, according to the technical documentation. The air flow can be adjusted manually between low, medium and high speed. The occupied rooms have intake and exhaust and are thus balanced ventilated on a room level.

Figure 1. Newly built dwellings in Sisimiut, west Greenland.

IAQ measurements and interview method

We measured T+RH in all the occupied rooms plus CO_2 in bedrooms from May to July 2023. Ventilation airflows were measured with a flowmeter at each air diffuser at all three speed modes. Then, the results were compared with the Greenlandic Building Regulation (Oqartussat, 2006) (GR).

The correct function of floor heating was verified via comparison between pictures from the infrared camera and thermostat settings. If the temperature of the internal air of the room is lower than the thermostat setting of the room, floor heating should be turned on and visible in the taken photos.

To understand better the habits of the users, interviews were made with all the owners of the assessed houses. We studied the patterns concerning the use of shading, when and how long they open windows, what was their perceived IAQ in the house and their habits concerning the use of mechanical ventilation.

Simulations

The simulations were done using IDA ICE. The climate file used was obtained using ERA5 and Asiaq's data. Internal gains and their schedules have been set based on conducted studies, best practices and conversations with occupants.

After validation of the model, the following parameters, their combination and their effect on overheating were studied: a) the SGHC factor of window panes; b) the speed of the AHU unit; c) the usage of openings for natural ventilation; d) the type of shading e) the combination of best resulting parameter of each class (a – d) of the variations. The assessed combinations sorted into categories are in **Table 1**.

Results

Measured indoor temperatures frequently exceeded 24°C and, in some periods even 26°C. **Figure 2** shows temperatures in living rooms in each house (K5; K7; U7; K18). Elevated temperatures (over 24°C) appear in all houses for over 25% of measured time and exceed 26°C for up to 10% (U7). The U7 house experiences the greatest temperature range (14°C to 30°C during the monitoring period). We noticed that the U7 house owners are trying to mitigate overheating by keeping their windows open for most of the time which results in the significantly low temperatures once the solar gains disappear at the end of the day.

Cumulative graphs for CO_2 concentration during night time (19:00 – 10:00) are presented in **Figure 3**. Most bedrooms experience CO_2 concentrations ▶

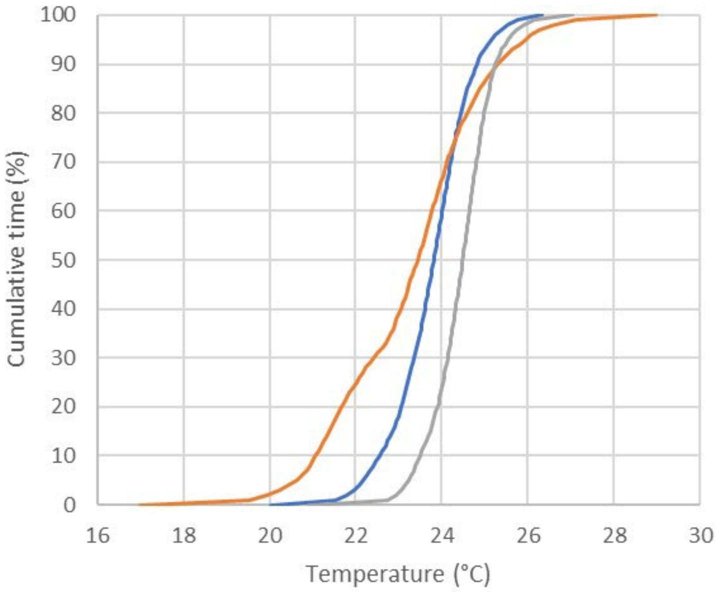

Figure 2. Cumulative graphs of living room temperatures measured in four houses during May-July

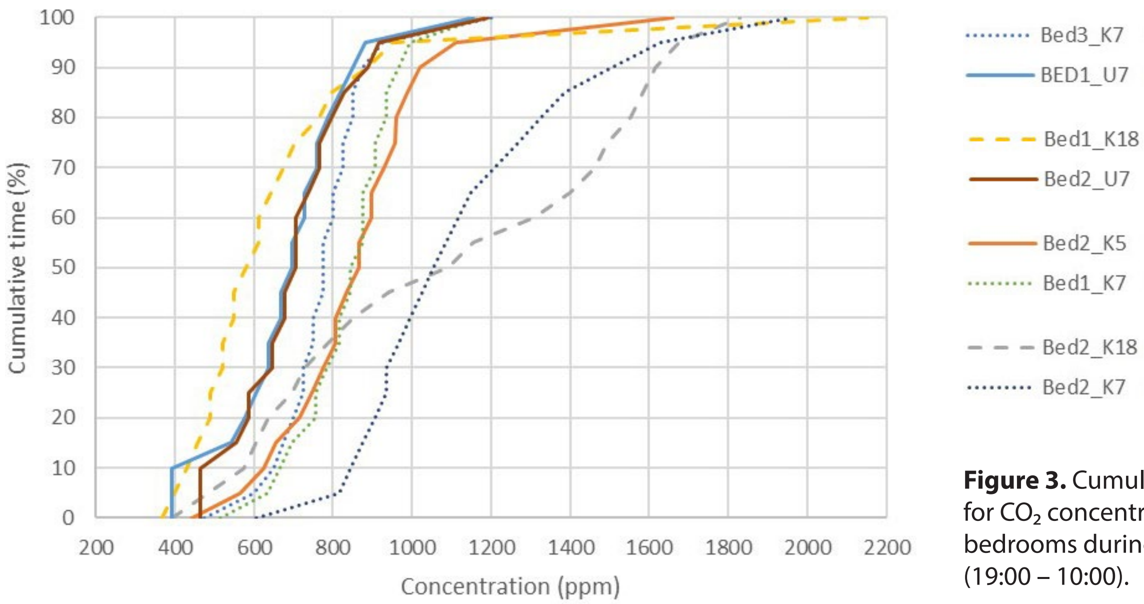

Figure 3. Cumulative graphs for CO_2 concentration in the bedrooms during nighttime (19:00 – 10:00).

Table 1. *List of scenarios simulated for overheating assessment.*

Category	Name in graph	Brief description
AHU flowrate setting	AHU – low	Setting of AHU with a minimum airflow (94 m^3/h)
	AHU – medium	Setting of AHU with a medium airflow (228 m^3/h)
	AHU – high	Setting of AHU with a high airflow (306 m^3/h)
Natural ventilation	NatVent 5	Windows opened for 5 min per day
	NatVent 10	Windows opened for 10 min per day
	NatVent 60	Windows opened for 60 min per day
	NatVent 10%	Windows opened all day but only on 10% of its area
SGHC	Validation	0,36
	SGHC 20	0,20
Shading	Validation	Internal drapes
	Mid panes	Blinds placed between window panes in a cavity opened to the outside air through vents, drawn when solar radiation level exceeds 100 w/m^2

above 1000 ppm for less than 10% of the night time. The highest mean concentration was measured in bedroom 2 of K18 house and is 1093 ppm. The highest percentage of time with CO_2 concentration above 1000 ppm is the bedroom 2 of the K7 house (occupied by four people) with 55% of the time. The U7 house results show the lowest concentrations that meet the 1000 PPM level requirement for the longest period of time.

Air flow measurements

The measurements of actual air flows showed that 1/3 of all the rooms is slightly under ventilated according to the Greenlandic Building Code. This was also confirmed by the results of the CO_2 monitoring. We believe this is simply due to improper regulation as the units have the capacity to meet the requirements. During the measurements we discovered that one of the K houses had very low or non-existent exhaust air flow at the low-speed setting. We assume that this was due to clogged return filter. As a result, the house was permanently over-pressured which is not desirable as this leads to indoor moisture being pushed into the construction.

Simulations

Simulation results for all scenarios presented in the method are shown **Figure 4**.

When assessing solutions for overheating, the minimum resulting temperature should not be neglected either. When opening the windows, the cold air immediately enters the rooms, creating drafts and reducing the temperature too much. Therefore, the scenario with the window opened all day on 10 % of its area (NatVent 10 %) may be without overheating, but results in too low temperatures causing thermal discomfort. This was also seen in the living room of U7 house.

The integrated shading solution shows temperature levels in a comfortable range. It means that there is no excessive overheating, no cool periods either and that the temperatures obtained are very consistent throughout the period. The shading blocks the radiation from entering the interior and can be cooled down thanks to its position in the outermost ventilated cavity.

Figure 5 presents measured temperatures (Real) and simulated best-case scenario (Sim) for each room of the K18 house. The results indicate, that excessive temperatures can be reduced significantly using a combination of integrated shading, increased air flows in ventilation system, and the g-value of 0,2. Temperatures would still exceed 24°C (elevated temperature) but for less than 5% of the time which we consider acceptable.

Conclusions

The study shows that new buildings in the Arctic experience solar overheating through large windows even though they are equipped with modern balanced ventilation systems. The ventilation systems are not designed to cool the interior (by increasing the air flow and by-passing the heat exchangers) when needed and the interior shadings and window opening does not

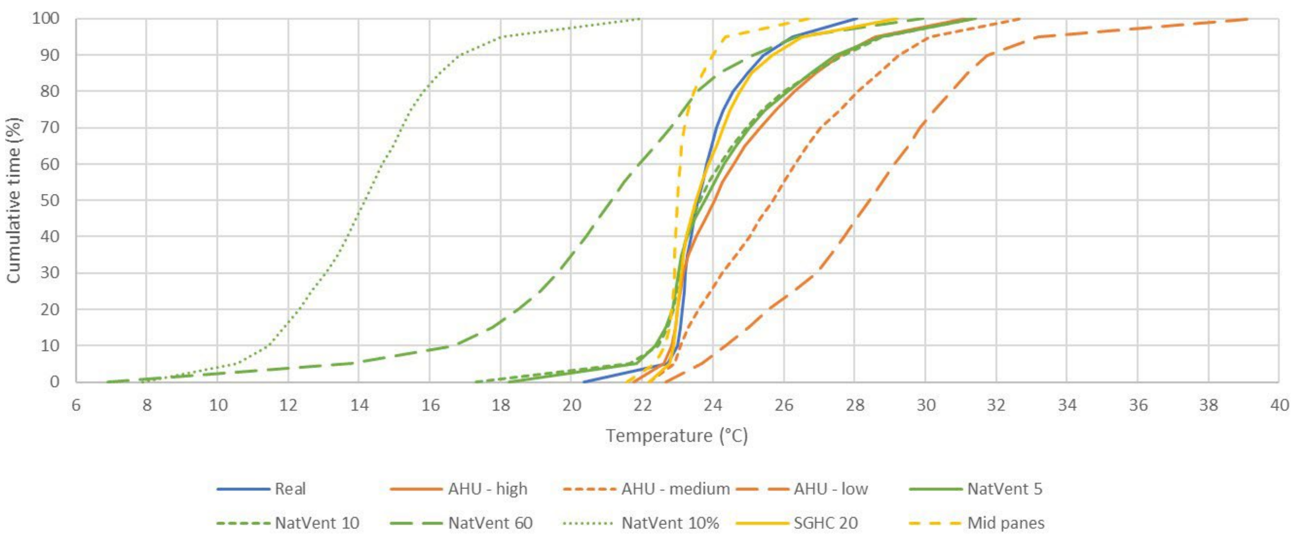

Figure 4. Cumulative graphs of the simulated scenarios.

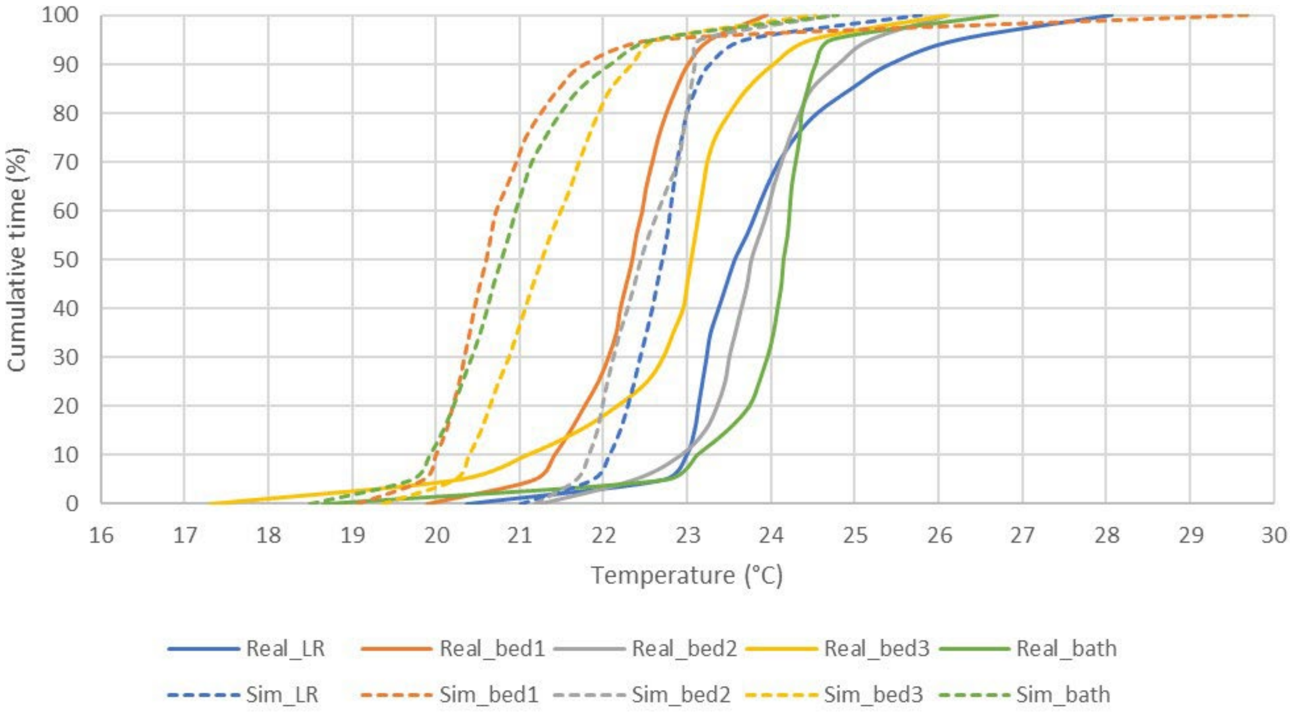

Figure 5. Measured and simulated (the best-case scenario) temperatures.

solve the problem either. Our simulations showed that with higher ventilation rates and the implementation of different (more suitable) technology such as integrated window shading and optimized solar heat gain coefficients on some windows, it is possible to improve the thermal comfort substantially. Additionally, we believe that regular maintenance, proper commissioning and appropriate user instructions will lead to better IAQ and thermal comfort of the occupants. ■

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