Weather and indoor climate in Greenland

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Abstract. To make a hygrothermal assessment of a building construction, e.g. wall or roof, weather files as well as information on indoor moisture load are needed, however only to some extent available for Greenlandic conditions. This paper describes a project that had a twofold aim: 1) create weather files for four different cities in Greenland in a simple way, 2) determine the typical moisture load in a Greenlandic dwelling to see if the international standard ISO 13788 is applicable in Greenland when describing indoor moisture load. The four chosen cities are placed at the west coast of Greenland. Hourly weather data of 10 years for the four cities were obtained from the meteorological institutes of Denmark and Greenland, from this a reference year with hourly values was created for each city. The paper also describes how incomplete data was treated. Five dwellings were chosen in each city to assess the indoor moisture load. Temperature and relative humidity were measured hourly in living rooms of these dwellings. Furthermore, outdoor temperature and relative humidity were measured in the four cities. The moisture load in the dwellings were scattered in humidity class 1-4, similar to what has been measured in Danish dwellings, consequently ISO 13788 may be applicable in Greenland.

1. Introduction
Hygrothermal simulations can be helpful when designing building components e.g. to assess moisture risks in facades or roofs, but simulations require reliable weather data and knowledge of typical indoor climate. In Greenland weather data has been registered for many years, however, design reference years for hygrothermal simulations have not been in high demand, due to the small population of 56,000. Greenland is the world’s biggest island (2,670 km x 1,050 km), 80% of the island is covered with ice [1]. With this size it is most likely that several reference years are necessary to cover the inhabited areas.

Most of the population lives at the west coast. In the energy requirements of the Building Regulations [2], Greenland is divided in two zones; north and south of the Arctic Circle. This may be a too simplistic way of looking at Greenland, the aim of this study was to create weather data for reference years for four cities at the west coast of Greenland, from the south to the middle of Greenland, covering an area where approximately 90 % of the Greenlandic population lives.

The study also investigates the moisture load in dwellings in the same four cities. The aim was to see if the humidity classes, as described in the international standard ISO 13788 for maritime climates [3], are applicable in Greenland. This is especially interesting as mould growth is a growing problem in Greenlandic dwellings and tenants are urged to reduce the moisture load [4]. If the moisture load is higher than in European maritime climates, hygrothermal simulations must reflect this by using different indoor moisture load than in ISO 13788 when assessing moisture conditions in building components.
Figure 1. Map of Greenland, showing the Arctic Circle, dividing the country in two zones for energy requirements [2]. The four cities that were chosen for this study are shown with yellow stars. From the North: Ilulissat, Sisimiut, Nuuk and Qaqortoq. These are the four largest cities and at the same time they represent north-south differences, which are the decisive differences at the Greenlandic west coast. With the weather files of these four cities the encircled area is covered. Approximately 90% of the Greenlandic population lives in this area.

2. Method
For this study the four biggest cities in Greenland were chosen, most of the population could be covered by the area along the west coast from the south of Greenland to the Ilulissat area. The east coast has approx. 3000 inhabitants, roughly the same amount lives at the west coast north of Ilulissat.

2.1. Climate files
The aim was to create weather files that could be used for hygrothermal simulations of building components with the simulation tool WUFI [5]. This program needs eight inputs on an hourly basis: 1) Air temperature [°C], 2) Relative humidity [0..1], 3) Solar radiation [W/m²], 4) Precipitation [mm], 5) Wind direction [°], 6) Wind speed [m/s], 7) Air pressure [hPa], and 8) Cloud index [0..1].

Most of these parameters could be obtained as raw data for the period 2007-2016 from Asiaq, a Greenlandic governmental company that collects weather data. However, cloud index was not available, nor was data for Qaqortoq. The Danish Meteorological Institute (DMI) could provide raw data from the period 1958-2015. These data covered all four cities and had cloud index for Nuuk and Qaqortoq. Unfortunately, there was no radiation data for Qaqortoq, radiation from a nearby smaller city was used instead. The weather data was not complete but by combining the data from the two sources, it was possible to collect believable data for ten years (2007-2016) for each city. Except for Qaqortoq, where only six years (2009-2014) could be collected. Asiaq data was used as starting point and DMI data filled in the gaps, unless only four or less hours were missing, then mean values of the two nearest measurements were used instead. Cloud index for Sisimiut and Ilulissat were obtained from the historical weather in [6].

Instead of creating an artificial year, the series of weather files were compared using monthly average of temperature, relative humidity, precipitation and wind speed. For each parameter the monthly average over the 10 year period was determined, and the differences to the averages for each specific year calculated. For each year the standard deviation of these differences were determined. Based on this, the years were ranked after the lowest standard deviation for each parameter. The year that had the best ranking overall, was seen as the most representative year and was chosen as reference year.

2.2. Indoor moisture load
Temperature and relative humidity were measured every 30 minutes in five randomly chosen dwellings in each city. Except in Sisimiut where the indoor climate was only measured in two dwellings but in several rooms. In total, twenty indoor climate measurements were performed over a period of at least two weeks in the period from mid-February to mid-March 2017. The sensors were typically placed at a
book shelf in the living rooms. These measurements were performed with sensors in data loggers from Lascar Electronics of the type EL-USB-2+ with an accuracy of 0.45 °C and 2.5 % RH [7]. Before installation the sensors were calibrated in a climate chamber.

Along with indoor climate, outdoor temperature and relative humidity were measured in each city. The outdoor sensors were placed close to one of the dwellings, protected against direct sunlight and precipitation. This made it possible to compare the moisture content in outdoor and indoor air and thereby calculate the internal humidity load. The moisture content was calculated according to [3]:

\[
p_{\text{sat}} = 610.5 \exp \left( \frac{17.269 \theta}{237.3 + \theta} \right) \text{ for } \theta \geq 0 \, ^\circ\text{C} \\
p_{\text{sat}} = 610.5 \exp \left( \frac{21.875 \theta}{265.5 + \theta} \right) \text{ for } \theta < 0 \, ^\circ\text{C}
\]

and

\[
\theta = \varphi \cdot \frac{p_{\text{sat}}}{0.4615(\theta+273.15)}
\]

therefore:

\[
\theta = \varphi \cdot \frac{610.5\exp \left( \frac{17.269 \theta}{237.3 + \theta} \right)}{0.4615(\theta+273.15)} \text{ for } \theta \geq 0 \, ^\circ\text{C}
\]

and

\[
\theta = \varphi \cdot \frac{610.5\exp \left( \frac{21.875 \theta}{265.5 + \theta} \right)}{0.4615(\theta+273.15)} \text{ for } \theta < 0 \, ^\circ\text{C}
\]

where

\(p_{\text{sat}}\) = Saturated vapour pressure [Pa], \(\theta\) = Temperature [°C], \(\theta\) = Humidity of air by volume [g/m³], \(\varphi\) = Relative humidity [-].

The average internal moisture excess was plotted against the average outdoor temperature in the period to determine the humidity class according to Annex A.2 (maritime climates) in [3].

3. Results
Climate data and indoor measurements are independent and will therefore be treated separately.

3.1. Climate files
For each year from 2007-2016 the monthly averages of temperature, relative humidity, precipitation, and wind speed were determined for each city. The years were ranked after how much the monthly average deviated from the 10 year average. The four cities were treated individually and the reference years were: Qaqortoq: 2014, Nuuk 2015, Sisimiut 2014 and Ilulissat 2011. Figure 2 shows how the monthly average of temperature and RH of the reference year differ from the average of ten years.

![Figure 2](image-url)
3.2. Indoor moisture load
The measurements were performed in different types of buildings (single-family, multi-storey and terraced houses), the occupancy was different and the ventilation system was either mechanical ventilation or natural ventilated, see Table 1. The humidity class borders can be seen in Figure 3.

Table 1. Overview of buildings where the indoor temperature and relative humidity has been measured. First letter in the house# describes the city. Average outdoor temperature has been the same for all buildings in the same city.

| House # | Outdoor temperature [°C] | Building type | Year built | Occupants Adults +children | Ventilation | Internal moisture excess [g/m³] | Humidity class |
|---------|--------------------------|---------------|------------|---------------------------|-------------|--------------------------------|----------------|
| Q1      | -1.9                     | Multi-storey  | ?          | 1+0                       | Mechanical  | 1.3                            | 1              |
| Q2      | -1.9                     | Multi-storey  | 2013       | 2+0                       | Mechanical  | 2.0                            | 1              |
| Q3      | -1.9                     | Single-family | 1971       | 4+2                       | Natural     | 2.9                            | 2              |
| Q4      | -1.9                     | Multi-storey  | ?          | 1+0                       | Mechanical  | 2.6                            | 2              |
| Q5      | -1.9                     | Multi-storey  | 2013       | 2+0                       | Mechanical  | 2.3                            | 2              |
| N1      | -7.4                     | Terraced      | 1979       | 5+2                       | Natural     | 6.8                            | 4              |
| N2      | -7.4                     | Multi-storey  | 2010       | 2+0                       | Mechanical  | 0.9                            | 1              |
| N3      | -7.4                     | Terraced      | 1979       | 2-4+0                     | Natural     | 4.4                            | 3              |
| N4      | -7.4                     | Multi-storey  | 2015       | 3+0                       | Mechanical  | 3.8                            | 2              |
| N5      | -7.4                     | Multi-storey  | 2012       | 2+0                       | Mechanical  | 2.1                            | 2              |
| S1a     | -13.4                    | Multi-storey  | 2014       | 5+3                       | Mechanical  | 5.4                            | 3              |
| S1b     | -13.4                    | Multi-storey  | 2014       |                           | Mechanical  | 5.5                            | 3              |
| S2a     | -13.4                    | Multi-storey  | 1981       | 4+2                       | Mechanical  | 6.1                            | 3              |
| S2b     | -13.4                    | Multi-storey  | 1981       |                           | Mechanical  | 6.0                            | 3              |
| S2c     | -13.4                    | Multi-storey  | 1981       |                           | Mechanical  | 5.9                            | 3              |
| I1      | -19.2                    | Terraced      | 1972       | 4+2                       | Natural     | 4.8                            | 3              |
| I2      | -19.2                    | Terraced      | ?          | 3+1                       | Natural     | 4.2                            | 3              |
| I3      | -19.2                    | Single-family | ?          | 5+3                       | Natural     | 4.6                            | 3              |
| I4      | -19.2                    | Single-family | 1987       | 4+2                       | Natural     | 4.2                            | 3              |
| I5      | -19.2                    | Multi-storey  | 1982       | 1+0                       | Mechanical  | 2.5                            | 1              |

In this study the ventilation system is closely related to building type and year of construction; buildings with natural ventilation are built before 1980 and are either single-family or terraced houses, except I4, a single-family house from 1987. The newer buildings are all multi-storey houses, and mechanically ventilated, i.e. mechanically operated exhaust from kitchen and bathroom. Size of the dwellings was not registered, neither were the ventilation openings checked. However, in N1 it was noticed that the air felt humid, ventilation openings were closed and there were discolorations in corners.

Dwellings with an indoor moisture excess corresponding to humidity class 1 were located in multi-storey houses and had 1 or 2 adult inhabitants and no children. Dwellings in humidity class 2 were similar, except for one case with 3 adults and no children, and Q3, a single-family house with 4 adults and 2 children. In humidity class 3, there were at least 3 adult inhabitants and a child (N3 had 2-4 adult inhabitants). The only dwelling in humidity class 4 had the highest number of inhabitants, although the same number was also seen in two dwellings in humidity class 3 (S1a and I1).

Measurements of air drafts, air tightness etc. were not made as this is not needed for assessing the internal moisture excess and thereby determination of humidity class. Neither is the construction type or material relevant. Detail about how much temperatures and relative humidity varied in each case is also left out as the definition of humidity classes in [3] is based on monthly mean values.
4. Discussion
Climate files and indoor moisture load were treated very differently, the climate files were obtained by using data from others while the indoor moisture load was determined by own measurements. Therefore, the discussion of the two parts are independent.

4.1. Climate files
Creating climate data for a reference year is not easy, and normally the task involves meteorologists, here it has been done in a more simple way that may be too simplistic and not be sufficient for an official reference year, but can be useful if there is no official reference year or it is based on too old data. ISO 15927-4 [8] could had been used, however, the standard was only created for the annual energy use, while the aim here was to be able to perform simulations of heat and moisture through building components. ISO 15927-4 [8] operates with mean values which has also been done in this project, although other approaches like median values could have been investigated.

Instead of creating an artificial year, composed of typical month from different years, this study has chosen specific years, that seemed to be “normal” years. However, this was only based on monthly averages, these may include extremes that goes both ways, or may be without extremes that in other years may occur relatively often. Nevertheless, it was a way to cope with a large amount of data. Choosing an actual year has the advantage that it is not necessary to create transitions from one month to another, which should be done if the year is created from typical months from several years, like in the Danish reference year [9]. If no transitions are made in an artificial reference year, there will be sudden shifts from month to month, this would slow down simulations considerably.

4.1.1. Missing data and other weather data files. Although the collection of weather data is professionalised and is an important part of the tasks of meteorological institutes, missing data is always a problem. In this case some of the parameters were not even measured by Asiaq or DMI and had to be manually transferred from a homepage. There is a risk of introducing errors when different sources are combined, the weather stations may be situated in the same city, but not at the same location. In Nuuk there are several weather stations, filling the blanks from another station is possible, which is a better solution than having no measurements, but it creates uncertainties; when data from both stations are available, these tend to deviate a little.

Although there are no official reference years based on recent measurements for the four cities, weather files are available, e.g. files in [10] and [11] can be used for simulations e.g. in EnergyPlus. In [10] there are two files for each city; one with the years 2004-2018 attached and one without further information. Unfortunately, the homepage does not explain the difference. In [11] it is possible to choose weather data for a specific period, the data is not measured on site but are estimates based on ERA5, that combine model data and observations from all over the world [12]. Figure 3 illustrates the differences between weather files from these sources and the reference year found in this study,
exemplified by the temperature in Nuuk. To better distinguish the different curves, the values are based on 24 hour running mean values.

![Figure 4](image)

**Figure 4.** Comparison of weather data (temperature in Nuuk) from different sources. EPW and EPW 2004-2018 are from [9], ERA5 for 2015 from [10] and 2015 is the reference year of this study.

The EPW weather files are in good agreement with the reference year, while the ERA5 data differ considerably. According to [11], the ERA5 data can be obtained between -56 and 71 latitude degrees. The four cities lie between 61 and 69 latitude degrees, but the disagreement between ERA5 data and the others are high; the higher north the bigger the difference, in Qaqortoq the curves are almost similar. But in general ERA5 data cannot be recommended for simulations in Greenland.

4.1.2. Local differences. Figure 2 and Figure 5 show how the monthly average of temperature, relative humidity, precipitation and wind speed differ in the four cities. Qaqortoq is the warmest and has the most precipitation, while Ilulissat is the coldest in the winter. There is a general tendency of the climate being warm and wet in the south and cold and dry in the North. This confirms the relevance of dividing Greenland in two zones (see Figure 1) when considering energy regulations. Nuuk has the highest wind speed. In the autumn both wind speed and precipitation is high, therefore wind driven rain or snow is a problem, especially in Nuuk and Qaqortoq.

![Figure 5](image)

**Figure 5.** Wind speed and precipitation in the four cities, monthly average 2011-2016.

In [14] an analysis was made to test how important the differences in climate are to the performance of different walls. The analysis shows that the wind driven rain load is twice as high in Qaqortoq and Nuuk as in Sisimiut and Ilulissat. Trough hygrothermal simulations [14] shows that e.g. brick or aerated concrete should not be used as exterior walls in Qaqortoq or Nuuk because of wind driven rain. While ventilated facades with a rain screen can be used in all four cities. The most exposed direction varied, but generally directions around east had the highest load, confirming that the foehn wind from the inland
ice plays an important role. Therefore, it seems relevant to use different climates for the cities when performing hygrothermal simulations, or at least use different weather data for Qaqortoq and Ilulissat.

### 4.1.3. Changes over the years

Older reference years are available for the four cities, these data were obtained from 1961 to 1990. Table 2 shows how the temperature and precipitation has changed since the old reference years were created. Temperatures have changed approx. 1 °C south of the Arctic Circle and 2 °C north of it. This illustrates that it is necessary to use recent climate data. If the changes continue with this speed, hygrothermal simulations must be performed with future weather files instead of historical data.

|                      | Qaqortoq | Nuuk  | Sisimiut | Ilulissat |
|----------------------|----------|-------|----------|-----------|
| **Yearly average temperature [°C]** |          |       |          |           |
| 2007-2016            | 1.5      | -0.6  | -2.0     | -2.8      |
| 1961-1990            | 0.6      | -1.4  | -3.9     | -5.0      |
| Difference           | 0.9      | 0.8   | 1.9      | 2.2       |
| **Yearly average precipitation [mm]** |          |       |          |           |
| 2007-2016            | 979      | 786   | 499      | 254       |
| 1961-1990            | 858      | 752   | 383      | 266       |
| Difference           | 121      | 34    | 116      | -12       |

### 4.2. Indoor moisture load

As Greenland has a big problem with mould growth, despite the low relative humidity in the indoor air, it has been discussed whether the internal moisture load would be higher than in other parts of the world, also because simple ventilation openings will cause draft with very cold outdoor air.

However, the measurements of internal moisture excess showed the same pattern as in Danish single-family houses [15]; high diversity but dwellings in humidity class 2 and 3. Apparently the interior moisture excess in Greenlandic dwellings follow the ISO standard [3] just as much as Danish dwellings. This is in line with the findings reported in [16] where indoor climates in 79 Greenlandic bedrooms were measured.

#### 4.2.1. Important parameters

In general the number of inhabitants seem to matter, and mechanical ventilated houses seem to have lower moisture load than those with natural ventilation. However, as building style, year of construction and ventilation system coincide, it is difficult to determine what has the most effect. In [16] it was reported that the indoor air quality was significantly worse in buildings constructed after 1990. In this study the interior moisture excess is lowest in buildings constructed after 1980, but this could be due to these houses being multi-storey houses and [16] only investigated single-family houses.

In Sisimiut measurements were only made in two dwellings, instead sensors were placed in different rooms. As the results are almost the same within the dwelling, it was not important whether the sensor was placed in the living room or the bedroom.

There was not enough data to determine if there was any difference between the cities, as other factors may drown geographical differences, e.g. there was a tendency of more people sharing a dwelling in the north compared with the south.

#### 4.2.2. The method

There are only few archetypes of dwellings in Greenland as 95 % of the buildings are less than 70 years old and mainly standardised buildings. The different building types were represented in this study, therefore not much effort was spend on ensuring representativeness. Measuring for two weeks in five dwellings in four cities may be too few measurements to declare that the internal moisture excess in Greenland is similar to what would be expected in more temperate climates as described in [3]. On the other hand, there is nothing in the findings that goes against that theory. Similar investigations should be made in more dwellings, over longer periods. Measurements in the autumn would be interesting as [14] showed that these month are the most critical for mould growth.
5. Conclusion

Based on existing weather data it was possible to find reference years to be used for hygrothermal simulations for building components in the cities Qaqortoq (2014), Nuuk (2015), Sisimiut (2014) and Ilulissat (2011). The chosen years were determined to be the least extreme of the years 2007-2016, based on monthly average of temperature, relative humidity, precipitation and wind speed. Where data was missing in the observations by the official Greenlandic source, these were obtained from other sources. Data showed that the differences between the weather in the north and south are too big to be ignored. Consequently, different weather data must be used in hygrothermal simulations. Further, the average temperature has increased 2 °C and 1 °C north and south of the Arctic Circle, respectively, since the official reference year was created on the basis of measurements from 1961 to 1990, which underlines the importance of using recent weather data or even creating data that considerate future climate.

Internal moisture excess was measured in dwellings in all four cities and compared to the humidity classes described in ISO 13788 [3]. Most dwellings were in humidity class 2 and 3, indicating that the humidity classes are also applicable in Greenland.

The combination of the reference year and the indoor moisture load constitute the boundary conditions for hygrothermal simulations of building components.

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