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Moisture related challenges in the Greenlandic building sector – results from a survey

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Abstract. The building industry is booming in the larger cities of Greenland; there is a need for housing, and the building stock is in urgent need of renovation, mainly due to the combination of extreme weather conditions and the lack of tradition to maintain buildings. The harsh climate with short summers and long periods of cold weather combined with occasionally high wind speed and precipitation makes it difficult to prevent moisture during the construction phase, causing high drying costs. These challenges highlight the need for guidelines on how to handle moisture especially in the construction phase, both at renovation or when erecting new buildings. To prepare the guidelines, a survey was carried out aimed at building professionals in Greenland. Focus was on identifying construction work challenged by the conditions in Greenland including geography and seasons. The feedback gave an overview on the main challenges and what kind of solutions that do or do not work, showing that handling of moisture in the construction phase is not the only problem. Further, the survey gave feedback on challenges related to specific technical solutions, e.g. crawl spaces, and what kind of information is missing in relation to moisture-safe construction in Greenland. As key-points, focus should be on project design, improved competences, handling of building materials and components at the building site, and explainable guidelines for specific solutions and building types.

1. Introduction

The building industry is booming in the larger cities of Greenland due to migration from smaller settlements to larger cities. Greenland covers more than 2 mio km^2 between 59th and 84th degree of latitude, of which about 20 % is not covered with ice, mainly situated along the coast. The country has 56,000 inhabitants of which about 90 % live along the west coast within the area shown at Figure 1, and only about 5 % at the isolated east coast. It is divided into a national park at the north-east and five municipalities, four along the west coast and one covering both the capital area at the west coast (Nuuk) and the eastern part of Greenland, in total more than 600,000 km^2. Due to the geography all building materials have to be transported by ship or plane, except for stone and sand used for concrete.

The buildings in Greenland are in urgent need of renovation, mainly due to the combination of no tradition to maintain buildings, and extreme weather conditions with monthly average temperatures at 5 °C in summer and -10 to -15 °C in winter, combined with occasionally high wind speed and precipitation compared to Copenhagen (Figure 2). This makes it difficult to prevent high moisture content in building materials and components in the construction phase, resulting in high drying costs, or moisture related damage uncovered at a later stage, as a result of inexpedient actions during construction. These challenges highlight the need for guidance on how to handle moisture especially in the construction phase, both during renovation or when erecting new buildings.

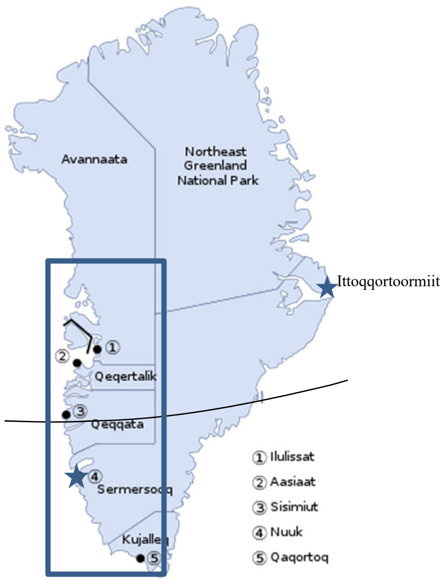
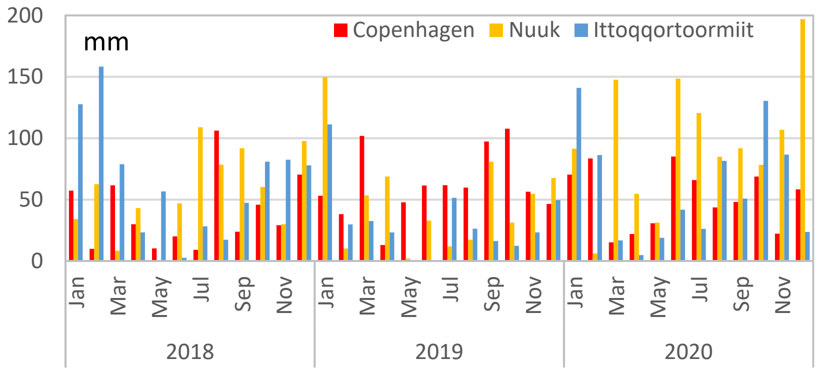
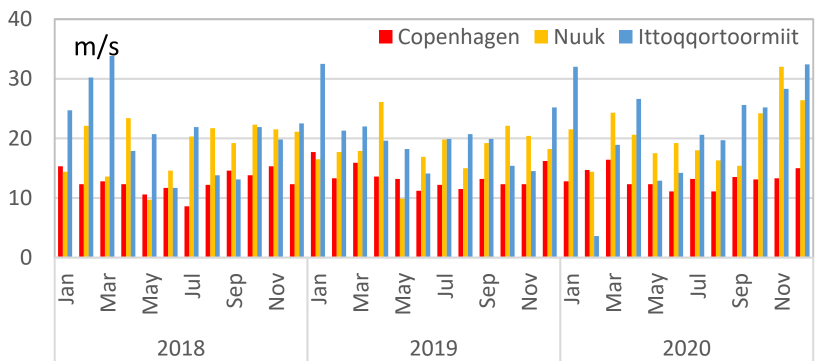


Figure 1. Map of Greenland. The map shows the five municipalities, the location of the main city in each municipality and the national park at north-east. The north-south oriented border between the national park and municipalities is located at 44th longitude. [1].
The Arctic Circle (at 66,7th degree of latitude) is added.
90 % of the population lives within the area marked with the box.
Stars mark cities in Greenland, for which weather data are shown at Figure 2; the capital city Nuuk at the West coast, with about 30 % of the population, and Ittoqqortoormiit at the East coast just north of the 70th degree of latitude. Although very few people lives at the East coast, Ittoqqortoormiit is chosen as the weather in this area is extreme, however still inhabited.



a)



b)

Figure 2. Precipitation [mm] (a) and wind speed [m/s] (10 minutes maximum) (b) in Copenhagen, Nuuk and Ittoqqortoormiit. Monthly average values for a 3-year period (Jan 2018 – Dec 2020) to illustrate variations. [2].

Section 2 compares how moisture in the construction phase is dealt with in building regulations in Greenland (GBR) [3] and Denmark (DBR) [4], as the content of GBR is inspired by DBR, based on what is regarded as relevant for Greenland. Further, it describes how constructions in Greenland differ from those in Denmark and how moisture is handled in the construction phase today in Denmark and Greenland. Section 3 and 4 presents the settings and results of a survey aimed at building professionals in Greenland to identify challenges related to moisture, discussed and concluded in section 5 and 6.

2. Moisture in the construction phase – regulations and practice in Greenland and Denmark

2.1. Handling of moisture in the building regulations

For many years, GBR and DBR have included general requirements concerning the design of the building envelope and the terrain around the building in regard to moisture. In GBR, simple guidelines are given directly at specific paragraphs, e.g. stating how wooden floor constructions above a crawl space can be safeguarded towards moisture related damage [3], which makes sense as long as a limited number of solutions are used in the building sector. DBR, being more function based, introduced requirements in 2008 stating that climate control measures, essential to the proper construction of a building, must be taken during planning, design, tendering and construction, and that building structures and materials should not, on moving in, have a moisture content that is liable to increase the risk of mould growth [5]. Not using unduly-moisture sensitive materials, allocating time for necessary drying out of building materials and structures, carrying out a cost-benefit analysis of the benefits of fully enclosing the building during construction, and the provision of shared facilities for storage of moisture-sensitive materials, were suggested as measures to comply to these requirements and are still part of the legislation. A specific guideline on handling of moisture in construction prepared in 2010, presented for each step in the building process, the basic decisions and the relevant documentation [6].

2.2. How moisture is dealt with in practice

As damage to buildings seen in Denmark tends with some delay to turn up in Greenland, it was suggested to prepare a similar guideline for Greenland [7], considering the particular local conditions, as building traditions in Greenland to some extent differ from the Danish. Roofs in Greenland are made with timber constructions and roofing felt, and external walls in multi-storey buildings are almost exclusively made as timber constructions mounted at in-situ casted concrete floors and inner walls (Figure 3) [8]. The use of timber constructions can be a challenge due to heavy wind and in-situ concrete requires time to dry out built-in moisture. Gypsum is widely used for internal walls, while brick masonry and aerated concrete, widely used in Denmark, e.g. for external walls, is hardly used in Greenland, regarded as much too expensive [9]. Apart from some larger dwellings constructed in 1960s and 1970s, now in need for renovation, prefabricated concrete elements are hardly used in Greenland, opposed to many years of use in Denmark. Today prefabrication in Greenland takes place on a small scale, however lack of lifting and transport capacity limits the use to larger cities at the West coast.

Figure 3. Multi-storey building with wood-based facades before and after installing wind barrier, and wood-based roof construction with roofing felt.

Figure 4. Windy conditions at building site during summer.

While weather protection gradually is becoming more used in Denmark, the windy climate and the costs related to scaffolding owing to the topography makes total enclosure of the building a challenge in Greenland. Even a simple cover can be a challenge (Figure 4). After closing the building envelope, and before installing thermal insulation, the building is heated by means of diesel generators to get rid of the built-in moisture as the natural drying potential in Greenland is quite limited; a time-saving but also expensive and not CO_2 friendly method.

As most buildings in Greenland are placed on sloping terrain, often directly on rock surface, crawl spaces are very common in Greenland, this also reduces the risk of flooding, and avoids a cold lower floor [10]. The crawl space is closed either by in-situ concrete (Figure 5a) or a wooden frame covered with boards of a non-organic material. In other cases, the building is supported as shown on Figure 5b and 5c. This allows for water and melting snow to pass below the building, which is relevant in areas with high rain load or a lot of snow.

Figure 5. Different ways to support buildings in Greenland, a) a closed in-situ casted concrete construction with openings for ventilation, b) a partly open concrete construction, c) a wooden construction, leaving the floor construction fully exposed.

3. Method
To collect updated and specific recommendations for the content of guidelines for the building sector in Greenland handling moisture, esp. in the construction phase, a survey was prepared together with a reference group with knowledge about Arctic building construction, aimed at building professionals in Greenland. The survey included both general questions to identify main challenges and whether they were located to specific geographical areas of Greenland or specific seasons, and questions about experience with specific solutions. The respondents were asked to give examples of solutions that do or do not work in Greenland. Some questions were with fixed possible answers, followed by the possibility to detail the feedback, giving examples etc. The survey was in late October 2020 sent to 110 contacts in Greenland representing consulting architects and engineers, contractors, clients, local and national authorities, and housing associations. Due to page constraints, only excerpts from the feedback are presented in this paper, focusing on some of the constructions that accentuates the challenges in Greenland, e.g. the terrain conditions (crawl spaces) and weather (two-step solution at façades).

4. Results
All categories that received the survey were represented in the respondents; 33 persons or 30 % of those invited filled in the survey completely, while 7 persons (6 %) filled it in partly. The largest groups among the respondents were clients, client consultants, consultants and contractors, however several respondents have had different functions during their career. 57% of the respondents had more than 20 years of experience from the Greenlandic building sector. Each of the five Greenlandic municipalities were represented by at least 15 respondents. As the municipalities covers large areas (cf. Figure 1) this does not indicate how many had experience e.g. from far north or the eastern part of Greenland, where the population is sparse.

4.1. Challenging issues and solutions that do or do not work
Table 1 and 2 list challenging issues and solutions that do work according to the survey feedback.

Table 1. Challenging issues.

Handling of building materials at site
Proper planning and project design
To choose suitable materials
Wood constructions installed when wet
Weather protection
A compressed time schedule
Water being pushed upwards between layers at facade
Lack of competences among craftsmen

Table 2. Solutions that do work.

Storage of materials in a closed container
Finish building envelope before doing interior finish, and finish roof before facades
Minimum number of protrusions and penetrations
Sufficient roof slope and overhangs
High quality wind barriers
Correctly placed vapour barrier
Ventilated roof constructions that keeps out drifting snow

Solutions that do *not* work were very much related to not having designed the construction towards the weather conditions, including high rain load (esp. in the southern part of Greenland) and heavy wind. In the case of wood-based facades, widely used in Greenland (Figures 3 and 4), it was pointed out that the cladding was often not sufficiently tight which means that the wind barrier became heavier exposed than expected. As an example, one of the respondents experienced wind barriers not being properly air tight, either due to the material itself or the joints. Cold wind could then enter further into the construction, eventually reach the vapour barrier and giving rise to condensation on the interior side. A vapour barrier was regarded by the respondents as vital to avoid moisture entering the building envelope and to avoid outward bound convection, lowering the effect of the installed insulation.

4.2. Limitations due to locations and seasons

Table 3 and 4 list major challenges related to locations and seasons. According to the survey, proper planning, ensuring that the building envelope is closed before autumn/winter, doing the interior work during winter, could make construction all year around possible.

Table 3. Challenges related to local conditions.

Major challenges	Location
Condensation and drifting snow	North of the Arctic Circle
Heavy and horizontal rain load, promoting mould growth	South of the Arctic Circle
High wind speed (piteraq). Need for long-term storage of building materials due to a limited number of ships arriving	East coast

Table 4. Challenges related to seasons.

Major challenges	Season/conditions
Sudden thaw, esp. in combination with snow at roof space	Spring
Heavy storms with wind driven rain	Autumn
Many freezing points; highlights need for proper storage and a design that ensures a smooth runoff of water	Spring and autumn
Ground work, casting of concrete, and work on exterior surfaces	At very low temperatures or high amounts of snow

Some respondents stated that when using organic materials, all seasons were a challenge. Increased use of pre-casted concrete elements (esp. in Nuuk) and sandwich panels (insulation material between two steel plates) were given as examples showing that construction has become less weather dependent.

4.3. Recommendations for crawl spaces

Despite specific Greenlandic guidelines on crawl spaces included in GBR [3], the survey confirmed that mould growth is regarded as a problem in crawl spaces, due to several causes: insufficient ventilation, storage of waste from the construction or placed by the occupants, ice that blocks openings in the walls close to the ground made to allow water and melting snow to run out of the crawl space, and the terrain containing cavities that can store water (Figure 6). GBR states that water entering the crawl space is not allowed to accumulate and that the terrain if needed have to be regulated to ensure that water is led to openings in the walls, further that ventilation of the crawl space can hinder moisture related damage in wood based floor constructions above the crawl space [3].

The respondents did not regard mould growth in the crawl space as a problem for the inhabited area of the building, provided some precautions were taken, listed in Table 5. Reducing the ventilation of the crawl space was not recommended, as a lower ventilation rate worsens the indoor environment due to moist air led from the crawl space into the living space.

Table 5. Recommendations for carrying out and using crawl spaces.

Sufficiently dry floor constructions before moving in
A sufficiently thermally insulated construction
That penetrations in the floor construction are made tight, using rubber gaskets
Not reducing ventilation of the crawl space as a way to avoid cold, not completely air tight floors
Use a thermal buoyancy from the crawl space (Figure 7) or keep the hatch to the crawl space open during summer as a way to increase ventilation.

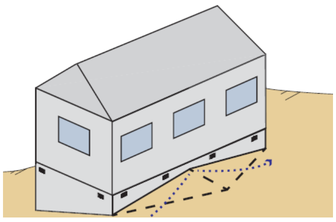


Figure 6. Principle for drainage on sloping terrain, avoiding water to be blocked at the crawl space [10].

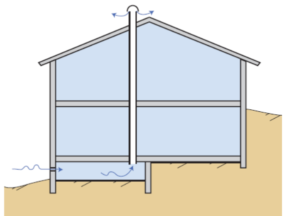


Figure 7. Use of thermal buoyancy to ventilate the crawl space where cross ventilation is not possible [10].

5. Discussion

When asked about solutions that do or do not work in Greenland, many aspects relating to design, production, storage, execution and use of buildings were mentioned, as experiences were very much related to locations and seasons and the respondent's background. Further, the survey showed that whether moisture in the construction phase becomes a problem or not, very much relates to the design of the building, which again relates to the available materials and the terrain, which promotes onsite construction, due to the infrastructure and limited lifting capacity in Greenland.

5.1. Content of guidelines

Table 6 lists suggestions for content of guidelines, often mentioned in the survey. Besides, building designers should know more about moisture and building physics in general.

Table 6. Suggestions for content of guidelines.

Best practice examples from Arctic countries with experience from moisture safe construction
To cover both planning and construction, dealing with troubles related to built-in moisture
How to store and protect building materials/elements at the building site (targeted at craftsmen)
How to accommodate to climate changes; resulting in larger parts of Greenland experiencing higher rain load and warmer, but more unstable weather
How users should handle fresh air inlets and crawl spaces

5.2. Learn from performance of existing building when designing new ones
It was highlighted to learn from the performance of existing buildings when designing new ones or preparing renovation. Buildings should to be kept as simple as possible, using the correct materials, to make the solutions as robust as possible, minimizing the risk for mistakes or damage at a later stage. This is not different from what is seen in other countries where exposure to wind driven rain need to be taken into consideration, however highlighted in Greenland due to the merciless conditions; weather, terrain, and infrastructure, making planning and design even more important. In a façade this is typically dealt with using a so-called two-step solution where an outermost rain shield acts as rain sealant, while an innermost wind barrier works as air sealant. The two layers are separated by a cavity ventilated from the outside through ventilation openings placed in the rain shield. The two-step tightening principle is illustrated in Figure 8. Most facades in Greenland today are built using this principle (Figure 9).

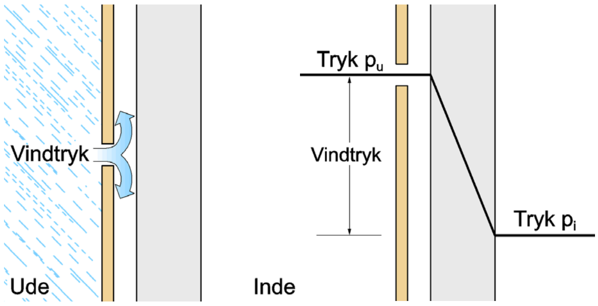


Figure 8. Two-step construction with an outermost rain shield and a wind tight part on the inside. Due to the openings, the pressure difference across the rain shield will be insignificant. Then, there is no pressure to force the water through the rain shield and across the cavity. The pressure reduction takes place across the wind tight part [11].

Figure 9. Facade before rain shield is installed showing the many joints that have to be sealed between fibre cement boards used as wind barrier.

5.3. Competences of craftsmen
Although the building physics is the same as in other countries, the consequences of not being careful at the building site are highlighted in Greenland, as shown by the example with the wind barrier not being sufficiently tight (Section 4.1). Solutions should never be more complex than possible to be executed by the craftsmen at hand, especially in North and East Greenland with few building professionals and most houses built for a cold, stable climate. This calls for simple guidelines, targeted at craftsmen. Lack of awareness/competence e.g. in performing (two-stage) joints or installing vapour barriers, not storing materials properly, makes guidelines highlighting this aspect even more important. Also when installing vapour barriers, competences could be improved according to respondents, as they are often not placed correctly when renovating a building, esp. in roof constructions, risking that they might work counteractive. Gradually, more focus has been put on correctly placed vapour barriers due to requirements of authorities, however many cases showed that execution is not done properly.

5.4. Simple guidelines targeted at specific building types
As Greenland consists of cities with more than 1000 inhabitants living in multi-storey buildings constructed as shown in Figure 3 and small villages with about 50-100 inhabitants mainly living in wooden houses (Figure 5a), guidelines targeted at the these two types of buildings might be the most important task to carry out. The results from this survey might not be surprising, but it has not been systematically documented at this scale before. At present, following the setup of GBR (Section 2), guidelines should be quite specific and explainable, however not too rigid as this risks to counteract innovation. This is considered more relevant to introduce than a complex guideline as the Danish [6] that even might not be used, as seems to be the case in Denmark.

6. Conclusion
A survey aimed at building professionals showed that the most challenging issues in relation to performing moisture safe construction in Greenland were handling of building materials and components at the building site, and to ensure proper planning and project design. It also showed that solutions that do not work were very much related to not having designed the construction towards the extreme weather conditions. The choice of solutions should match the competences of building designers and craftsmen. Further, the survey showed that specific, explainable, but not too rigid guidelines on how to design, construct and renovate the most common types of buildings are needed, targeted at Greenlandic conditions regarding climate and competences; a kind of best-practice on moisture safe construction. Guidelines should deal with challenges related to built-in moisture, but also pinpoint how to use and maintain the building.

Acknowledgements
This study is part of a project financed by the Self-Government of Greenland, developing guidelines for the Greenlandic Building Regulations.

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