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Concepts and type building for carbon neutral construction in arctic Finland based on tradition

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Abstract. This paper discusses traditional solutions for carbon neutral construction in arctic conditions. We consider that vernacular architecture forms an important source of knowledge to resource-wise, energy-efficient and sustainable ways to organize human dwellings and settlements. The key tasks of our research were to (1) identify the factors of traditional arctic construction that have an impact to sustainability and carbon-neutrality of arctic building and to (2) develop and assess a type building for arctic districts (Finland), based on traditional solutions, that fulfills the functional prerequisites for modern living comfort and energy requirements. The study is based on literature, fieldwork and Life Cycle Assessment calculations for the theoretical case. The life cycle assessment includes greenhouse gas emissions and carbon storage in timber and bio-based materials. Energy usage follows the principles of carbon neutrality. Wooden products used in the construction store biogenic carbon from the product stage to the building demolition stage. The case study calculations showed that operational energy demand could be fulfilled with the use of solar PV, solar collectors, ground source energy and district-scale wind energy supply. Results show that the biogenic carbon content is more than enough to offset the emissions from building materials and renewable energy technologies needed for operating the building. The research was funded by the Finnish Ministry for Foreign Affairs.

1. Introduction

Built environment and how it is constructed and maintained has a considerable effect on sustainable development. The task of this paper is to provide a research-based approach in order to understand how vernacular building materials and processes can be turned into modern innovations and solutions that could mitigate the energy consumption, use of resources and associated greenhouse gas emissions in future arctic construction. The central outcome is a case study building, where traditional materials and construction meet modern standards of living. The methodological novelty of the project was to bring together the approaches of architectural history and the Life Cycle Assessment methods to develop a concept that would be both sustainable and carbon neutral.

Tradition and vernacular architecture provide information on the local and global solutions that the arctic cultures have developed to adapt to the varying local climate and resources during thousands of years. Therefore, vernacular architecture contains a wealth of knowledge that can be applied to solve present-day problems of sustainability.

Despite the relatively numerous publications on vernacular architecture and sustainability, only an extremely small amount of research has concentrated on arctic buildings. [1] The harsh climate and scarce resources make the arctic the most challenging permanently populated region on earth. Thus,



traditional solutions of arctic building and living provide an illustrative example of adaptation, creativity and use of local and scarce resources also in the global perspective.

2. Methodology

The main goal of the research project was to develop a sustainable and carbon-neutral building concept, based on traditional solutions, for the Arctic region. Existing, preserved examples of buildings that have had a service life of centuries confirm the significance of tradition and vernacular architecture. They present a source of knowledge to structural and material innovations that can be evaluated and used in modern buildings.

Since the 1990's, a wealth of literature has addressed the issue of applying the principles of vernacular architecture to introduce sustainable solutions in contemporary building. Vernacular solutions are generally not easy to integrate into the processes of industrial technology. Traditional building techniques and dwellings are often appreciated as cultural heritage or in picturesque and historicized contexts, but seldom conceived as sources of innovation for modern construction.

Life cycle assessment, LCA, is based on a philosophy that considers all environmental impacts in a product's life cycle, from extraction of raw materials to disposal. This study follows the basic principles of life cycle assessment as defined by ISO. It focuses on the assessment principles of greenhouse gas emissions (kg CO₂e) and carbon storage (kg CO₂). However, together with developing recommendations for carbon neutral building in the arctic district, the study also considers the aspects of indoor environment and comfort and the building-related aspects of cultural heritage. The indoor climate conditions and the hourly operational energy consumption were modelled with dynamic simulations [3].

The method for assessing the environmental performance of the buildings is specified in EN 15978 [4]. The standard presents a system boundary for the building assessment, life cycle stages, data requirements and lists of indicators and indicator calculation methods.

3. The case study building

The case study building is a Finnish residential house designed for the arctic district. This building is used as a case to study alternatives to sustainable and carbon neutral building in cold climate.

The underlying philosophy of design stems from the traditional disposition of buildings in Arctic Finland. The case study building can be used to form individual units or village-like settlements, inspired by the historical constellations of villages in arctic Finland. In order to meet the target of carbon neutrality, the availability of local resources for building materials and local manufacturing is an important factor.

The main constructional solution, traditional log construction, has several advantages. First of all, standing examples show log construction has a structural service life of hundreds of years. Secondly, it is a local material that has no need for long transportation or complex processes of manufacturing.

Thirdly, log construction may improve indoor climate conditions [5]. Log also functions as a carbon sink, and it has versatile potential for reuse. As traditional examples show, log construction as a solid structure sustains well the arctic climate with large amounts of water, snow and ice. In addition, log construction enables innovative and modern architectural solutions and designing attractive modern dwellings.

The case study building was designed to fulfil 1) the requirements of carbon neutral building and 2) the standards of sustainable building materials and 3) the requirements for



long service life. For this reason, a modified version of the house was designed to compare the energy-efficiency of solid and insulated structures. The modified case study building with cellulose insulation and mechanical ventilation with heat recovery was designed to iterate a more energy-efficient solution.

The first case (called ‘TRADITIONAL’) was based on traditional material choices and natural ventilation. The second case (called ‘MODIFIED’) was designed for better energy-efficiency and better material efficiency. In the MODIFIED case, alternative materials were used in the iteration phase for reaching the carbon neutrality target. Both cases strive for normal comfortable indoor environment. We have also considered the energy performance gap [6], which means higher energy consumption in reality than in simulations in the case of HVAC.

The idea was to use a parametric approach to compare the two buildings in terms of carbon neutrality. The objective was to develop knowledge about the potentials of improved insulation, alternative renewable energy solutions and material choices, carbon storages and carbon sinks.

4. Results

In this assessment, TRAD. and MOD. buildings had a different structural efficiency for external walls (U-values). The indoor climate conditions were equal and the heating system was based on a ground source heat pump in both cases. Solar power was used as a local renewable energy source and during insufficient sunlight hours, the electricity was produced with a district level wind power system.

Table 1. Two simulated cases for the hourly average sizing of the grid capacity and greenhouse gas emissions (CO₂e).

Design solution	Electricity demand		Difference	Hourly electricity grid peak		Difference	GHGs for the life cycle phases A1-C4 ^{**)}	GHGs for the phase D ^{*)}
	kWh/a	kWh/m ² ,a		kW	W/m ²			
Traditional, PV & GSHP ^{*)} (A)	10 970	91,4	50 %	4,3	36	38 %	318	-29
Traditional, PV & GSHP ^{*)} (B)	10 970	91,4	50 %	4,3	36	38 %	-1007	-18
Modified, PV & GSHP ^{*)} (A)	7 300	60,8	0 %	3,1	26	0 %	458	-21
Modified, PV & GSHP ^{*)} (B)	7 300	60,8	0 %	3,1	26	0 %	-393	-14

^{*)} Both cases had the solar electricity (PV) and ground source heat pump (GSHP) as local renewable energy source

^{**)} Life cycle phases A1-C4 according to the EN 15978 standard [4]. GHG result including also embodied carbon content (calculated as CO₂).

The summary of the energy simulation results, and the sizing of the grid connection, and GHGs (including carbon storage) are presented in the Table 1. The TRADITIONAL building consumes about 50 % more electric energy than the MODIFIED building. It also needs 38% more capacity reservation in the wind power system than the MODIFIED building. The TRADITIONAL building case had higher operational electricity load mainly due to the lack of ventilation heat recovery and due to less insulation in the outside walls. In greenhouse gas assessments, both buildings have two end-of-life scenarios: Case A with incineration of bio-based material and Case B with extension of materials lives.

We have also considered the impact of additional factors (phase D) and we assume that:

- the use of renewable energy substitutes for energy produced otherwise (use of wind energy replaces other electricity production, use of solar energy replaces electricity production during the most favorable season (from April to the end of September))
- steel and aluminum content, salvaged from the demolition, replaced virgin material production

The results show that the biogenic carbon content of both buildings is more than enough to offset the emissions from building materials and renewable energy technologies needed for the building operation and in case when biogenic carbon storage is extended (phases A1-C4). Results also indicate that GHG emissions could be reduced beyond the building’s life cycle (phase D), because of energy types and materials substituted with sustainable alternatives.

5. Discussion and conclusions

As the arctic regions have, with a few exceptions, very limited infrastructure, the mitigation of the transportation costs may be achieved by using materials *sourced as locally as possible*. At the same time, *the low level of processing* and the question of *local processing technologies* of the building materials is important. Therefore, *resource-wise disposition of buildings and settlements* becomes an important issue of consideration.

Use of timber or processed wood products is beneficial, for their biogenic carbon content. Timber and especially logs were the dominant, and in vast regions, *the only* available building material in the Northern Europe until the second world war. In addition, log constructions are suitable for arctic climate: they are understandable, repairable and have a long service life.

The biogenic carbon acts as a ‘minus’ GWP in global warming potential calculations, if the wood is collected from a forest with an increasing carbon pool. This is the case for Finland. The biogenic carbon content of the production stage (A1-3) is released in the end of life (C4) stage, if the wooden material is incinerated after demolition. With reuse, the service life and carbon storage time of the wooden material is extended. Therefore, long service life of structures and circular economy are a key element in mitigating GHG emissions.

Another important issue in the arctic regions that is cleverly solved in traditional architecture, is *tolerance to temperature fluctuations and temporary abandonment*. Traditional architecture has also developed inventive solutions concerning *tolerance to water damage*, as well as *tolerance to the accumulation of snow and ice*, and the structural principles are worth considering in modern arctic building.

A key feature in traditional construction all over the globe is *understandable and conceivable structural solutions*. The maintenance of the buildings, also because of the limited infrastructure, should be feasible by the dwellers themselves to maximal extent.

It is essential to highlight the importance of the secondary use of building components. In the assessment, this was the most remarkable factor affecting the GHG emissions in both versions of the case study building. This means that there is a need to salvage components and materials from demolished building stock.

Arctic regions are a sparsely populated area with varying climatic conditions and natural resources. Universal solutions for carbon neutral and sustainable arctic building probably do not exist, but this study presents general guidelines that can be tested elsewhere. This requires researching traditional solutions and linking new design with the long history and the valuable information about how past generations have adapted to local climate conditions and local resources.

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