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Buildings In Artic Circle

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Abstract: This study deals with the comparative analysis of buildings build inside the Arctic Circle based on the climatic conditions on that particular region and the various materials, design methodology and challenges faced in those regions in Arctic Circle.

***Index Terms* - Comparative analysis, Arctic Circle, Climatic Conditions, Design methodology, Challenges.**

I. INTRODUCTION

In an exploration of the Arctic Circle, a realm defined by its extreme climate and unique human habitation, this collection of data provides a comprehensive overview of the region's population distribution, historical settlements, and geographical characteristics. With a focus on the communities that thrive within the Arctic's icy embrace, as well as the challenges posed by its harsh climate, this data sheds light on the intricacies of life in this remarkable and often challenging part of the world. From indigenous presence to climatic categorizations, this information offers valuable insights into the Arctic's past, present, and the strategies required to navigate its ever-freezing environment.

1.1 Human Habitation

Approximately 4 million individuals reside within the Arctic Circle, with indigenous peoples constituting around 10% of the region's population. Settlements in the Arctic have a long history, dating back thousands of years. The largest communities situated north of the Arctic Circle can be found in Sweden, Russia, and Norway, such as Murmansk (population 295,374), Tromsø (75,638), Norilsk (178,018), Vorkuta (58,133), Kiruna (22,841), and Rovaniemi (62,667) in Finland, located just south of the Arctic Circle by 6 km (4 miles). Notably, Salekhard (51,186) in Russia is the sole city situated directly on the Arctic Circle.

In contrast, the most populous North American community north of the Arctic Circle is Sisimiut in Greenland, home to approximately 5,000 inhabitants. In the United States, Utqiaġvik, Alaska, boasts the largest settlement with around 4,000 inhabitants, while Inuvik in Canada's Northwest Territories houses 3,200 residents.

1.2 Geography and Climate

The Arctic Circle spans about 15,933 km (9,904 miles) and covers an area of approximately 20 million square kilometers, constituting roughly 4% of Earth's surface. This latitudinal line traverses the Arctic Ocean, Greenland, North Asia, and the Scandinavian Peninsula. The Arctic climate is characterized by extreme cold, though the coast of Norway experiences milder conditions due to the Gulf Stream, which prevents ice formation throughout the year in northwest Russia and northern Norway. Temperatures in the Arctic can reach highs of 86 °F (30 °C) during summer and plummet to lows of −58 °F (−50 °C) in winter.

Considering the significant human presence in the Arctic and the increasing numbers of inhabitants, it is essential to find effective solutions to cope with the region's ever-freezing climate.

1.3 Classification of Areas

Based on Herbertson's Thermal Regions, a modified Koppen Classification, the ASHRAE definition of hot-humid climates, and average annual precipitation from the U.S. Department of Agriculture and Environment Canada, the Arctic regions can be classified into two primary cold regions: "Severe-Cold" and "Cold" regions.

1.3.1 Severe-Cold areas in Arctic Region (greater than 8,000 heating degree days)

Severe-cold climates, experiencing approximately 8,000 heating degree days or more, are prominent in the North and South Poles. While the North Pole is comparatively warmer than the South Pole due to its location at sea level amid an ocean, it still exhibits characteristics similar to a tundra climate, with temperatures slightly above freezing during July and August. The Polar region is dominated by permanent continental and sea ice, experiencing dense, cold air masses in both summer and winter. The low angle of the Sun's rays contributes to significant heat loss in the Arctic region.

1.3.2 Cold areas in Arctic Region (4,500-8,000 heating degree days)

Cold areas, defined by approximately 4,500 to 8,000 heating degree days, encompass lands in the southernmost part of the Arctic Circle, including parts of Norway, Sweden, Russia, Canada, Greenland, and the USA. While the climate in these regions is generally cold, coastal areas benefit from a milder climate thanks to the Gulf Stream, preventing year-round ice formation. Summers can be relatively warm, while winters are extremely cold, with locations like Norilsk, Russia, experiencing occasional temperatures as high as 30 °C (86 °F) during summer and frequent temperatures below −50 °C (−58 °F) in winter.

II. TYPES OF BUILDINGS

The design and construction of buildings in Arctic regions are highly influenced by the specific climatic conditions in each area, necessitating a careful examination of existing structures and future projects.

2.1 Buildings in Severe-Cold Areas (greater than 8,000 heating degree days)

2.1.1 Halley VI British Antarctic Research Station

2.1.1.1 Introduction

Halley, managed by the British Antarctic Survey (BAS), stands as the southernmost scientific research station on the 150-meter thick Brunt Ice Shelf. This ice shelf moves 400 meters annually towards the sea, making it a challenging location. With snow levels increasing by 1 meter each year and 105 consecutive days of winter darkness, Halley faces extreme temperatures as low as -56˚C and winds exceeding 160 kph. The station's access is limited to a 3-month summer period, and it has been continuously occupied since 1957. Notably, in 1985, researchers at Halley were the first to witness the formation of the ozone layer hole. Halley V was completed in 1992 but faced precarious occupation due to its drifting away from the mainland, posing a risk of calving as an iceberg. Consequently, in 2004, the BAS and the Royal Institute of British Architects (RIBA) organized an international competition to select designers for a new station.

Fig -1: Halley VI British Antarctic Research Station view.
https://hbarchitects.co.uk/halley-vi-british-antarctic-research-station

2.1.1.2 Environmental and logistic constraints

Addressing the harsh climate demands of the region, the construction and operation of the new station must adhere to the stringent requirements outlined in the Environmental Protocols of the Antarctic Treaty. Delivering materials presented a considerable challenge, as the ice shelf protrudes 20 meters above sea level, necessitating unloading onto fragile sea ice with a maximum bearing capacity of only 9.5 metric tons. The materials were then transported on skis and sledges across the area to the Brunt Ice Shelf using specially constructed snow ramps situated in natural creeks at the cliff-like edge of the ice shelf.

2.1.1.3 Design, materials and methods of construction

The design, materials, and construction methods of the new station comprise standardized blue modules housing bedrooms, laboratories, office areas, and energy centers. Additionally, a larger two-story light-filled red module serves as the social hub for living, dining, and recreation, with inspiring interior design aimed at sustaining the crew's morale during the extended dark winters and counteracting Seasonal Affective Disorder. Halley VI integrates medical operating facilities, air traffic control systems, and CHP power plants, functioning as a self-sufficient, infrastructure-free micro-community.

For optimal snow management and vehicle movement, the station is strategically arranged in a straight line perpendicular to the prevailing wind, allowing snowdrifts to accumulate on the leeward side and keeping the windward side free from drifts. The base is divided into two halves for life safety, with each half containing its energy center, ensuring self-sufficiency in emergencies. A bridge link facilitates power, drainage, and water sharing between the two halves.

The modules are supported on large steel skis and hydraulically driven legs, enabling the station to "climb" out of the snow every year. As the ice shelf moves towards the ocean, the modules can be lowered and towed by bulldozers further inland, and eventually dismantled when necessary.

Constructed with a steel framework and clad in highly insulated composite GRP panels, the modules were predominantly prefabricated within the limitations of the sea ice. Sourcing materials from various parts of the world, with pre-construction activities centered in South Africa, a full-scale trial erection of modules was conducted before shipping to Antarctica via an ice-strengthened cargo ship. The modules were assembled during three 12-week summer seasons using a factory line approach at Halley V, where they were fully clad before being relocated 15 km inland to the Halley VI site, successfully validating the relocation strategy.

Fig -2: Isometric view central module.
https://hbarchitects.co.uk/halley-vi-british-antarctic-research-station

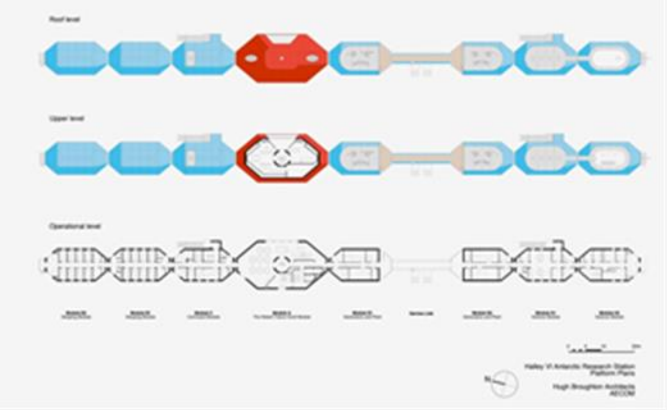

Fig -3: Halley VI Plans.
https://hbarchitects.co.uk/halley-vi-british-antarctic-research-station

2.1.2 Scott Base Redevelopment

2.1.2.1 Introduction

Located on Pram Point, Ross Island, Scott Base endures extreme winter temperatures below -40°C and experiences 24-hour darkness for around four months. Originally constructed for Sir Edmund Hillary's Trans-Antarctic Expedition in 1957, the base has continuously hosted a permanent presence in the Ross Dependency. However, many of the existing structures have reached the end of their lifespan. To address this, Antarctica New Zealand initiated the redevelopment of Scott Base in 2017, aiming to create a modern facility to support scientific endeavors for the next five decades.

Fig -4: Scott Base View – 1.
https://hbarchitects.co.uk/scott-base-redevelopment

2.1.2.2 Design, materials and methods of construction

The proposed design solution comprises three interconnected, aerodynamically shaped two-story buildings cascading down the hillside of Pram Point. To minimize snowdrift risk, the buildings are offset from each other and linked with enclosed passages. Elevated above the ground, the buildings encourage wind flow beneath, reducing snow accumulation.

The upper building serves as the primary entrance to Scott Base and houses living accommodations, including single and twin bedrooms, ablution blocks, and communal spaces. Capable of accommodating 100 individuals during summer and 15 during winter, the upper level also features a dining room with a panoramic view of Mount Erebus and Mount Terror. Meanwhile, the lower level contains essential facilities such as the medical suite, laundry, recreational spaces, food storage, shop, locker room, welcome lounge, and plant areas.

The middle building houses laboratories and offices on the upper level and offers open-plan deep-field science expedition preparation on the lower level, linked to field stores in the lower building.

Lastly, the lower building accommodates the vehicle workshop, inter-continental cargo handling area, waste management facilities, and central storage. Additionally, a small roof deck allows for unimpeded views required for certain scientific activities.

To create a warm and welcoming environment while minimizing maintenance, the interior design focuses on durable, comfortable, and aesthetically pleasing finishes. The architects strive to incorporate New Zealand's cultural and natural landscape elements, reflecting Māori values and the country's historical involvement in Antarctica. Furthermore, the strategic placement of windows enhances natural light and strengthens the connection with the Antarctic surroundings, promoting collaboration among occupants.

Fig -5: Scott Base View – 2.
https://hbarchitects.co.uk/scott-base-redevelopment

To reduce the base's environmental impact, the majority of its energy demands will be met through wind turbines as part of the Ross Island Wind Energy network. Electric boilers will provide heating, with fuel-powered generators used only in the absence of wind. Waste heat from the generators will be collected to help warm the base. Water will be produced via reverse osmosis, converting seawater into drinking water, while a vacuum drainage system will efficiently manage wastewater, saving water and energy. Critical services like water storage, power production, and communications will be duplicated throughout the base to maximize resilience.

2.2 Buildings in Cold Areas (4,500-8,000 heating degree days)

2.2.1 Introduction

Areas with 4,500 to 8,000 heating degree days experience less severe climatic impact compared to "severe-cold" regions. However, unique challenges must still be addressed when designing buildings in such environments.

2.2.2 Challenges and Recommendations in Design

One major challenge faced in these regions is frostbite prevention. Ensuring a proper vapor barrier, not just a vapor retarder, is essential, as even tiny air leaks can lead to significant frostbite issues. A comprehensive solution requires a "perfect" air and vapor barrier, involving fully adhered sheet membranes with all insulation placed externally. All services, such as wiring, plumbing, communications, and HVAC, should remain inside the membrane to prevent moisture infiltration.

When constructing on permafrost, it is crucial not to directly touch the ground, as heat from the building can melt the frozen ground and cause problems. Elevating the buildings with ventilated airspaces between them and the ground helps control heat loss. Using a "space frame" with adjustable piers provides an elegant foundation solution, thermally isolating the building from the ground.

Managing the roof and walls is equally important. The roof cladding should be at the same temperature as the exterior to prevent snow melting and refreezing, causing dangerous ice formations. Ventilated claddings and ventilation spaces under the roof and exterior wall cladding help compensate for flaws in the interior air and vapor barriers.

To avoid discomfort and excessive energy consumption when bringing in cold outside air, air-to-air heat exchangers are crucial for heat recovery and maintaining a comfortable indoor environment.

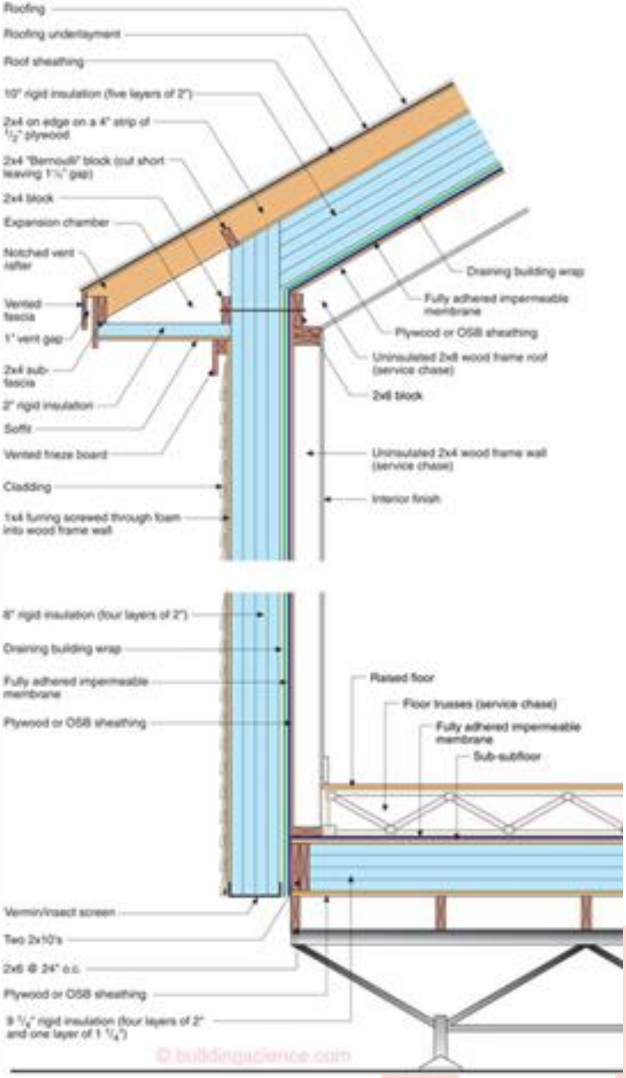

Fig -6: Building supported on space frame.
https://buildingscience.com/documents/insights/bsi-031-building-in-extreme-cold

III. CONCLUSIONS

When constructing a building in places with cold temperatures, it is important to understand the climatic conditions of the area and changes in execution of project should be implemented accordingly. Some generals' ideas for buildings in cold are use of right materials, securing the building such as to prevent the pathway of snow particles in the building, escape of heat during harsh temperature drops, managing the transport of construction materials and implementation of services in a specific manner.

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[10] All the arctic research station case studies were developed by the official documentation of the projects in Hugh Broughton Architects.

[11] Much of the fundamental research work demonstrated in the building constructed by the Hydaburg Tribe was published in the Building Science Corporation journal by Joseph Lstiburek and was developed under the U.S. Department of Energy’s Building America Program.