The Built Habitat in Polar and Circumpolar Environments: An Environmental Behavioural Approach of Design

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Introduction

The polar and circumpolar regions present a physical and social environment that greatly challenges human habitation. The challenges include not only the physical environmental conditions such as the hostile climate, high attitude, extreme light-dark cycle, low humidity and lack of sensory stimulation, but also social environmental conditions such as prolonged isolation from family and friends, confinement in small groups and lack of privacy. The harsh environment makes surviving in the polar and circumpolar regions no less difficult than surviving in undersea or space habitats.

Since the 1950s, several research stations have been constructed in polar and circumpolar regions to host scientists and their support personnel to conduct field studies in these regions. The duration of their stay in research stations varied from a few days to several months to entire polar winter seasons. Due to the extreme polar and circumpolar climatic conditions, the research stations often become a place of nearly total social isolation and physical confinement. As one of the principal resources to help users cope with the physical and social environment, the research station has not only to provide protection from the harsh physical environment, but also facilitate adaptation to the environment and maintain the well-being of its inhabitants.

Recently, the authors of this paper undertook, as principal members of a team, a project to develop a new research station at the summit of Greenland for the National Science Foundation of the United States. The station is to host scientists and their support personnel working on research projects at the site through winter seasons. The design process of the station started in October, 1996, and the construction of the station was completed in June 1997. It has been in use since July 1997.

Drawing from findings of literature studies and design process of the new station, as well as preliminary evaluations by its initial users shortly after it was built and occupied, this paper discusses two related subjects: (i) critical issues pertinent to the design of habitats in Isolated and Confined Environments (ICEs) in general; and (ii) design considerations of the new station at the summit of Greenland, in particular. The discussion builds upon a premise that appropriate design and management of the built environment can help facilitate human adaptation to the harsh and unforgiving polar and circumpolar conditions, and contribute to the psychological well-being of its occupants.

Critical Issues in the Design and Management of Built Habitats in ICEs

Many studies have been conducted since the late 1950s which identify physiological and psychological stresses unique to Isolated and Confined Environments (ICEs) under polar and circumpolar conditions (Rivolier et al, 1988; Taylor, 1987). The stresses include the hostile climate and physical danger (Offen, 1994; Palinkas, 1991; Suedfeld, 1991), deprivation of a variety of environmental sensory stimuli (Palinkas, 1991; Gunderson & Nelson, 1963), extreme light-dark cycle (Palinkas, 1991), lack of privacy and personal territory identification and control (Carrere & Evans, 1994; Suedfeld, 1991, Weybrew and Noddin, 1979), prolonged social isolation and confined small group (Cravalho, 1994; Suedfeld, 1991; Palinkas, 1991; Oakley, 1986; Natani and Shurley, 1979), and restricted mobility and outdoor recreational activity (Carrere & Evans, 1994). While some studies discovered positive psychological growth during the ICE experience as a result of appropriate personnel selection and training, high job morale, and unusual polar and circumpolar scenery (Mocellin & Suedfeld, 1991; Oliver, 1979), physiological and psychological stresses did cause many symptoms of stresses. Among them are feeling blue, feeling lonely, sleeping disturbances, feeling easily annoyed or irritated, feeling critical of others, feeling nervous or tense, inability to concentrate, feeling uneasy, over worried and concerned, depressed, visual distortion, debilitation of behaviour, severe anxiety, deepening sense of fatigue, disengagement from social contacts, and 'third quarter' declination in motivation and morale (Palinkas, 1991; Leon, 1991; Steel & Suedfeld, 1991; Ursin, 1991; Evans et al, 1988; Suedfeld, 1987; Gunderson, 1974).

Since the beginning of development of research stations in polar and circumpolar regions, the primary emphasis has been placed on providing necessary safety and survival protection to their users while meeting work requirements. However, both anecdotal reports and scientific studies of ICE design factors indicate that the built environment plays a major role in inhabitants' psychological well-being in ICEs (Carrere & Evans, 1994; Suedfeld, 1991). Many of the stresses associated with ICEs can be neutralised, and many symptoms resulting from living and working in ICEs can be alleviated, to a certain extent, by appropriate design and management of the built environment. There are consistent themes in the design recommendations developed from research on ICEs such as submarines, orbiting spacecraft, underwater habitats, and Antarctic research stations.

In fact, many stresses and stress symptoms associated with the extreme physical and social environmental conditions in polar and circumpolar regions have clear implications for the design and management of the built environment. For instance, the depression due to a lack of privacy can be alleviated through appropriate design and management to provide adequate private space and time. The sleeping disturbance due to the extreme light-dark cycle and exterior and interior noise can be reduced through lighting and acoustic designs. Many other symptoms and stresses can be reduced through appropriate design and management of the built habitat: the depression due to inadequate means of personalisation to one's individual space; the visual distortion due to deprivation of a variety of sensory environmental stimuli; the stress due to a lack of control over personal space, territory and interior ambient environment; the increased sensitivity to lighting, heating and acoustic conditions; the increased irritability and anxiety due to confined environmental conditions; the raised levels of concern about fire and weather safety due to limited means of protection; and the decreased environmental satisfaction due to reduced mobility and flexibility.

Extensive literature review and the design process of the new research station at the summit of Greenland suggest to us the following nine issues that are crucial to the design of built habitats in polar and circumpolar ICEs from an environmental behavioural perspective.

1. *Privacy*. Many studies have found that privacy by far constitutes one of the most important issues in the design of built habitats in ICEs (Carrere & Evans, 1994; Mocellin & Suedfeld, 1991; Taylor, 1987; Connors et al, 1985; Stuster, 1986; Gunderson, 1974). The physical confinement associated with ICEs heightens the need for privacy and for personal territory since there is much less opportunity to regulate one's interactions with other people in the research stations than in normal environmental settings. In fact, some early U. S. Navy studies on ICE habitability conclude that the longer the confinement, the greater the amount of individual space that should be provided (Celetano & Adams, 1960). The often enforced togetherness of small groups in isolated and confined environments makes it a necessity to gain a sense of autonomy, self-identity and an emotional release and retreating. The concept of privacy has a clear implication for the design of built habitats, as it is closely related to personal space and territoriality. When adequate space for personal needs, sleeping, working, and leisure activities, and means of identifying territory are provided for people living and working in ICEs, it helps enhance a sense of privacy. Otherwise, it can lead to low morale and fatigue, especially when lack of privacy lasts for extended periods of time (Carrere & Evans, 1994);
2. *Social Space*. While facilitating a need for privacy is of extreme importance in the design and management of built habitats in ICEs, providing space for social activities also affects the well-being of its inhabitants greatly. It was noted in several studies that shared common spaces in the built habitat in ICEs often became a highly used place (Lugg, 1974). For instance, in their study of behaviour of the winter-over crew at the Palmer Station, Antarctica, Carrere and Evans (1994) found that people spent about 35-40% of their waking hours in the dining room and pub/lounge. Socialising with other people in the pub/lounge accounted for a majority of the hours (55%) spent in it. It was also frequently used for other personal solitary activities, as an alternative to one's own bedroom. A provision of social space and its appropriate design and management can help promote socialising activity, which can, in turn, help reduce the social alienation often found in mid-winter among people staying in polar stations (Leon, 1991);

3. *Separation Between Private and Public as Well as Spaces of Distinct Functions.* While providing private and public space is important to the well-being of people living and working in polar and circumpolar ICEs, appropriate separation between private and public space is also necessary. The separation involves three aspects: spatial separation in terms of physical and/or perceived distance and barrier; visual separation in terms of views; and acoustic separation in terms of sound intrusion and acoustic privacy. Because of the complete isolation and confinement, the station structure often becomes the only built environment where people live and work. Appropriate separation between the public and private has to be optimally maintained in the design of built habitats in polar and circumpolar regions to ensure the well-being of its inhabitants;
4. *Flexibility in Interior Environments.* Flexible interior environments that permit changes in the arrangement of furniture, colour schemes, lighting, and so on are believed to be important design elements in ICEs (Connors et al, 1985; Stuster, 1986). This is especially true for those stations that host people for extended periods of time in isolation and confinement. One of the most serious challenges associated with ICEs is the monotony of their visual environments, and the lack of changes in sensory stimulation. Due to the extreme physical confinement and impoverished means and resources available, living and working in polar and circumpolar stations of ICEs means a deprivation of changes in one's physical environment. Flexibility helps human adaptation to ICEs as it facilitates a reduction in adverse effects of the 'sameness of environment' that is often associated with ICEs (Strange & Klein, 1974). Ability to change or modify one's physical surroundings is part of human environmental behaviour that often results in an increase in satisfaction, well-being and productivity. In fact, monotonous interiors and non-flexible objects and elements in ICEs are believed to contribute to dulling minds and subsequently adversely affecting people's morale (Berry, 1973);
5. *Means of Personalisation.* As one of the key behavioural mechanisms by which human beings interact with their environment, personalisation is used to achieve a level of satisfaction and psychological well-being. This is especially true in cases in which the environment and habitat is not favourable or ideal. The personalisation of territories becomes a more important issue when that territory is going to be a long-standing part of a person's life (McAndrew, 1993). The ability to personalise one's space and its significance has been noted by ICE researchers and inhabitants (Stuster, 1986; Huntford, 1987). For instance, submariners invariably decorate their space with personal items such as photos and memorabilia (Suster, 1986). Crew members of the Tektite and Skylab also decorated the interior public and private space within spacecrafts;
6. *Noise.* Noise conditions within built habitats in polar and circumpolar ICEs affect two aspects of human well-being: sleeping disturbance (Potter et al, 1998) and acoustic privacy (McAndrew, 1987). Noise in built habitats in polar and circumpolar ICEs usually comes from two sources: high speed wind and interior human activity and machinery. While living in polar and circumpolar regions enjoys a void of urban traffic noise, sustained high speed wind is not uncommon in these regions. Furthermore, due to the fact that many of the built habitats in the regions are spatially cramped and physically limited, and are occupied around the clock, human activity and machinery can become a significant source of internal noise.

What makes noise even more an issue is the fact that prolonged stays in ICEs often result in increased sensitivity to physical and social stimuli (Natani & Shurley, 1974). Living in complete isolation and confinement for an extended period of time may result in less tolerance to undesirable outside physical stimuli, of which noise is certainly one. Intrusion of unwanted sound from neighbouring rooms and common spaces could lead to serious stress when the problem persists (McAndrew, 1993). Sound-proofed, multi-functional personal spaces for sleeping and other individual uses is a necessity for personal refuge (Carrere & Evans, 1994);

7. *Lighting*. The extreme light-dark cycle in polar and circumpolar regions makes lighting design for the built habitat one of the most critical issues. In fact, the prolonged daylight of mid-summer in polar and circumpolar regions often becomes one of the major sources of serious sleeping disturbance for many (Suedfeld, 1987; Edholm & Gunderson, 1974; Strange & Klein, 1974; Gunderson et al, 1963). On the other hand, the constant darkness of mid-winter in the regions can also cause stress. It was observed that a high level of light inside the dome at South Pole Station during the isolation period tended to decrease the stress and increase the morale of the crew (McAndrew, 1987). The extreme light-dark cycle results in the loss of a sense of time. To alleviate the adverse impact of the extreme outdoor lighting condition on its inhabitants, special considerations have to be given to the design of windows and interior lighting for the built habitat in polar and circumpolar regions;
8. *Visual Stimuli*. Living in ICEs in polar and circumpolar regions inevitably results in the problem of sensory deprivation, or monotony in visual environmental stimuli (Strange & Klein, 1974; Gunderson, 1963). It was reported that the visual monotony of the Skylab colour scheme disturbed the astronauts and that Apollo astronauts disliked the monotony of the visual interior of their space capsule (Berry, 1973). For polar and circumpolar regions, the absence of a landscape with the green colour of plants is significant (Natani & Shurley, 1974). In addition to the complete isolation and confinement of the built habitat in these regions, inhabitants often have to endure a landscape of complete 'white-out'. In fact, a study by Taylor (1974) found that one of the principal initial impressions, feelings and sensations and experiences of winter-over people on returning home is the 'increased sensitivity to sights and colours'. The increased sensitivity is related to extended deprivation of colours while wintering-over at Antarctica;
9. *Perception of Safety*. The safety of human beings and physical properties has always been of the utmost importance in designing the built habitat in polar and circumpolar regions. To withstand the extreme climatic and weather conditions, many design and construction criteria have been developed for the built habitat in the regions. So far, there have been few reports of major failures or problems associated with design of the built habitats. The complete isolation and the lack of emergency rescue resources available in polar and circumpolar ICEs often causes a raised concern about weather and fire safety in the minds of its inhabitants, or a concern for safety (Yan et al, 1998). While some training in fire prevention will help reduce the level of concern, additional special considerations in the design of built habitats would also further ease the minds of inhabitants with regard to the perception of fire and weather safety.

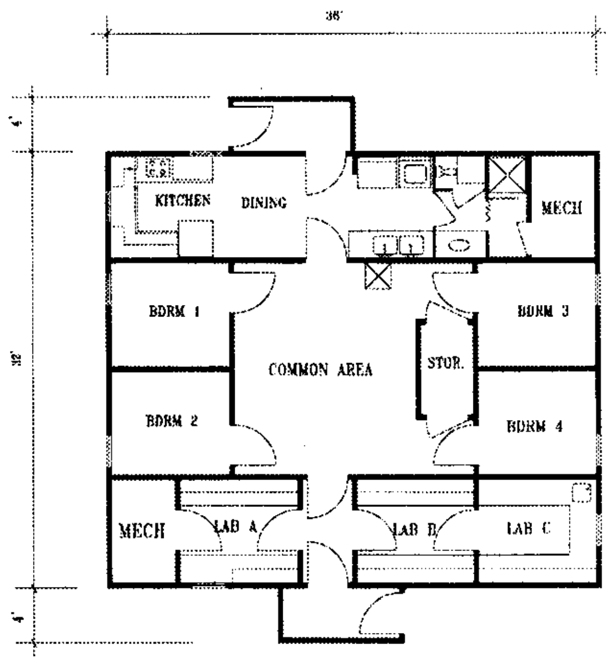

Figure 1: *Floorplan of the Station*

The New Greenland Summit Station: A Case Study

The new winter-over station is part of the Summit Camp at the summit of the Greenland ice sheet operated by the Polar Ice Coring Office of the University of Nebraska-Lincoln for the Office of Polar Programs of the U. S. National Science Foundation. It is located on a flat, white and almost featureless plateau, at latitude 72°34' N and longitude 38°28' W. The altitude at the location is approximately 10,600 feet (3,230 metres) above sea level. The logistical base of support is a coastal airport at Kangerlussuaq, Greenland, located approximately 450 miles (724 kilometres) to the Southwest. The winter temperatures can stay at -50° F (-45° C) for extended periods of time during the winter months with extremes recorded below -85° F (-65° C). Winds have been recorded above 40 knots. The annual snow accumulation averages 2.3-2.6 feet (70-80 cm). The project site is only accessible by ski-equipped aircraft.

The new station provides a semi-permanent, air-transportable living and working space at the camp to be used in 'winter' seasons to support science projects at the summit from August through April. The structure is made of two stand-alone modules, one as a kitchen/bath unit, and the other a lab unit. The two modules were pre-fabricated and pre-assembled, and transported in their entirety to the site using ski-equipped aircrafts. The kitchen/bath module is equipped with a shower place, a water closet, a lavatory, fixed base cabinets and cupboards and appliances such as a refrigerator, an electric stove, a microwave, a dishwasher, a garbage compactor, a washing machine and a dryer. The lab module has three work areas with base cabinets and adjustable shelves. The communication centre of the station is also located in the

Figure 2: *Exterior View of the Station*

lab module. There are two Arctic entries, one to the kitchen/bath module, and the other to the lab module. The Arctic entries provide not only a buffer zone of temperature differences between the inside and the outside, but also a space for putting up, or taking down, bulky winter clothes. The middle part of the structure is made up of pre-fabricated panels that were assembled on the site. It contains four bedrooms, a common area and a storage room. To minimise on-site assemblage of the central part, and to be flexible for a possible expansion and/or re-arrangement in the future, the middle part has no mechanical ducts and electrical wires. Supply of air and electricity to the central part is furnished through diffusers and outlets mounted on side walls of the two modules. Figures 1 and 2 illustrate the floor plan and an exterior view of the station respectively.

The design of the new winter-over station had many constraints such as materials, construction methods and cost. It also encountered much stricter requirements for air transportability. Working within the constraints, however, the design was developed with a conviction that appropriate design and management of the built habitat in polar and circumpolar ICEs would help facilitate human adaptation to the extreme environment. The built environment of the station can play a significant role in helping alleviate adverse effects of the ICEs on inhabitants when living and working for an extended period of time. The station has been in use since the end of June, 1997. An informal exit survey of the initial ten occupants of the station was conducted. The preliminary results indicate that overall the station seemed to be fairly well evaluated by the users, although much is yet to be discovered. It should be noted the survey is informal and very preliminary. It was conducted shortly after the station was built and occupied. An extensive post-occupancy evaluation (POE) of the station has been planned for its first year in commission. It will conduct a longitudinal survey of its winter-over users throughout the "winter" season from August till April. The study aims to find out to what extent design and use of the summit station in particular, and the built habitat in ICEs in general affect users' well-being. It is the hope of the authors that results of the POE study will further the discussion of the criteria for design and management of the built habitat in polar and circumpolar ICEs.

The following reports some design considerations of the new station addressing the built habitat in ICEs from an environmental behavioural perspective. It also includes preliminary evaluations by its initial users as well as informal observations by the authors of this paper during their visits to the station at the end of June and the early August shortly after it was built and occupied.

One of the most noteworthy design considerations is the provision of a common area in the station. Although the station is small and every square foot of its interior space is precious and needed for various functions, a relatively sizeable common area is provided to serve as a multi-functional space for social and other activities. Provision of this common area was due, in part, to the consideration that a shared space in ICEs is important. Results from the exit survey indicates that the provision of a common space is indeed liked by almost all initial users of the station.

As privacy is another important factor that affects well-being of inhabitants in ICEs, the station provides individual rooms for each occupant. In addition, in view of the fact that wintering-over at the station may last for as long as nine months, and based on the suggestion that the longer the confinement, the greater the amount of individual space should be provided, each of the bedrooms has a net space of about 65 square feet (6 square metres). The size is much larger than the minimum size suggested by some studies (GDM, 1988). In addition, sound proof insulation walls and solid core wood doors are used for the bedrooms as a way to improve acoustic privacy.

To help facilitate the flexibility of the interior environment, which is considered to be a highly desirable feature of built habitats in ICEs, the bedrooms do not use any wall-mounted furniture. By doing so, it offers the possibility of being re-arranged by their occupants as part of personalisation from time to time during their stay at the station. The preliminary observation by the authors revealed that some activities of personalisation had already taken place as soon as the building was occupied. Some occupants took advantage of the flexibility in furniture re-arrangement, while others constructed shelves in their own bedrooms.

The separation between various functions of spaces, and between the public and private is facilitated in several ways. For instance, the station is made up of three distinct zones: the kitchen and bathing/laundry unit, the lab unit and the berthing area with clear demarcation between them. Using different types of doors, ceiling heights and furniture, it attempts to help create different perceptions of the spaces which in turns could enhance a psychological feeling of separation and distinction. Similarly, being in its own module, the lab/communication centre becomes fairly well separated from the living and the kitchen functions both physically and perceptually. As such, it helps facilitate research functions of the station to meet work requirements, and create a perceptual distinction between work and living environment.

To safeguard its occupants against dangers of weather, fire and other hazards such as oxygen depletion, the station is fully equipped with required smoke and CO detectors, fire extinguishers and emergency exit lights. In addition, to help further ease the concern for safety, the design of the new station has adopted five concepts for personnel safety. First, the heating and air circulation is supplied by two completely independent units located on two opposite ends of the station so that if one fails, the other can continue providing emergency heating and air supply. Second, an auxiliary heating system is also available to provide emergency heating if both of the heating systems would fail at the same time. Third, the two Arctic entries face in opposite directions so that in case of severe snow drifting, one of the two is likely to have a lesser problem. Fourth, all windows are operable for additional emergency exits from bedrooms, kitchen and lab unit. Finally, the kitchen and lab units are equipped with a roof hatch for exit upwards to further reduce danger of severe snow drifting which could bury the station over-night.

Due to the constraints of air transportation, the lab and kitchen modules have a low floor-to-ceiling height of 74" (1.88 meter). To help alleviate potential adverse effects of the low ceiling on perception of the interior space, the middle part, which was constructed on site with pre-fabricated panels, has a raised ceiling of 94" (2.39 metres) above the finished floor. According to the authors' informal interviews with the initial users, the raised ceiling height in the common area was noticed by many, and appreciated by all of the users.

The design for natural lighting includes one window of 30" x 36" (76cm x 91cm) for each bedroom and windows of 18" x 24" (46cm x 61cm) throughout the lab and kitchen modules. The common area which is surrounded by bedrooms and the two modules have a skylight. Fluorescent lights in groups of four are used as artificial lighting which provides a condition simulating the natural daylighting during the mid winter when it is dark and no direct sunlight is available. The abundance of windows not only helps lighting design for its interior, but also provides views to the outside that can help improve the visual environmental quality.

The exterior and part of the interior of the station has bluish green paint. The green colour makes a good contrast to its 'white-out' surrounding so that it can be more noticeable when visibility is poor during storming days. It also helps add a green colour to the visual stimuli, which, according to some early studies, is one of the colours that are common in normal visual environment, but are often deprived in polar and circumpolar regions.

Conclusion

Extreme environmental and social conditions in polar and circumpolar regions present great challenges to human beings living and working there. The conditions are much harsher and the challenge is much greater for those who spend extended periods of time at remote stations in isolated and confined environments (ICEs). The station facilities often become the only built environment available to alleviate the harshness of the natural environment and to assure the users' well-being. While high task motivation and unusual scenic landscapes help humans adapt to the harsh conditions, appropriate design and management of the stations can play a significant role in reducing stress and the adverse effects of ICEs on human well-being. Based on extensive study of the literature, and experience learned through the design of a new winter-over station at the summit in Greenland, this paper concludes with nine issues that should be appropriately addressed in the design and evaluation of similar stations in polar and circumpolar regions in the future. The nine issues are: privacy, social space, separation between private and public and spaces of distinct functions, flexibility in interior environment, means of personalisation, noise, lighting, visual stimuli, and perception of safety. Considerations in designing built habitats in ICEs with regard to these issues will help make the habitat more than merely a survival protection. It can help ease the adaptation process, alleviate stresses associated with polar and circumpolar ICEs, maintain a higher level of well-being among its inhabitants, and subsequently improve work performance and productivity.

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