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Environmental factors influencing microbial growth inside the historic expedition huts of Ross Island, Antarctica

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Abstract

Explorers to Antarctica during the Heroic Era of exploration built three wooden huts on Ross Island, Antarctica in 1902, 1908 and 1911. The structures were used as bases of operation while their occupants participated in scientific endeavors and strived to reach the South Pole. The huts, and the thousands of artifacts in and around them, have survived in the Antarctic environment for 9–10 decades, but deterioration has taken place. The successful preservation of these important historic structures and materials requires information on the agents causing deterioration and factors that influence microbial growth. Temperature and relative humidity (RH) were monitored in the expedition huts for several years. During the austral summer months of December and January it was common for temperatures to rise above 0 °C and RH to exceed 80%. Extensive fungal growth was observed on wood and artifacts within the Cape Evans hut, and fungi isolated were identified as species of *Cladosporium*, *Penicillium*, *Cadophora*, *Geomyces* and *Hormonema*. The factors that influence RH within the huts and methods to control moisture and arrest microbial growth are discussed.

Keywords: Antarctica; Historic huts; Relative humidity; Temperature; Fungi

1. Introduction

During the Heroic Era of exploration, three huts were built on Ross Island, Antarctica. The huts served as bases for the expeditions of Ernest Shackleton and Robert F. Scott to explore the continent, carry out scientific investigations and to be the first to reach the South Pole. The structures housed men, supplies and food for several years during their endeavors. Robert Scott led the National Antarctic Expedition (1901–1904) and built *Discovery* hut in 1902 at Hut Point, which was also used by others in later expeditions. In 1908, Ernest Shackleton's British Antarctic Expedition built a relatively small hut adjacent to a penguin rookery at Cape Royds. Scott returned to Antarctica in 1911 leading the British Antarctic Expedition (1910–1913) and built another hut at Cape Evans in 1911. Thousands of artifacts were left in and around the huts as expedition members hastily left the Antarctic when relief ships arrived. Although the cold, dry Antarctic environment has aided preservation of the huts to a greater extent than if they were located in a more temperate climate, considerable deterioration has occurred over the past decades (Blanchette et al., 2002; Held et al., 2003). Fungi have been observed growing within the huts on wood, textiles and other artifacts. Fungi are dependent on moisture, and relative humidity above 80% is usually sufficient for mold growth to occur on wood (Pasanen et al., 1992). A preliminary study by Mason (1999) in the Cape Evans hut indicated that relative humidity is high within the historic structure and cultural properties cannot be effectively preserved in these conditions.

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Conditions that favor fungal growth appear similar to those occurring at other historic huts in Antarctica, such as Borchgrevink's hut at Cape Adare where molds have been found growing in the hut (Antarctic Heritage Trust, 2004) and Mawson's hut at Cape Denison, where RH above 95% is common making fungal growth a problem (Hughes, 1988). Increased visitation by tourists and their impact on raising relative humidity inside the huts have also been of concern (Hughes, 1992; Mason, 1999). Decay fungi that cause soft rot have been identified in exterior woods of the huts but little to nothing is known about the fungi growing within the huts on wood and other historic materials (Blanchette et al., 2004; Held et al., 2003).

This investigation was done to monitor relative humidity and temperature in Scott's hut at Hut Point (*Discovery* Hut), Shackleton's hut at Cape Royds and Scott's hut at Cape Evans and to determine what influence these environmental factors have on fungal growth within the huts and on artifacts. Fungi were isolated and identified from areas within the Cape Evans hut where extensive fungal growth was observed.

2. Materials and methods

Two Hobo® H8 Pro data loggers were placed in each of the historic huts at Cape Royds, Cape Evans and at Hut Point in December 1999 to record temperature and relative humidity. Three additional data loggers were placed in the huts at Cape Royds and Cape Evans and two additional data loggers within the hut at Hut Point in December 2000. One data logger was placed outside of Cape Evans hut in the historic meteorological station in 2000 but this data logger recorded only intermittent data due to its exposure to the extreme Antarctic environment. Locations of the data loggers at Cape Evans hut included (1) on a shelf near the entrance (galley/mess area) approximately 2.0 m from the floor, (2) near the center of the hut among food stores approximately 1.7 m from the floor, (3) under a bunk approximately 0.5 m from the floor, (4) in the darkroom near the ceiling approximately 2.2 m from the floor and (5) in the stables on a crate approximately 0.2 m from the ground. At Cape Royds hut they were located (1) on a shelf on the north wall approximately 2 m from the floor, (2) on the floor under a bunk directly below the logger on the north wall shelf, (3) on the floor among crates along the south wall adjacent to the galley, (4) 2.3 m from the floor on top of Shackleton's room near the entrance, (5) on a shelf in Shackleton's room 1.6 m from the floor. Hut point locations were (1) on the floor in the center of the hut behind crates, (2) along the east wall among boxes of stores approximately 0.2 m from the floor, (3) in the stove pipe hole in the false ceiling above the stove 2.0 m from the floor, (4) on a shelf in the physical laboratory approximately 1.6 m from the floor. All data loggers recorded temperature and relative humidity and had a sampling interval of one hour throughout the year. Data was downloaded from the loggers each year in the Austral summer during field visits to the huts. Boxcar® Pro 4.3 and Microsoft Excel software were used to analyze the data. The data collection period was from December 1999 to January 2003.

Samples of wood taken for fungal isolation (under Antarctic Conservation Act permits #2001-015, 2002-001 and 2004-019) were carefully removed from inconspicuous locations in the huts and placed in sterile sample bags. Sterile swabs were used to wipe the surface of wood where it was not possible to take a wood sample. Samples were kept frozen until isolations were made in the laboratory. Fungi were isolated by incubating small wood segments or wiping swabs on culture medium. Several types of culturing media were used for isolation of microorganisms including malt yeast agar (MYA) containing Difco malt extract 1.5%, yeast extract 0.2%, agar 1.5%, MYA with antibiotics added (chloramphenicol 0.2 g, streptomycin sulphate 0.1 g), MYA with antibiotics and cycloheximide (chloramphenicol 0.2 g, streptomycin sulphate 0.1 g, cycloheximide 0.4 g), a semi-selective media for basidiomycetes (malt extract 1.5%, yeast extract 0.2%, agar 1.8%, chloramphenicol 0.2 g, benlate 0.06 g, streptomycin sulphate 0.1g) (Worrall, 1991) and Vogel Bonner media, (glucose 25%, agar 2.0%, 20 ml VB concentrate containing 670 ml distilled water, K_2HPO_4· anhydrous 50%, $NaNH_4PO_4 \cdot 4PH_2O$ 17.5%, citric acid $\cdot H_2O$ 10%, $MGSO_4 \cdot 4H_2O$ 1%) (Vogel and Bonner, 1956). Plates were incubated at 4, 15 and 25 °C and pure cultures were transferred to separate plates for identification. Fungi were identified using taxonomic literature for these genera and analysis of rDNA internal transcribed spacer (ITS) sequences. DNA was extracted from cultures using Qiagen DNeasy Plant Mini-kits using manufacturer's instructions. The ITS sequences were amplified by PCR using primers ITS1 and ITS4 (Gardes and Bruns, 1993). PCR amplification was performed using Amplitaq Gold PCR Master-mix following manufacturer's instructions (Applied Biosystems) with 1 μl DNA. PCRs were performed in a MJ Research PTC Mini-cycler. PCR conditions were as follows: 94 °C for 5 minutes; 35 cycles of 94 °C for 1 min, 50 °C for 1 min, 72 °C for 1 min followed by a final extension step of 72 °C for 5 min. After visualization of amplicons on ethidium-bromide stained 1% agarose gels, the amplicons were purified using EXO-SAP (exonuclease-shrimp alkaline phosphatase) PCR product cleanup systems (USB Corporation). Sequencing reactions were performed using both primers using the ABI PRISM Dye Terminator Cycle Sequencing Ready reaction kit (Applied Biosystems) and an ABI Prism 377 automated

DNA sequencer. DNA sequence data were assembled into contigs using Chromas software (Technelysium Ltd.) and the Emboss pairwise alignment algorithm (www.ebi.ac.uk/emboss/align/). The sequences were compared to those present in GenBank using BLAST and the best match was recorded.

3. Results

3.1. Cape Evans

Relative humidity within Scott's hut at Cape Evans was typically above 80% and sometimes above 90% in the austral summer months of December and January. Temperatures above 0 °C were common and reached as high as 9.4 °C within the hut during the monitoring period. Fig. 1 shows RH and temperature data over a three year period from a single data logger located in the center of the hut at approximately 1.7 m from the floor. Relative humidity averaged 74.6% for the 3 years with a maximum and minimum of 87.3% and 59%, respectively. The average temperature was −14.7 °C and the maximum and minimum were 9.4 and −35.1 °C, respectively, over 3 years. Data collected over a 4 week period during the austral summer, December 23, 2001–January 20, 2002, from a data logger placed in the galley near the inner hut entrance is shown in Fig. 2. The average RH and temperature for this period was 82.7% and 3.7 °C, respectively, and the maximum RH observed was 93.1% with a temperature range of −1.5 to 7.8 °C. The data logger placed in the stables area of the hut recorded relatively high RH over the same period of data collection. The average RH for that

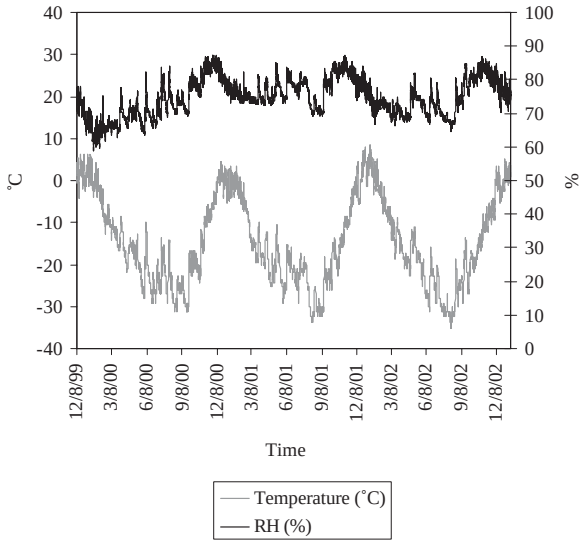

Fig. 1. Temperature and RH in Cape Evans hut over a three year period obtained from a data logger located in the middle of the hut, 1.7 m above the floor.

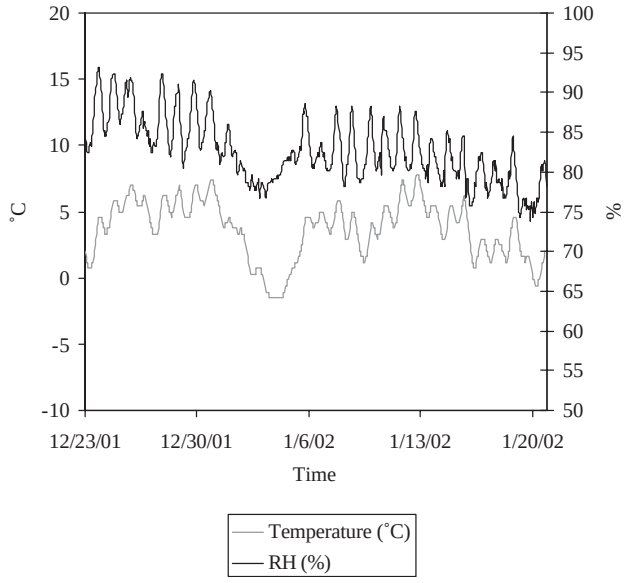

Fig. 2. Temperature and RH in Cape Evans hut over a four week period during the austral summer months of December and January.

period was 81% and the maximum and minimum was 93% and 64%, respectively, as compared to the average of 76.4% obtained from a data logger located near the center of the main hut.

Isolations were made from swabs taken from wood surfaces in the galley area of the hut where extensive mold growth was found. The fungi identified are listed in Table 1. The sequence from one particular fungus that was isolated infrequently did not match well with any presently in GenBank, and has remained unidentified. Mold growth was visually evident on a number of artifacts made of wood, leather and textiles in several areas. In the galley, extensive mold growth was observed in areas between wooden supply crates (Fig. 3), on the legs and underside of a table and on the lower portion of the south hut wall. The affected area also extends to an area of crates adjacent to bunk beds along the south wall. Moisture in this area appears to originate from frost that occurs on the wall in the galley (Fig. 4). This is likely due to the snow and ice that accumulates on the hut exterior (Fig. 5) causing the south wall to be colder than surrounding temperature in the hut. The high RH inside the hut and the temperature differential allows condensation to occur and frost builds up on the wall. As the temperatures rise in the hut, the melting of the frost and the presumably higher RH in this area provides sufficient moisture for fungi to grow prolifically.

To determine the duration of an environment inside the huts that may be conducive to mold growth, the number of hours per year in 2000 through 2002 in which the temperature was above 0 ° and RH was at or above 80% was calculated for each data logger and is displayed in Table 2. Although some differences were

Table 1
Fungi identified from wood located along the south wall in the galley area of Cape Evans hut

Isolate number	Location	Species identification
182	Wall at lower bunk	*Cadophora malorum*
711	Wall at lower bunk	*Geomyces* sp.
262	Wall at lower bunk	Unknown
487	Wall behind table, galley	*Cladosporium cladosporioides*
517	Wall behind table, galley	*Cadophora malorum*
660	Wall behind table, galley	*Cladosporium cladosporioides*
719	Wall behind bed frame, galley	*Cladosporium cladosporioides*
723	Wall near floor under bed frame, galley	*Penicillium echinulatum*
537	Near floor 1st box west of 1st bunk	*Penicillium expansum*
814	Near floor 1st box west of 1st bunk	*Cladosporium cladosporioides*
6E113-2	Wall above frost in galley	*Hormonema dematioides*
6E114-2	Wall above frost in galley	*Cadophora luteo-olivacea*
6E115-2	Wall above frost in galley	*Cadophora* sp. *E*

Fig. 3. Mold growth on food crates in the galley area of Cape Evans hut. The arrow on the right points to a large area of fungal growth and the arrow on the left points to scattered colonies of fungi.

found among the various positions for the data loggers, on average there were 287 h in 2001 and 247 h in 2002 that met these conditions inside Cape Evans hut.

3.2. Cape Royds

Shackleton's hut at Cape Royds is the smallest of the three huts studied. Fig. 6 shows data from a logger placed on the floor in the kitchen area over a three year period where RH ranged between 53.6% and 89.3% and

Fig. 4. Frost accumulation inside Cape Evans hut at the base of the south wall in the galley. When temperatures rise above 0 °C the frost melts producing sufficient moisture for mold growth in this area.

Fig. 5. Cape Evans hut in mid December showing a large amount of drifting snow that accumulates over the winter months.

averaged 71.6%. Temperatures were between −35.1 and 2.5 °C. Data from a logger placed on the floor under a bunk over a four week period during the austral summer from December 23, 2001 to January 20, 2002 showed the average temperature and RH was −0.1 °C and 77.4%, respectively (Fig. 7). The highest temperature and RH recorded for this period was 2.9 °C and 83.0%, respectively.

To determine if there are vertical temperature and RH differences occurring within the hut, two data loggers, one on the floor under a bunk and another approximately 2 m above it on a shelf were compared. Fig. 8 shows four weeks of data from these two loggers taken between December 15, 2000 and January 12, 2001. The environment on the floor has a slightly lower temperature averaging −2.9 °C as compared to the average shelf temperature of 0.2 °C. Relative humidity varied more significantly. The average RH on the floor was 84.2% compared to 63.6% on the shelf. It can also be noted that there were larger fluctuations in both temperature

Table 2
The number of hours per year in which temperature was greater than 0 °C and RH was greater than or equal to 80% in Cape Evans, Cape Royds and Discovery huts

Location	Year		
	2000	2001	2002
Cape Evans			
Floor, S wall, under bunk	79	269	433
Middle of hut (1.7 m)	268	157	83
Shelf, near entrance (2 m)		569	461
Darkroom, ceiling (2.2 m)		257	120
Stables, stores (0.2 m)		185	138
Cape Royds			
Floor, S wall	0	33	6
Shelf, N wall behind reams of paper (2 m)	13	0	0
Floor, N wall, under bunk		55	12
Behind acetylene generator (2.3 m)		3	0
Shelf, Shackleton's room (1.6 m)		0	5
Discovery hut			
Floor, center of the hut	8	0	0
Stove pipe hole, false ceiling, galley (2.0 m)	11	0	0
Shelf, physical laboratory (1.6 m)		0	0
Stores, east wall (0.2 m)		0	0

Values in parenthesis denote distance of data logger from floor.

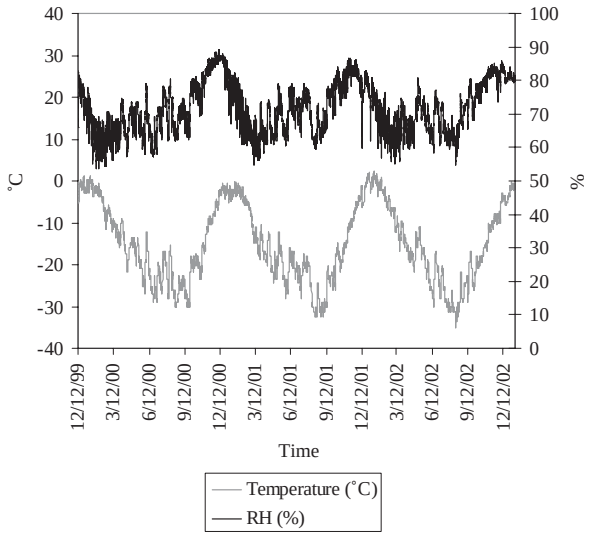

Fig. 6. Temperature and RH in Cape Royds hut over a three year period from a data logger located on the floor in the galley area.

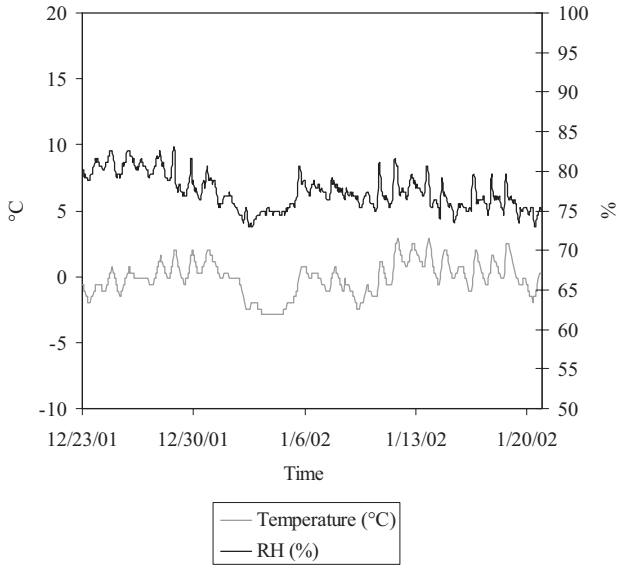

Fig. 7. Temperature and RH in Cape Royds hut over a four week period during the austral summer months of December and January.

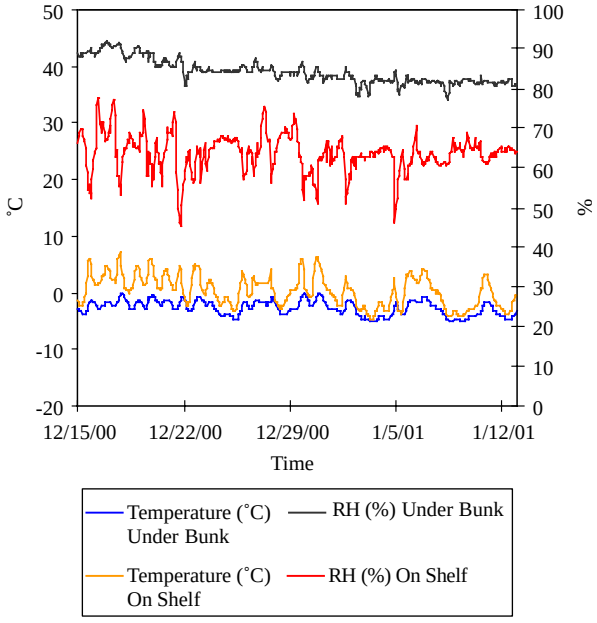

Fig. 8. A comparison of temperature and RH from two data loggers with different vertical positions in Cape Royds hut.

and RH between the data loggers located on the shelf as compared to the data logger on the floor.

The hours per year at or above 0 °C and above 80% RH averaged from all five data loggers for the years 2001 and 2002 are shown in Table 2. This data shows that these conditions are more often occurring in lower areas of the hut than at higher positions. The number of hours with environmental conditions conducive for fungal growth is considerably less (30 h in 2001 and only 8 h in 2002) in this hut as compared to Cape Evans hut (Table 2). The temperature and RH data observed in Cape Royds hut shows a similar trend to the Cape Evans hut in which the number of hours at or above 0 °C and RH greater than 80% decreased between 2001 and 2002 at most data logger locations. This appears to indicate that the huts' environments were reacting similarly to exterior conditions. No extensive areas of active mold growth were observed in the hut but localized areas of dark fungal colonies exist on interior woods and artifacts.

3.3. Discovery hut

A representative view of temperature and RH data for Scott's hut at Hut Point (*Discovery* hut) from the data logger located on the floor in the center of the hut over a period of three years is presented in Fig. 9. The maximum and minimum RH for this time period was 91.3% and 49.2%, respectively, and averaged 73.5%. Temperatures ranged between −39.0 and 6.6 °C. Temperature and RH over a four week period from December 2001 through January 2002 recorded from the data logger on a shelf in the physical laboratory is shown in Fig. 10. The maximum and minimum RH was 76.4% and 62.3%, respectively, and averaged 68.3% for the four weeks. The maximum temperature reached was 8.2 °C and had an average temperature of 2.0 °C. During the three year period of data collection, only 19 h of temperature greater than 0 °C and RH above 80% were recorded in 2000 but no hours with these conditions occurred in 2001 and 2002 (Table 2). This is significantly lower than the hours at these conditions recorded for Cape Evans or Cape Royds huts. Extensive areas of fungal growth have not been observed in *Discovery* hut but several small, inactive colonies have been observed on various wall boards and some artifacts.

3.4. Visitor impacts

To determine if visitors entering the huts affect RH, visitor log books were used to determine when large groups of people (82 to 276 individuals) entered the hut during the 3 years of data collection. The selected dates for this evaluation were when groups of visitors entered

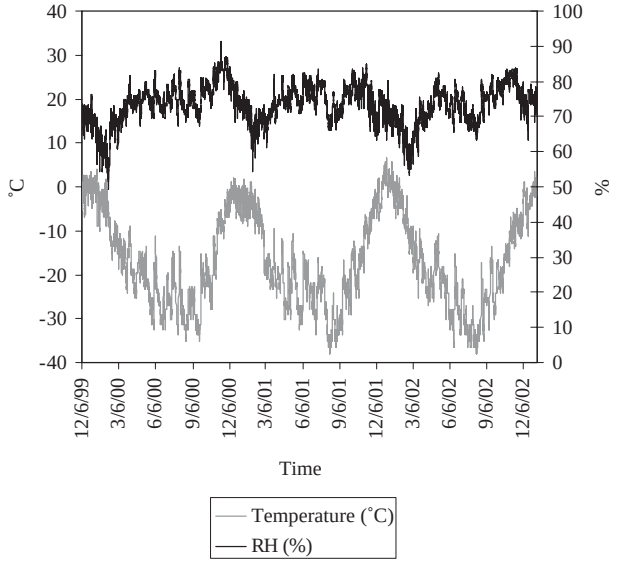

Fig. 9. Temperature and RH in *Discovery* hut over a three year period from a data logger located on the floor in the center of the hut.

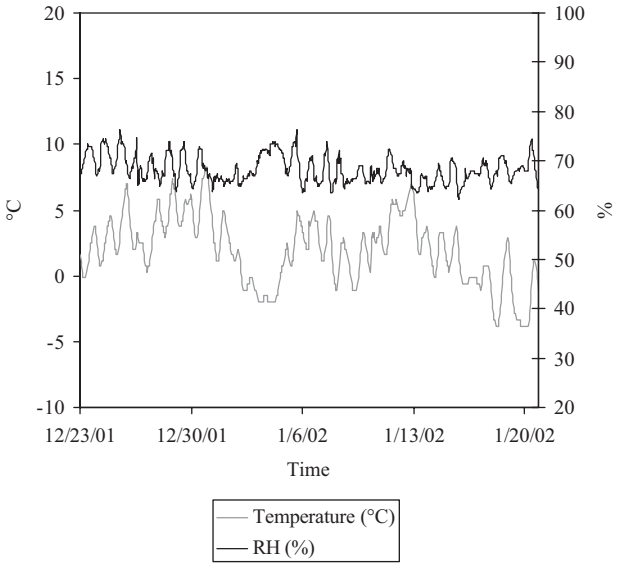

Fig. 10. Temperature and RH in *Discovery* hut over a four week period during the austral summer months of December 2001 to January 2002.

the huts, while having no visitors entering two days prior and two days after the events. Comparing temperature and absolute humidity on the day of the visit to days before and after these events show that moisture fluctuated with temperature and did not exhibit an increase during or after visitors entered the hut (data not shown). Several other visitor events were studied in each hut and the results were similar; no substantial elevation in RH was recorded even after large numbers of visitors entered the huts. To determine how exterior weather influences the interior conditions of the huts during times of visitation, the exterior and interior temperature and RH were studied over a five day period from February 11 to February 16, 2001 (Fig. 11). Twenty-eight individuals entered the hut on February 13, 2001. The average exterior RH and temperature during this period was 67.4% and −6.5 °C, respectively, as compared to the average RH of 74.8% and temperature of −4.7 °C for the interior. The data also shows no increase in RH from visitors entering the hut on February 13. It appears that although the exterior RH and temperature fluctuates more widely, the interior environment is very close to the average exterior environment.

4. Discussion

Environmental conditions are important factors that regulate microbial growth, and it is well-known that moisture is one of the main factors that influence microbial growth and decay in historic buildings located in temperate areas (Park, 1999). The results presented

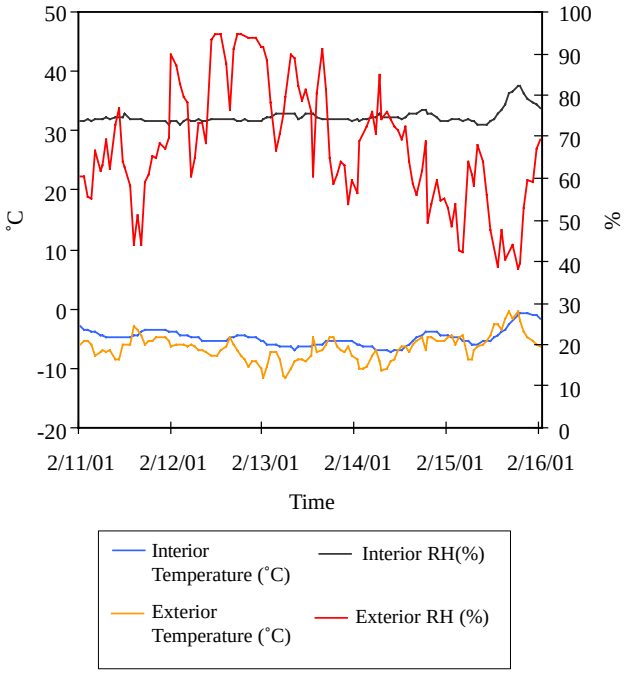

Fig. 11. Temperature and relative humidity of the exterior and interior environments at Cape Evans hut. Twenty-eight visitors entered the hut on 2/13/01. No visitors entered the hut 2 days before or after.

here suggest that RH has a significant effect on microbial growth in the Antarctic expedition huts of Ross Island. This is based on the presence of numerous, active fungal colonies and the high RH for extended periods in the Cape Evans hut, as compared to limited fungal growth and lower RH in the Cape Royds and *Discovery* huts. Although the huts have survived relatively well over the last 9–10 decades as compared to a more temperate or tropical location, they have been significantly impacted by Antarctica's unusual conditions (Blanchette, 2000; Blanchette et al., 2002; Held et al., 2003). An environment conducive for microbial growth has resulted in molds growing on wood, textiles and food stores in Cape Evans hut. Some evidence of mold also occurs in *Discovery* and Cape Royds huts but these areas are not widespread and appear to be localized. The monitoring of temperature and RH has provided important information about the huts internal environments and has demonstrated that despite their location in Antarctica, RH and temperature suitable for microbial growth occurs for an appreciable amount of time in all the structures and especially Cape Evans hut. Other historic structures in Antarctica also appear to have similar problems with mold growth such as Borchgrevink's hut at Cape Adare and Mawson's hut at Commonwealth Bay, Antarctica (Antarctic Heritage Trust, 2004; Hughes, 2000). Metal in the huts are also subjected to significant corrosion due to high RH and temperatures above 0 °C (Otineo-Alego et al., 2000). Food cans, metal equipment and artifacts in the huts have deteriorated significantly due to oxidation caused by these conditions.

4.1. Relative humidity and temperature

Relative humidity conducive for fungal growth ranges from 76% and 96% depending on temperature, length of time, substrate and fungal species (Coppock and Cookson, 1951; Block, 1953; Grant et al., 1989). As RH exceeds 80% conditions for fungal growth improve (Pasanen et al., 1992). The generally accepted range for RH of wooden cultural properties kept in museums to prevent fungal growth is between 47% and 55% (Thompson, 1978; Bachmann, 1992). Recently, revised environmental guidelines in Smithsonian Museum buildings have been established at 45% RH +/− 8% RH and 70 °F (21 °C) +/− 4 °F (2 °C) to insure no fungal growth occurs (Mecklenburg et al., 2004). Our results have shown relative humidity within the Ross Island historic huts is commonly over 80% during the austral summer months (Figs. 1, 6, and 9). This does not, always correlate with temperatures above 0 °C which is usually necessary for most types of mold growth to occur. However, fungi such as *Cladosporium* species have been observed to grow on some substrates when temperatures were −5 °C (Gill and Lowry, 1982). In our evaluations reported here, a conservative estimate of the number of hours during the year when temperatures were above 0 °C was used along with a RH of 80% or above as an indicator for adequate conditions for microbial growth. The data in Table 2 shows that Cape Evans hut has considerably more hours of high RH and temperature than the other huts. These differences in the temperature and RH observed between huts may be attributed to several factors. The huts are different in size, construction, insulative properties, aspect and location which all have an effect on the interior environment. Cape Evans hut commonly has snow that drifts around it from the SE side extending from the ground to the roofline. Snow often nearly encapsulates the structure except for areas on the east and west ends (Fig.5). The melting of this snow causes significant moisture problems in numerous locations around the hut. Cape Royds and *Discovery* huts have some accumulation of drifting snow but not to the depth and extent of Cape Evans hut. The authors have noted considerable snow ingress in the annex of Cape Evans hut as well as some areas in Cape Royds and *Discovery* huts. As the snow melts it can add moisture to the hut environment.

Prolific mold growth is occurring in the Cape Evans hut where microenvironments provide favorable conditions for fungal growth. This appears to be in places where there is also a lack of air movement. In the Cape Evans hut galley area, frost accumulates where the wall

and floor join and also along the wall boards about 0.5 m from the floor (Fig. 4). Frost subsequently melts in the summer months forming free water on the surfaces of wood that provides ample moisture for fungal growth. The formation of free water also likely increases RH in this area creating a microenvironment conducive to mold growth. At present no significant decay is evident in the wood colonized by these fungi but degradation of paper, textiles and other substrates in the hut is likely occurring. *Cadophora* and *Cladosporium* species have the capacity to attack wood and other substrates and have been shown to cause a soft rot form of wood decay (Blanchette et al., 2004; Zabel et al., 1982). Continued growth of these fungi in the huts will undoubtedly result in significant damage over time.

Results obtained from data loggers in different huts show considerable differences when comparing the number of hours above 0 °C and 80% RH. From the data in Table 2, it can be seen that in Cape Evans hut, the location near the entrance is warmer and more humid than other locations. This could be due to the data loggers close proximity to the door where it is likely influenced by the more humid air in the annex or it may be correlated to variations in conditions due to the difference in height from the floor. The data logger under the bunk also exhibits similar conditions, which may be due to decreased air flow in its position. A similar phenomenon is seen in the Cape Royds hut where loggers on the floor and under a bunk have more hours above 0 °C and 80% RH than other loggers placed in different positions. Similar comparisons in *Discovery* hut were not made since there were only 18 total hours above 0 °C and 80% RH over three years.

Visitors' impact on the interior environment of the huts has been a growing concern as hundreds of people enter the huts each year. Although the number of visitors to the huts is limited per season and at any one time by the Antarctic Treaty, the overall impact remains an important consideration for the conservation plans of the huts. Visitors originate from nearby U.S. McMurdo Station and New Zealand's Scott Base as well as from a number of cruise ships that visit the Ross Sea Region each year. The most probable impact visitors could have on the interior hut environment is increasing RH and/or adding moisture. This can occur by bringing snow in on footwear, increasing water vapor from breathing, or allowing air exchange with the outdoor environment. Temperature and RH collected on the days before, during and after large numbers of visitors entered the huts suggests that the current visitation does not cause a rise in RH during the visit or several days after. The amount of moisture in the air inside the huts appears to be more greatly influenced by frost build up, snow melt water, lack of air movement within some parts of the huts, and exterior environmental influences.

5. Recommendations

Relative humidity is sufficient in the huts, especially Cape Evans hut, to support fungal growth. To control this growth, moisture must be reduced. The most direct solution to the problem would be to dehumidify the interior hut air. However, this is extremely difficult given the remote location of the huts and lack of electricity. Localized areas where moisture and temperature are sufficient for mold growth suggest microenvironments of high RH exist in the huts, such as in the galley area of Cape Evans hut where *Cladosporium* and other fungi are growing profusely. The moisture source in these areas needs to be controlled. Possible methods may include periodically removing frost that accumulates on the lower wall or making structural changes and reducing snow on the exterior of the hut that will prevent frost from forming. Increasing air circulation could also help eliminate microclimates of high RH and limit mold growth where it is occurring. Ventilation should be considered to vent and remove warm moist air when it exists inside the huts. Regular inspections of artifacts and problem areas should take place so that mold does not grow unnoticed and cause irreversible harm. This is especially true in areas where air flow is limited and objects are in close proximity to one another. To remove existing fungal growth and the large number of spores that are currently present, hepa vacuuming followed by surface cleaning is warranted (Florian, 2002). Further monitoring of visitors to the huts and their possible effects will also be of value to insure that their numbers do not elevate RH in the future. Although our findings do not show visitors affecting the RH or temperature, continued diligence regarding snow removal from boots and clothing and monitoring the internal environment should be carried out.

The historic huts of Ross Island are valuable historic resources and conservation efforts are needed to protect them from further deterioration. Elevated relative humidity, temperature, and moisture are a continual threat to the huts and the artifacts in them. Addressing the current problems associated with the environmental conditions reported in this paper can be viewed as an integral part of future hut preservation efforts to ensure the protection of these iconic remnants from the Heroic Era of Antarctic exploration.

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