# Protecting Arctic Commercial Buildings during Periods of Electrical and Thermal Systems Outage

## Introduction

The aim of this report is to offer guidance on protection of buildings and building operation in commercial buildings in arctic climates that are affected by interruptions of fuel or electricity. Following this guidance should improve the resilience of these buildings.

The guidance in this report relates to DOE climate zones 7 (very cold) and 8 (subarctic) for non-residential buildings. Original building envelope and equipment design is predicated on full occupancy.

### Normal fuel, thermal and power supply—interruption

In response to utility interruption , the building management may choose to 1) continue normal building occupancy with full operation, 2) simply protect the building and ensure its permanence but forego occupancy and operation or 3) some middle course, perhaps with reduced building occupancy and use, either with lowered input into space conditioning and process/plug loads, or shorter-term occupancy. This report aims to address these three conditions. See below under Thermal Requirements for Buildings.

## Thermal requirements for buildings

Managers of buildings that are subject to utility interruption must prepare for such an eventuality, and must respond correctly when the occasion arises. A first assessment, after safety of occupants is assured, is to determine the likely extent and impact of the interruption.

| | Full operation | Reduced operation | Mothballed |
|---|---|---|---|
| **Operation** | Mission-critical | Mission-critical elements | Suspended |
| **Electrical (generator) requirements** | Similar to normal utility provision | Depends on criticality assessment | Little, none, or battery operated. |
| **Space conditioning** | Similar to normal operation | Depends | None, or minimal (dry) heating to reduce surface microorganisms |
| **Duration** | Backup utilities must be long-term dependable | One factor in backup utility allocation | Expected long-term. |

# Building Heat Load

## Conduction

Heat loss through building envelopes is the primary basis for providing heating space conditioning. See below for recommendations for commercial buildings in the arctic. Conductive heat loss is generally characterized and calculated using

- Clear field heat loss through opaque walls, as a function of wall area
- Clear field heat loss through roofs, as a function of roof area
- Heat loss through glazing and doors
- Frame heat loss around glazing and doors
- Linear anomalies such as roof/wall junction and foundation/wall junction
- Point anomalies such a fastener thermal bridges, and
- Heat loss through foundations.

Of these, heat loss through foundations is the most difficult to calculate or to estimate. The others lend themselves to simple building modeling.

## Ventilation

Ventilation for commercial buildings in the arctic should be expected to comply with ASHRAE 62.1. In buildings designed to have an effective air barrier, it is recommended to provide heat exchange for ventilation air, with 80% efficient heat exchange.

## Infiltration

Infiltration comes at a very high cost in arctic climates. A leakage rate of < 0.25 cfm75 per sf of envelope area (6 sides) is recommended.

## Heat storage

Elements of the building enclosure and materials within the building will affect heat storage in the building. Heat storage may prolong the ability of the building to withstand interruptions in utility supply, though this ability will be only a matter of hours, not days or weeks. Means to calculate the heat storage effect are provided below and in Appendix A.

# Other loads

## Cooling

The number of days when air conditions is needed or desirable in Climate Zones 7 and 8 is small, though that number may rise in coming years with climate change. Interruptions in air conditioning should not be considered, at this point, to be critical to building performance or building operation. Maintenance of cooling systems should not be considered an element in an Alaska building's resilience.

### DHW

Domestic hot water in the arctic is usually provided  via electric units.  DHW may be provided by a sidecar unit where heat I provided by a boiler, or it may be provided using a closed-combustion heater. It is uncommon to find DHW provided by a naturally-vented hot water unit, given the penalty for providing venting to such a unit.

## Building design for arctic climates

"Criteria for MILCON north of the Alaska Range" provides guidance for military construction in the arctic. Much of the guidance is derived from ASHRAE 90.1, and it includes guidance gained from field experience at several bases. This report presumes building compliance with the Criteria report.

### Foundation:

Permafrost is being lost to warming. Foundations on permafrost will require extensive engineering intervention and analysis. It is expected that most arctic buildings will need to rely on unfrozen ground support.  The Criteria report recommends R-20 insulation for foundation walls and R-30 insulation below heated slabs. It also notes that stem wall insulation may be extended outward from the wall to "further enclose the thermal bulb that will inevitably build as the building is heated."

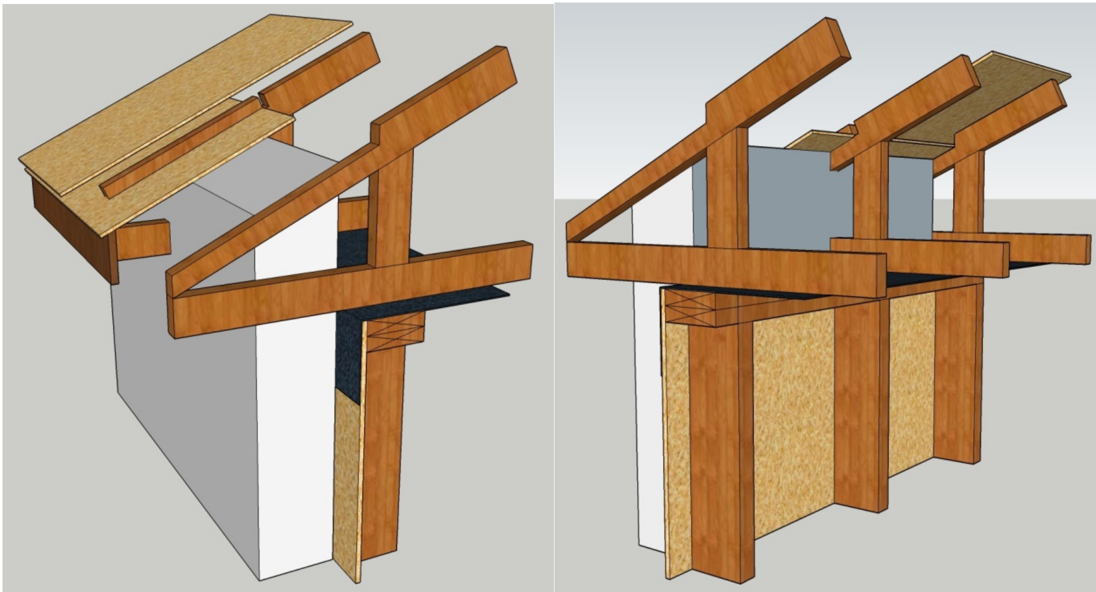
### Wall construction:

Commercial wall construction is typically mass (concrete or masonry), metal framing, or wood framing. Continuous insulation lies outside the structural framing and is fastened to the wall structure. The continuous insulation is protected against weather with a cladding system that sheds any water that penetrates the cladding back to the outside. Continuous insulation is necessary to avoid thermal bridges, and is typically the building layer that serves as an air barrier. The Criteria report recommends R-45 wall insulation, which is typically achieved with 6 inches of exterior rigid continuous insulation plus batt or fill insulation in framing cavities.

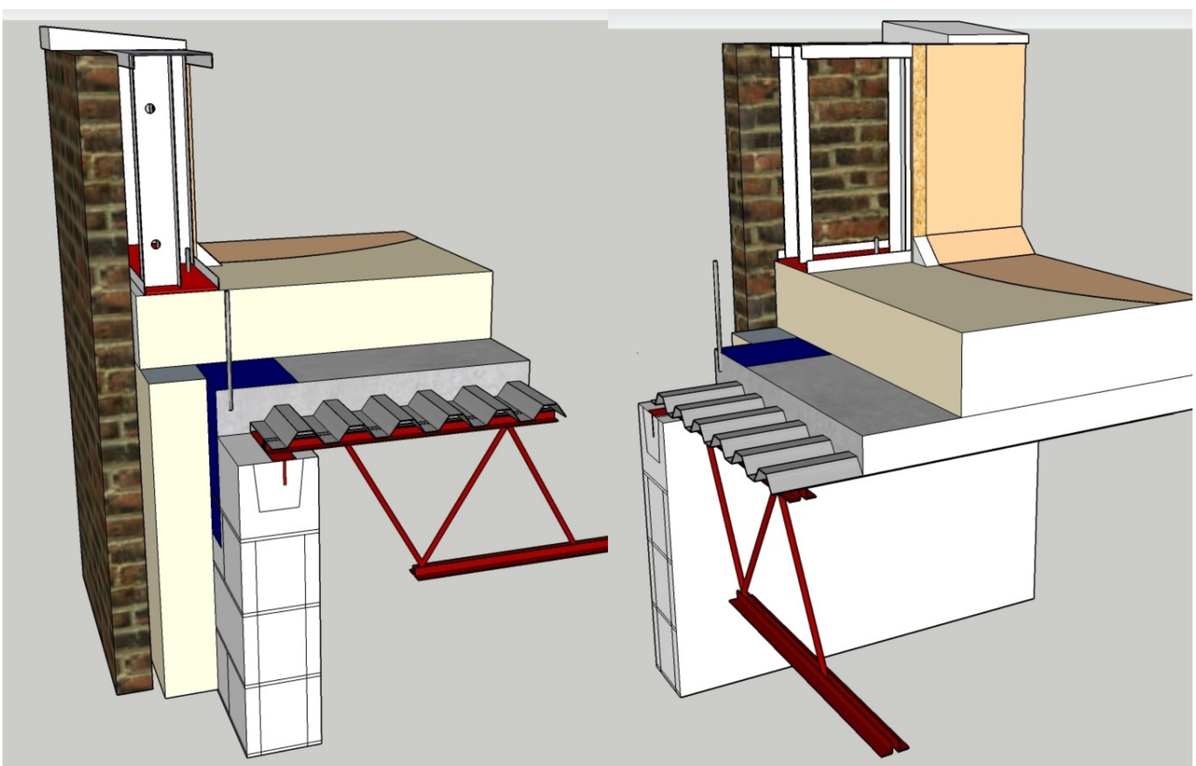
### Roof construction:

Commercial roofing is typically low-slope. It is composed of a roof structure, roof decking, insulation above the decking and roof membrane. It must accommodate roof penetrations such as drains, bulkheads and equipment supports. The membrane and insulation must be protected against uplift using fasteners through to the decking, or ballast. Roof drains must be warmer than the typical roof deck temperature in order to assist drainage.

The roof-wall junction is a common site of excess heat loss in the building. A strategy to avoid this is provide continuity of exterior continuous insulation from the wall to the roof, and provide overhangs and parapets as accessories outboard of the insulation layer. Two examples are provided below. These examples are intended to show an air barrier membrane at the air barrier layer, and maximum continuity of the roof and wall insulation layers.



**1. Wood frame roof-wall junction. A peel-and-stick membrane is placed over the top plate prior to placing the trusses. If eave ventilation is required, the truss top chord may be cut, leaving sufficient room for blown-in insulation.**



**2. Roof-wall junction with CMU walls. Note the air barrier membrane (blue), and the vertical threaded rods embedded in the concrete deck, used to fasten steel-framing parapet.**

## Windows

The Criteria report recommends triple glazing with low-e coating for a field U-value of 0.34. Frames should have a thermal break.

## Summary

A comparison of various sources for Zone 8 construction are provided in the table below.

| Parameter/source | ASHRAE 90.1 Climate Zone 8. CERL Thermal Study | Finnish Building Code | Alaska Housing Finance Corp. (Zone 8) | Energy-Efficient Housing Guidelines for Whitehorse, Yukon Territories, Energy-Optimized |
|---|---|---|---|---|
| **Wall R (hr-sf-F/Btu)** | Mass: R-19 SteeL: R-13 + R-18.8ci<br>Wood: R-13 + R-18.8 ci | R-33.4 | Wood: R-30 | R-58 |
| **Roof-R (hr-sf-F/Btu)** | R-35 c.i.<br>Attic: R-60 | R-63 | R-30 ci | Attic: R-110 |
| **Window-U (Btu/(h F sf)** | Nonmetal: U-0.32<br>Metal: U-0.38 | U-0.17 | U-0.25 | U-0.122 |
| **Window SHGC** | 0.45 | | 0.45 | 0.4 |
| **Ventilation heat recovery** | <50%, function of flow rate | 55% | | 70% |
| **Airtightness** | Continuous air barrier | Design: 2.0 ($m^3$/(h $m^2$) | | 0.5 ACH |
| **Wall below grade** | R-15 ci | R-35 | R-15 ci or R-19 | R-28 |

3. Building Envelope parameters for construction in DOE Zone 8.

# Building performance with utility interruption

Building operations must provide emergency planning to prepare for utility (electrical and combustion fuel) outages. This will include providing a generator, fuel for the generator, and backup fuel source. The table below may assist in emergency planning.

## Emergency steam and hot water

In case of interruption of fuel supplies, (gas or oil), in buildings with a hot water or steam boiler, the heating need may be met with temporary hot water or steam from a service such as Ware, Inc. that provides mobile boilers. Availability of this equipment in Alaska currently is not known.

## Temporary space heaters

For reduced occupancy and use, an option for temporary space heating is the use of unvented space heaters. These are available as temporary local construction heaters (“salamander”) or as smaller household units meant for permanent use. The unit input is typically propane. In addition to heat output, these units produce $CO_2$, CO, $NO_x$, particulates, water vapor, and they deplete oxygen in the space.

A study of residential unvented space heaters by the University of Illinois found that indoor air surpassed published IAQ standards for NO2 in more than half the homes. It found that none of the field cases showed CO levels in excess of the short term (1 hour) or long-term levels, but 20% exceeded published levels for 8-hour averages. During the cold, dry winters of the field study (Champaign IL), no moisture problems appeared.

Of course, the heating effectiveness of these units will depend on the unit size and the space configuration. IAQ outcomes will depend heavily on air change within the space. The Illinois report includes a model for determining the heat and IAQ effects of use of these devices.

## Pipe burst protection

Research at the University of Illinois has illustrated the mechanism by which water pipes burst when surrounded by cold temperatures. Cold air temperatures cause the temperature of water in pipes to decline. Water temperature may decline below 0C, often to -4C. With continued cold temperatures, ice nucleates in the water, raising the temperature of the two-phase mix to 0C. With continued cold temperatures, ice begins to grow on the pipe wall, growing inward; the rate of ice growth depends on several factors such as air temperature, pipe thermal conductivity, water circulation, and effect of the air film surrounding the pipe. Through this entire process, prior to the formation of blockage, the pipe system is not put at risk, and with rising air temperatures the system will recover to the original condition with no ill effects.

If the ice grows inward to the point of blockage, then water pressure effects become important. The blockage can grow along the length of the pipe and act like a piston. Piston action toward the water source will generally have no ill effect, in the absence of a backflow preventer. But piston action toward the remaining liquid water confined downstream will cause the water pressure to rise. Pipe rupture or fitting failure will occur once the water pressure reaches a sufficiently high level.

There are several means to prevent pipe bursting due to freezing:

1. Avoid subzero air temperatures at the pipe.
2. Drain the water from the pipe system. Compressed air may be used for systems that do not drain entirely by gravity.
3. Provide pressure relief at any at-risk portion of the pipe system. A single pressure relief valve is usually sufficient to protect a clustered fixture group. A ballcock assembly in a typical toilet serves as a pressure relief device (which explains the greater likelihood of hot water rupture during freeze events).
4. Provide air expansion (using water hammer arresters for example) to protect piping systems where the slight water leakage from pressure relief valves is undesirable, such as in wet fire suppression systems.

It is particularly important to avoid individual sites of particularly cold temperature along the pipe length, as these are preferred sites for blockage to initiate. Such sites will occur at interruptions in pipe insulation (often at fittings such as elbows) and at air leaks in the envelope, where moving air can reduce the air film thermal resistance.

## Excess building envelope moisture

Cold conditions may lead to excess moisture accumulation in wall and roof assemblies of buildings.

Of course, liquid water sources must be addressed prior to any concerns for cold weather moisture accumulation arising from indoor water vapor. These sources may include roof leaks, plumbing leaks, spills, and water entry through the foundation.

Moisture accumulation within the building assembly is addressed by ASHRAE Standard 160 (2016) "Criteria for Moisture Design Analysis in Buildings". This standard makes use of one-dimensional hygrothermal analysis using design or default inputs for material properties, surface properties and indoor/outdoor conditions to determine the likelihood of mold growth on interstitial surfaces. The standard uses research by Viitanen and others to determine if surfaces within an assembly are likely to show evidence of mold growth. The Mold Index output of the standard has been validated in research reports.

Moisture may also accumulate on the interior exposed wall and ceiling surfaces. Such visible moisture conditions are usually local, so they do not lend themselves to analysis using a one-dimensional tool. They occur typically at cold bridge anomalies in the thermal insulation, at sites of lower air film conduction such as corners and fixture placement restricting air flow, and at sites of local moisture production. They are best diagnosed using infrared thermography to determine a design minimum surface temperature, which can be compared to design indoor humidity levels. Indoor dewpoint temperatures should be kept several degrees below the design minimum surface temperature.

If the building is provided with minimal operation (no occupancy) it may be beneficial to operate one or more humidifiers in the space. The effects of dehumidification and the mild heating provided by the unit will both act to reduce the likelihood of surface moisture accumulation. However, at low temperatures, mold growth is greatly lowered.

## Monitored conditions

The indoors and outdoors may be monitored for temperature and humidity. As long as the interior is being conditioned, indoor monitored temperatures indicate little besides functioning of the conditioning equipment.

We may express the ability of the building to retain temperature in terms of the temperature "half-life" ($t_{1/2}$), that is, the time it would take for the temperature to decay to half of the indoor-outdoor temperature difference. This can be calculated from monitored data as follows:

1. Isolate building data that is not influenced by occupant activity or by operation of conditioning equipment. This may be done if a night-time temperature setback occurs when the building is not in use. A longer data set will provide more accurate results.
2. Use multiple linear regression to determine the quantity *a* in the regression of indoor conditions compared to outdoor: $x_{i,t} = ax_{i,t-1} + bx_{o,t} + c$ where x is the measured value (usually temperature), *I* and *o* represent indoor and outdoor respectively, and *t* represents the time step.

3. The time constant τ =-1 / ln($a$). The half-life $t_{1/2}$ = τ · ln(2), in units of the time step.

See the appendix for a more complete explanation.

## References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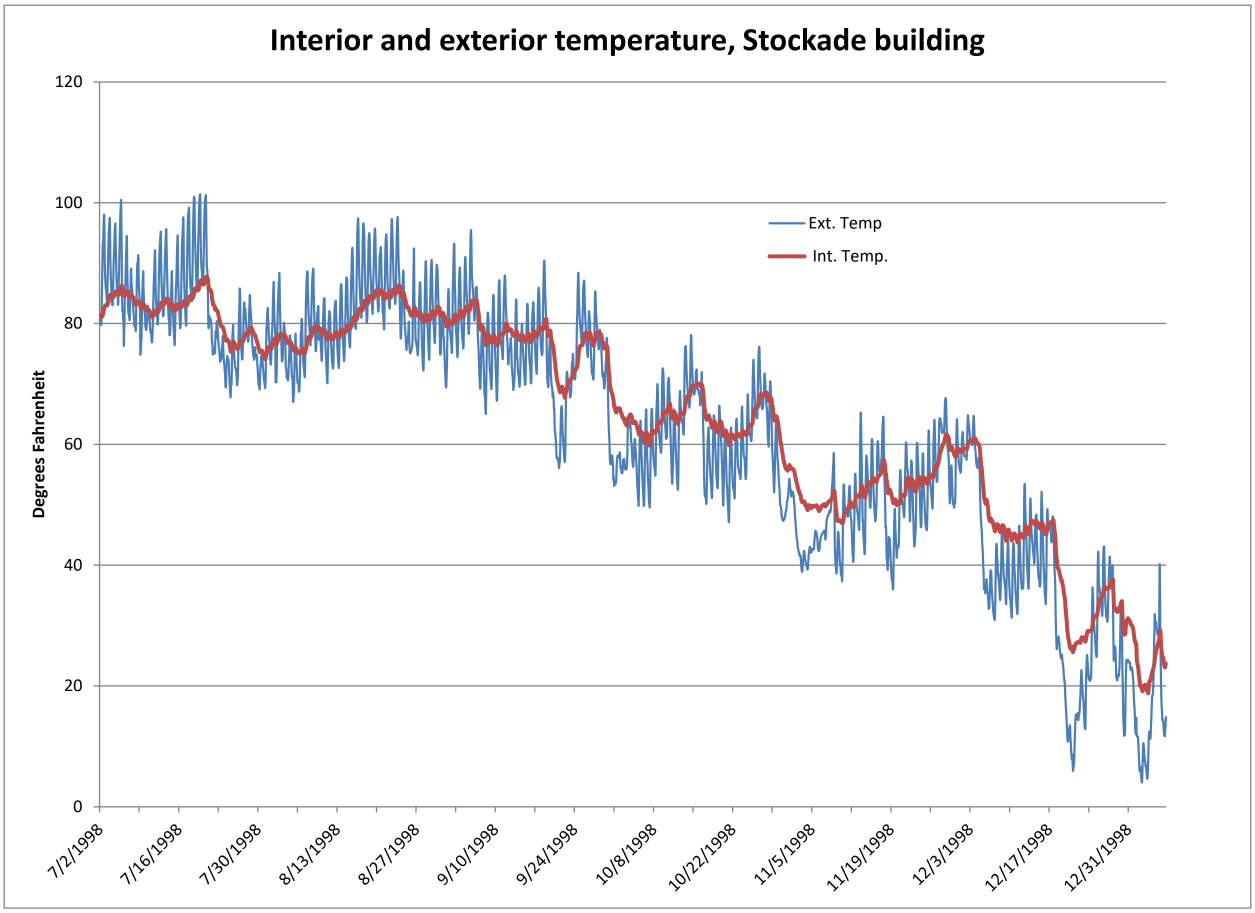
# Appendix A. Half-life example and calculation.

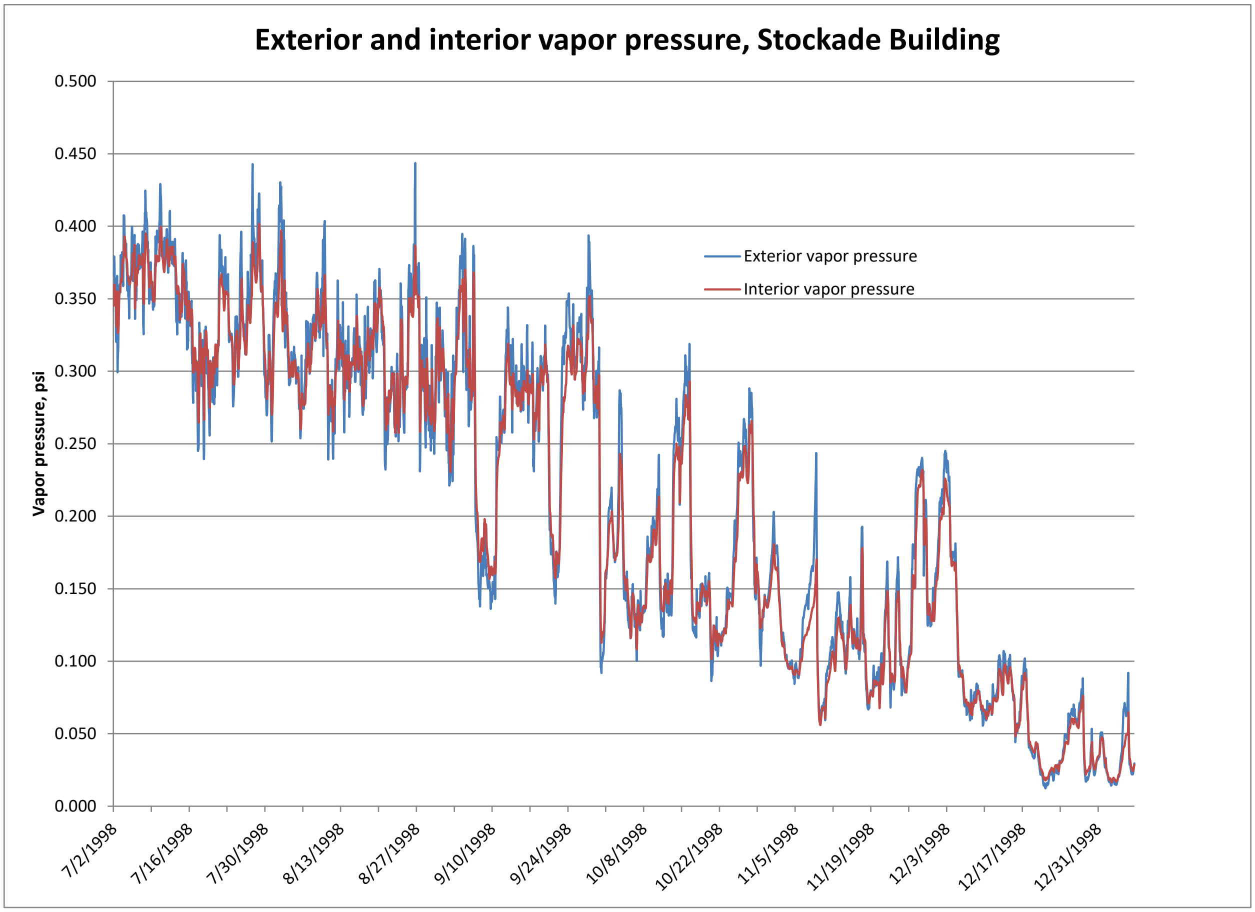
From July 1998 to January 1999, temperature and humidity measurements were taken at an unconditioned unoccupied 100-year-old stone building at Fort Riley Kansas, the Stockade Building. Exterior conditions were measured on site, and interior temperature and humidity were measured at four sites at the interior of the building, one of which is presented here.

An unconditioned stone building will typically show a long lag time, that is, a long time for the exterior signal to reach an interior measuring point, and the amplitude will be dampened due to heat storage in the surrounding materials. Indoor and outdoor temperatures are shown in Figure 1.




**4. Interior and exterior temperature measurements**

We may also track the indoor and outdoor humidity. For these purposes, relative humidity must be converted to a measure of absolute humidity. Vapor pressure units (psi) are the absolute humidity units used here. See Figure 2.




**5. Vapor pressure measured values, indoor and outdoor, Stockade Building**

We see in Figure 2 that moisture storage has a far lower effect than the heat storage seen in Figure 1, as the measured indoor vapor pressure tracks outdoor much more closely. In fact, the interior surfaces were painted with several layers of paint, so the underlying stone would have little interaction with the interior. First we note that the building was unconditioned and unoccupied, two conditions that are necessary for this analysis.

We perform a multiple regression of the interior measurement against the concurrent outdoor conditions, and against the interior conditions in the prior time step. The time step in this example is one hour. Multiple regression was calculated using the LINEST function in an Excel spreadsheet.

$$x_{i,t} = ax_{i,t-1} + bx_{o,t} + c$$

where *x* is the measured value (usually temperature), subscripts *I* and *o* represent indoor and outdoor respectively, and *t* represents the time step.

The *a* coefficient represents the impact of the recorded value at the previous time step, thus it represents the heat storage effect. With a high level of storage or buffering we expect the “storage coefficient” (a) of this regression to be high—close to a value of 1. In a building with a low level of storage or buffering, we expect the storage coefficient to be low. If the exterior conditions are quickly transmitted to the interior, the “transfer coefficient” (*b*) is expected to be high.

The regression coefficients may be applied to an idealized decay curve with a starting value and an eventual settled value. The decay curve is represented by

$$a = {}^{x_{t-1}}/_{x_t} = e^{-t/\tau}$$

Where x represents the value (usually temperature) at time step *t* and *t-1*, and τ represents the time constant. The time constant is product of the resistance and capacitance regulating the heat flow. Solving for τ gives

$$\tau = {}^{-1}/_{\ln(a)}$$

The results for the data shown in the foregoing graphs are shown in Table 1. The long measurement period allows the data quality to be very good, as illustrated by the high value (close to 1) of the $R^2$ (or RSQ) value for the regression.

**Table 1. Half-life calculation for temperature and vapor pressure at the Stockade Building**

| Calculated value | Temperature | Humidity (vapor pressure) |
|---|---|---|
| a. Storage coefficient | 0.9762 | 0.7963 |
| b. Transfer coefficient | 0.0207 | 0.2008 |
| c. constant | 0.2322 | -0.0002 |
| RSQ | 0.99995 | 0.9994 |
| Time constant (= -1 / ln (a)) | 41.46 hr | 4.39 hr |
| Half life (= time constant*ln(2)) | **28.73 hr** | **3.04 hr** |

We may note that there is a constant coefficient (c) for temperature (0.2322) which indicates that, although unconditioned, there is a heat contribution, presumably from earth contact. There is essentially no vapor pressure constant coefficient, indicating no or negligible water leakage into the building.

The techniques shown here may be used to calculate the temperature half-life of a building, presuming a set of measured data of sufficient duration.