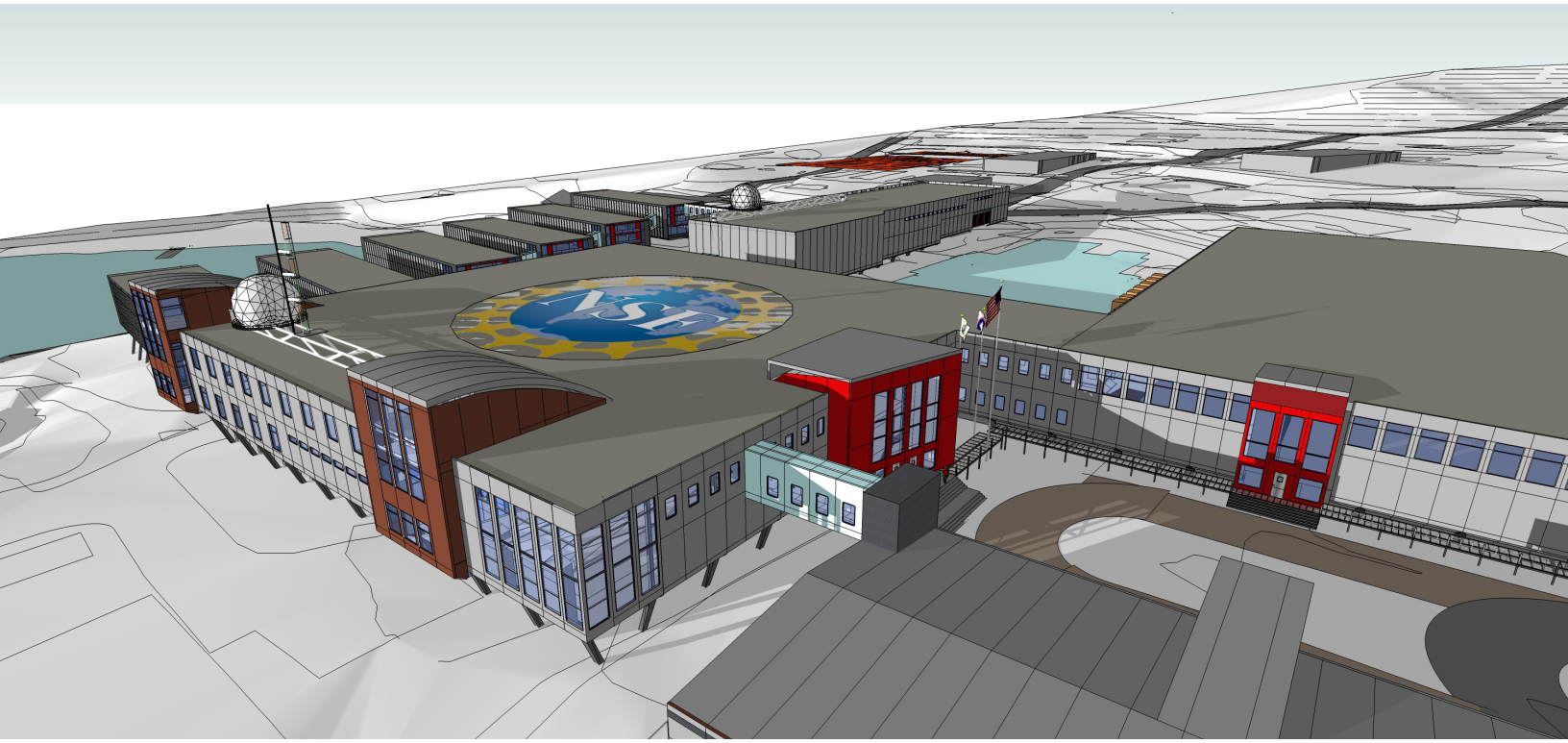

McMURDO STATION MODERNIZATION STUDY

Building Shell & Fenestration Study

April 29, 2016
Final Submittal

NSF

UNITED STATES ANTARCTIC PROGRAM
NATIONAL SCIENCE FOUNDATION

ASC
ANTARCTIC SUPPORT CONTRACT

MERRICK®
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        ii. Graphic
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        ii. Graphic
    c. Best
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(a) Meeting Notes

(b) Environmental Data

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To be provided at 95% submittal

(e) Fenestration Data —

To be provided at 95% submittal

(f) Energy Model and Analysis

(g) References — *To be provided at 95% submittal*

(h) *Utilizing Off-Site Construction* report

SECTION 1
OVERVIEW

Team Directory

CLIENT

National Science Foundation, United States Antarctic Program

Antarctic Support Group, Lockheed Martin Corporation
Logistical and Base Operations Support

AUTHOR

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Architecture, Interior Design, Planning

CONSULTANTS

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Consulting Engineers

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Subject Matter Expert / Peer Review

Integrated Technology in Architecture
Logistics and Fabrication

Simpson Gumpertz & Heger
Building Skin Specialists

Rocky Mountain Institute
High Performance Buildings

Parametrix
Construction Cost Estimating

Project Description

This study identifies and evaluates the appropriate components and systems for consideration in the building envelope of all primary new facilities at McMurdo Station.

From the evaluation of the various building envelope alternatives, this study makes recommendations for the most appropriate systems to contribute to the Basis of Design of the McMurdo Station facilities.

Ultimately, this Basis of Design of the building envelope will be conveyed during the Design-Build solicitation without limiting the respondents' ability to meet the performance standards via comparable means.

Building Envelope

> *"The envelope has to respond both to natural forces and human values. The natural forces include rain, snow, wind and sun. Human concerns include safety, security, and task success. The envelope provides protection by enclosure and by balancing internal and external environmental forces. To achieve protection it allows for careful control of penetrations. A symbol of the envelope might be a large bubble that would keep the weather out and the interior climate in."*
>
> – *Richard Rush,* The Building Systems Integration Handbook

Methodology

This McMurdo Building Envelope Study involves:

1. DESIGN CRITERIA
This first step establishes the various design criteria for McMurdo Station's building envelope. Such criteria involves the *physical* parameters of climatic, energy use, aesthetic, constructibility, logistical considerations, the *cultural* parameters of aesthetics, and the *value* parameters of first and life-cycle costs. Specifically, these design criteria are established for the various portions of the facility's building envelope: roof, wall, and floor.

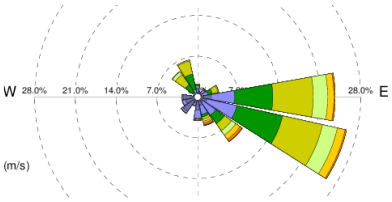
2. BENCHMARKING
Here, the report investigates solutions used for the building shell at a number of other recently constructed Antarctic Research Stations and Arctic facilities.

3. COMPONENT RESEARCH
This step involves the identification of the full range of potential building envelope components. This range represents the full spectrum, from those that have been proven through general use in the building industry, to those at the forefront of innovation both within the building industry and allied industries. However, this study does not entertain technologies that are either unproven in the building industry, or are employed at an advanced level with the aerospace industry.

4. COMPONENT EVALUATION
Upon identification of both performance criteria and component characteristics, this study evaluates these components for their ability to satisfy the performance criteria. This evaluation involves the relative ranking of performance, summarized in both graphic and written form.

5. ASSEMBLY RECOMMENDATION
Finally, based on this evaluation, this study recommends the optimal combination of building components to form the building envelope system for the facilities at McMurdo Station.

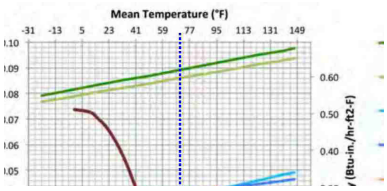
Methodology



1 DESIGN CRITERIA

2 BENCHMARKING

3 COMPONENT RESEARCH



4 COMPONENT EVALUATION

5 ASSEMBLY RECOMMENDATION

Design Criteria

The following parameters are used as the basis of establishing the Design Criteria by which the range of building envelope components and systems are evaluated. Design Criteria are the factors and forces that impact the building shell and fenestration.

GENERAL

1. All aspects of the construction, lifespan and removal of the building envelope shall be in conformance with the Antarctic Treaty.
2. Life Span of the McMurdo facilities shall be 50 years. This lifespan does not preclude replacement or refurbishment of specific envelope components.
3. On-site Labor to construct the enclosure shall be minimized.
4. Performance of the envelope shall be optimized to achieve an energy goal of 144 M BTU/yr.

PHYSICAL PARAMETERS

As the graphic diagram below indicates, the various physical parameters that form the basis for the physical design criteria involve:

1. Air Temperature gradients
2. Lateral and up-lift wind forces
3. Air infiltration
4. Ultra-violet intensity
5. Abrasion from air-born particulates
6. Structural & Thermal movement
7. Internal loading forces
8. Moisture Management

CULTURAL PARAMETERS

In addition to performing within the various physical parameters listed above, the building envelope shall respond to the following cultural parameters:

1. United States long-term Antarctic presence
   Durable, aesthetically timeless materials and forms
2. NSF presence and mission
   A display of the importance of the science mission through a design demonstrating thoughtful deliberation of the forms and the quality of the construction
3. Sensitivity to Place
   Facilities shall be designed to complement the unique Ross Island topographic, geological and climatic environment.
4. Promotion of Well-Being
   Indoor air quality, Thermal comfort, Views, Daylighting

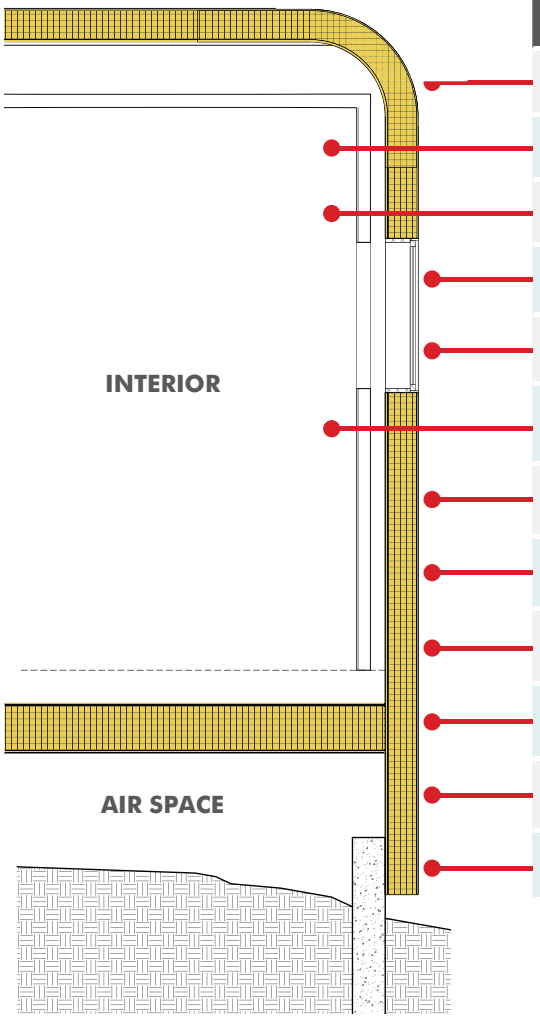
VALUE

Both first cost and life-cycle cost are considered and evaluated. Life-cycle is not the life span of the building. Life span refers to the designed service life of the building, whereas life-cycle refers to the overall cost of the building through its life span as its is constructed, maintained, used, and removed.

SYNERGIES

The enclosure components being a part of a larger whole interact with other systems such as mechanical and structural designs. The ratios of opaque vs transparent enclosures are also a factor in the selection of the types of enclosures. The Design Phase will necessarily tune the enclosure components and assemblies to optimally satisfy the performance criteria in a cost effective manner.

Design Criteria



FORCES	PERFORMANCE CRITERIA WALLS/ROOFS | FLOORS | FENESTRATION
TEMPERATURE -40F TO 30F	THERMAL RESISTANCE DETERMINED BY ENERGY MODEL
AIR MOVEMENT	AIR INFILTRATION RESISTANCE 0.0002 CFM/SQFT | N/A | N/A
MOISTURE MIGRATION	MOISTURE INFILTRATION RESISTANCE 0.1 PERM | N/A | N/A
WIND 150 MPH	STRUCTURAL REQUIREMENTS YES | N/A | YES
FIRE	SMOKE DEVELOPED AND FLAME SPREAD CLASS A
ENVIRONMENTAL	GLOBAL WARMING POTENTIAL LOW GWP & ZERO OZONE DEPLETION
CORROSION	CORROSION RESISTANCE CATAGORIZED AS ACCEPTABLE
ULTRAVIOLET	UV RESISTANCE CATAGORIZED AS EXCELLENT
ABRASION	MATERIAL HARDNESS ____ | N/A | ____
HUMAN WEAR	FRACTURE TOUGHNESS ____ | N/A | ____
CONSTRUCTABILITY	IN SITU LABOR AND COMPLEXITY
AESTHETICS	SUBJECTIVE

THERMAL RESISTANCE

Thermal Expansion is measured in terms of a coefficient known as coefficient of friction (CTE). CTE is a measure of the linear change of a material as the temperature changes. This measure will look specifically at envelope skin and, to a lesser extent, the thermal insulation.

The performance criteria is directly related to the joinery of the matrials and panels. The joints and panel seems will influence the thermal performance as much as the thermal resistant value of the materials themselves. As the building moves and its parts undergo stress, joints and panel seems will have redundancy to reduce the potential for these joints and seems to fail.

A substance having a small CTE but is not sealed properly is much worse than a substance with a high CTE that has been sealed, or designed for redundancy, to withstand the environment and movement for the life of the project. The thermal expansion of the materials chosen must be compatible with the detail and design of the material joints and attachments.

Design Criteria

THERMAL CONDUCTIVITY

Thermal conductivity is the ability of a material to conduct heat and cold through its molecular structure. With greater conductivity there is greater risk of permitting cold temperatures to be transferred through the construction. If highly conductive materials are planned (eg metals) then the systems need to be designed to minimize risk of thermal conductivity through appropriate isolation.

AIR INFILTRATION

Air barrier performance is measured in cfm/ft^2 per ASTM E2357. The maximum airflow through an exterior air barrier shall be 0.0002 cfm/ft^2. This minimum requirement will limit the barrier to Self-Adhered Sheets and Fluid Applied Barriers. There is an opportunity for advanced materials to be included as an air barrier. The selection of barriers also needs to take note of the impacts of melt water flowing over building surfaces and of the low term impact of static snow.

MOISTURE INFILTRATION

The component for moisture infiltration control is an internal vapor barrier, as moisture will move from the interior moisture laden air to the dry exterior. The barrier should act as a barrier, not simply act as a retarder to limit any moisture migration.

Class I vapor barriers will only be considered. A Class I vapor barrier is defined as having a Perm rating of 0.01 or less as measured per ASTM E-96 Method A.

STRUCTURAL CRITERIA

Forces that act upon the building (wind, gravity, sun exposure, building occupants, and equipment) can be static or dynamic, and will influence the selection of components of the wall assemblies based upon their ability to resist the various forces and loads placed upon the material and other systems. The materials are dependent upon the other building systems to perform their function as intended.

There are wide ranges of structural performance criteria that inform the selection of the exterior cladding material. Those range from the materials' ability to absorb thermal radiation from the sun to its resistance to impact from an air borne projectile. Specific examples of criteria used in evaluating cladding materials were:

- Elongation rate of the material
- Elasticity
- Coefficient of Thermal Expansion (measured as the CTE)
- Toughness
- Thermal shock
- Brittleness at extended low temperature
- Stiffness
- Weight and thickness
- Permissible deflections

AERODYNAMICS

Alongside site layout, the form of the building will have significant impact on aerodynamics and therefore snow accumulation. The ability of a building shell to be molded to improve wind flow needs to be considered. Right angle corners for example are not desirable as they create local vortices, which can create drifting of snow.

SCIENCE

Design Criteria

Materials that make up the shell must not negatively impact any science conducted at McMurdo. The system selection will need to be discussed and analyzed by the science community.

SEISMIC & WIND RESISTANCE

The station has historically used Seismic Site Class A, which is a "low risk" categorization. The structures will also be designed according to Risk Category as defined by the International Building Code and approved by NSF/ASC. The construction may require additional stiffness to resist the impact of ground acceleration and this may have an impact on joint design, panel size and connections to the primary structure.

ELECTROSTATICS

Due to the dry atmosphere and high winds in Antarctica there are significant issues with electrostatic conduction of materials. This can cause significant shocks to the occupants. The panels must be able to dissipate the electrostatic charges so as not to effect the occupants or science.

FIRE AND SMOKE SAFETY

Materials are measured by their surface burning characteristics as tested by ASTM E84. This measure shall be applied to both skin and thermal insulation. Each material needs meet the ability to resist surface spread of flame as tabled in the International Building Code.

Materials are also tested against a the smoke-development index (SDI) under ASTM E84 which measure the smoke emitted by a material as it burns. SDI will follow IBC for interior walls and finishes.

Assemblies will provide structural resistance to the impact of fire. Again, the exterior assemblies will follow the requirements and restrictions in the IBC.

The goal for the project is to use material with non-flammable surfaces. If these materials cannot be avoided, measures will be taken to mitigate fire risk.

ENVIRONMENTAL IMPACT

Determination of a substance's GMP (global warming potential) shall be listed. The substances that will be scrutinized are any materials that require blowing agents in the manufacturing process. This is measured by the amount of CFC's (chlorofluorocarbons) and HCFC's (hydrochlorofluorocarbons).

A goal for the project is zero uses of substances with Global Warming Potential. Per the Montreal Protocol 2007, there is a current freeze on any new GWP substances, with mandatory reductions starting in 2015. By the time the construction of this project commences, it is assumed most of the top manufacturers will have developed different processes that remove GWP's.

Additionally the project must be developed taking account of the Environmental Protocols of the Antarctic Treaty. While these are non-specific when applied to construction, the design should minimize impact on the environment and allow for easy de-commissioning at the end of its life. To avoid the import of foreign organic matter, all components need to be carefully checked and packed prior to export to Antarctica. Additional time and measures are required for this to be managed effectively. A comprehensive environmental evaluation (CEE) will be required for presentation to the Antarctic Treaty Consulative Meetings, and the approach to construction will form a significant component in this submission.

Design Criteria

CORROSION (METALS) / DEGRADATION (POLYMERS)

Corrosion is the slow destruction of a metal when a metal comes in contact with an accelerant (chorines, sulfides, etc.) and moisture. When this happens, the metal begins an electrochemical reaction that oxidizes the surface of the metal. The oxidation of the material affects the strength and appearance of the metal. Degradation refers to the loss of strength, color or shape in polymer-based material affected by heat, light or chemicals. Both Corrosion and Degradation are considered in the selection of components for the Exterior Cladding Assemblies to be able to maintain integrity and the ability to perform in the assembly.

In order to evaluate the degree of resistance to corrosion and degradation, it has to be known if specific chemical compounds or environmental factors are present in the environment. This helps to determine if there is the potential for corrosion to occur and if there is enough risk of exposure in high enough concentrations to affect the building component. An example of this would be when the presence of liquid water and salts comes in contact with a metal surface in high enough concentrations, oxidation or rusting begins to occur.

DURABILITY

The ability of a material to meet its performance criteria over a duration of time as defined by its useful life (life span). The metric for evaluating durability would be life cycle cost analysis based upon "competing alternatives to purchase, own, operate, maintain and, finally, dispose of an object or process, when each is equally appropriate to be implemented on technical grounds." [1]

In the context of McMurdo the building shell will need durability to resist:

- UV
- The sand-blasting effects of spin drift (small wind born ice particles) and volcanic dust particles from Mt Erebus
- Freeze-thaw action
- Thermal shock

CONSTRUCTIBILITY

The criteria relates to a materials ability to be constructed on site and the quality control of its installation. Again, there is no real scientific qualitative measure. Judgment will be based upon industry knowledge of the material.

It is preferred a material is a known product in the industry, and this product is known as a high quality material. As an extra precaution it is highly advisable to construct full-scale mock-ups or trial assembles of systems in the US prior to full-scale manufacture. This will assist constructibility and will allow for testing against key design criteria.

CONSTRUCTION LOGISTICS

As all materials must be shipped to the site, the construction of buildings in Antarctica requires a clear logistics plan. Components and systems must be selected and designed within the logistic constraints of the ship's hold and cranes and a possible plant retained on site. This will impact the size and weight of the panels. Additionally the ability to construct the enclosure within limited time frames is very important to allow for erection during the warmer months. This will also determine panel sizes.

Design Criteria

MAINTAINABILITY

The maintenance of the building includes all preventive and operation maintenance that is necessary to keep the exterior envelope in good working order over its 50 year life. Warranties and guarantees may not be available for some components due to the temperatures experienced on site – many components are not warrantied below -13°F, which is the low temperature common in food and beverage cold stores.

BUILDING IN USE

The system is to be designed in accordance with the varied and multiple expected uses of the building. The skin will enclose residential, office, industrial, and medical fuctions. The exterior will provide a uniform expression but the interior must adapt to the individual uses. Within occupied spaces (admin, recreation, dining etc.) a higher quality finish will be designed by comparison with the storage areas where robustness is the key parameter. The system should also allow for installation of various fixtures and fittings (cables, accessible roof decks, lights, balconies, science equipment, PV and solar thermal panels, air intake and extract grilles and graphics) at the time of construction and in the future to suit the needs of science programs.

AESTHETICS

The evaluation of a building based upon its materials, composition and form. It is also the ability of a building to convey meaning about its purpose and function. Material and how they are detailed have a direct effect on perceived quailty and stature of a building.

1. *Definition Wikipedia.org https://en.wikipedia.org/wiki/Life-cycle_cost_analysis*

Design Criteria

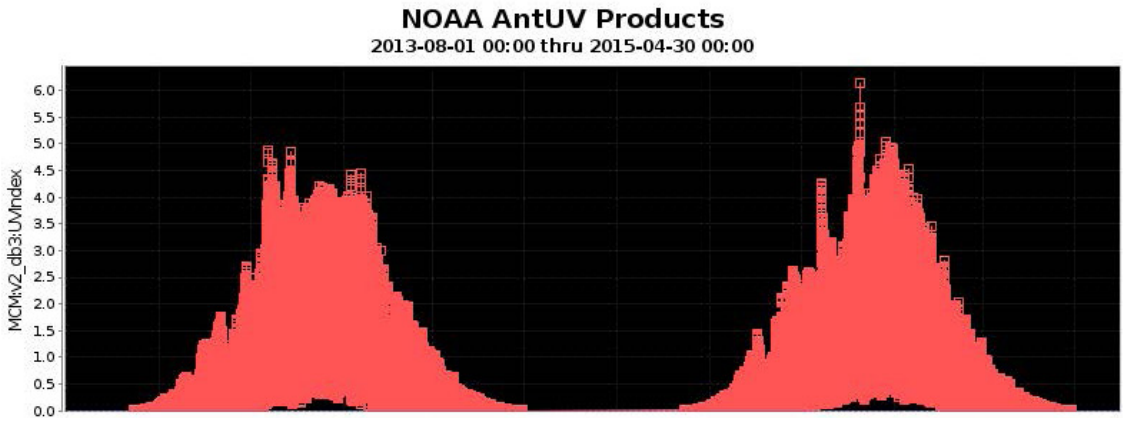
BUILDING CODES
2015 ICC INTERNATIONAL BUILDING CODE (IBC)
2015 ICC INTERNATIONAL FIRE CODE (IFC)
2015 ICC INTERNATIONAL FUEL GAS CODE (IFGC)
2015 ICC INTERNATIONAL ENERGY CONVERVATION CODE (IECC)
2015 ICC INTERNATIONAL PLUMBING CODE (IPC)
2015 ICC INTERNATIONAL MECHANICAL CODE (IMC)
2015 ICC INTERNATIONAL EXISTING BUILDING CODE (IEBC)
2014 NFPA 70- NATIONAL ELECTRIC CODE (NEC 2014)
2012 NATIONAL ELECTRICAL SAFETY COE (NESC) IEE C2-2012
BUILDING DESIGN CRITERIA

Design Wind Speed (Ultimate Wind Speeds)
Risk Category 1= 150 MPH
Risk Category 2= 170 MPH
Risk Category 3= 180 MPH
Risk Category 4= 180 MPH
Design Temperature= -42 F (ASC)
Ground Snow Lead = 40 PSF
Seismic Design Category A

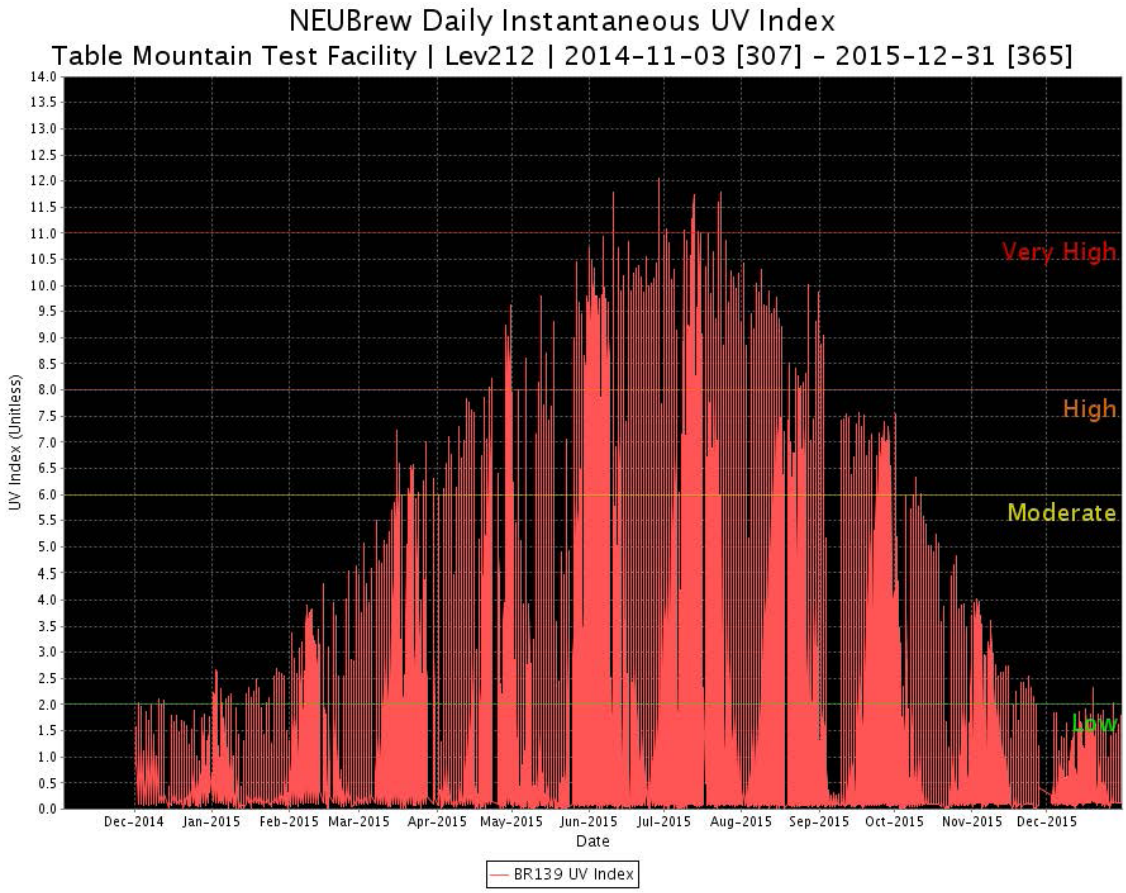
ULTRAVIOLET
The UV Index is a measure of the sun-burning ability of solar irradiance, is a unit-less value and is proportional to the instantaneous erythemal dose rate. The effect on the building shell will be the degredation of components that are sensitve to UV radiation such as paint colors and butylrubber products such as applied waterproofing, among others.

Values greater than 8 are considered high. Values greater than 11 are considered extreme by the World Meterological Organization.

Data recieved from NOAA compares McMurdo Station, Antarctica and Boulder, CO. Based on the data received, McMurdo Station peaks at approximately 5.5 and Boulder, CO peaks at 11.0. Boulder, CO has approximately 5 months above 5.5. Inferred from this is that component selection needs to take into account the effects of UV exposure, but that products used at McMurdo Station should see a longer lifespan than the same product used in a location such as Boulder, CO.



Data UV index values for two austral summer seasons at McMurdo (Arrival Heights) from August 2013 through April 2015.



Daily UV index values for Table Mountain (Boulder), Colorado Dec 2014 – Dec 2015

Benchmarking

The section of the report investigates solutions used for the building shell at a number of other recently constructed Antarctic Research Stations and Arctic facilities. It provides an overview of the systems used illustrated with photos and a typical joint detail and explains the advantages and disadvantages of each. The systems considered are:

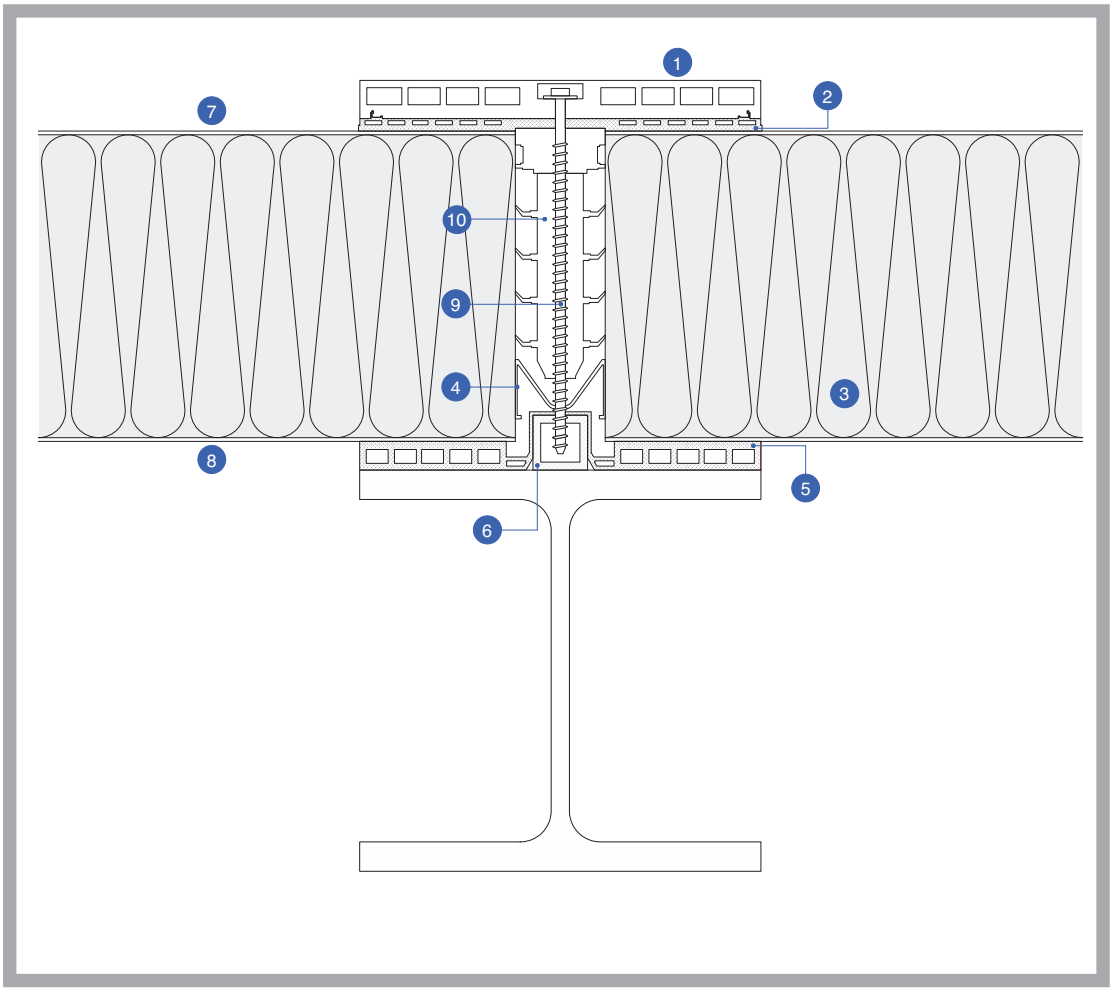
SYSTEM	*PRECEDENT STATION*	*NATIONALITY*
Metal Composite panels	Neumayer III, Bharati	Germany, India
Structural Insulated panels (SIP)	Scott Amundsen Base	USA
Timber engineered panels	Princess Elizabeth	Belgium
GRP panels	Halley VI, Juan Carlos 1	UK, Spain

ANTARCTIC PRECEDENTS

Information has been gathered from questionnaires issued to other Antarctic operators and designers of Princess Elizabeth (Belgium), Neumayer 3 (Germany), Concordia and Dumont Duville (France) and Bharati (India) and from the specific input of Hugh Broughton, architect of Halley VI (Britain), Juan Carlos 1 (Spain) and the Atmospheric Watch Observatory at Summit Station (USA), Greenland for the NSF.

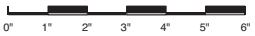
The systems used at other Antarctic Stations provide useful precedence for the analysis of building shell systems for the modernization of McMurdo. However all these stations are in the region of 15-20,000 square feet in area, which is significantly smaller than the McMurdo project. In addition Neumayer III, Halley VI and Concordia Stations are located on permanent ice sheets and incorporate hydraulic lifting systems to climb above rising snow levels. This leads to specific movement criteria for the shell which are different to those prevailing at McMurdo. As a result, this section of the report also includes an overview of recent Arctic architecture. Examples provided are in Svarlbard and Greenland and illustrate the approach taken in these locations to the design and construction of public buildings in exposed locations, with significant snowfall, low temperatures and located on permafrost.

Metal Composite Panels



Key

1 Aluminum cover strip
2 Water proofing
3 6 5/8" polyurethane foam insulated core with U-Value = 0.138WsqmK
4 Metal spacer
5 Sealing
6 Screwing channel welded to structure
7 Enamel coated micro-ruling galvanised steel sheet
8 color coated standard-ruling galvanised steel sheet
9 Fixing screw
10 Polyamide insulation sleeve



McMurdo Station Envelope

Cladding detail study

Bharati Indian Antarctic Research Station

Scale: 6" = 1'0" @ ANSI B

Sandwich panels with metal outer skins and cores of rigid closed cell insulation, such as rigid polyurethane or polyisocyanurate, are commonly used to enclose cold store factory and storage units. These are used in situations where internal temperatures are as low as -500F and will form a sealed monolithic envelope. Cold Store systems have tested thermal resistance up to R-49 at 6" thickness of insulation core, and greater if the core is thicker.

Metal Composite Systems

Cold store systems have been used for cladding Neumayer III and Bharati Indian Research Station. Composite cold store cladding has also been used recently by IPREV to clad warehousing at the French Dumont Durville Station. At both Neumayer and Bharati accommodation within the bases is provided by insulated adapted ISO shipping containers. The cladding provides the outer shell for the building and is fixed to a steel frame. The system was engineered by Ramboll IMS of Hamburg and manufactured by Kaefer. Bharati was also designed by IMS Ramboll in collaboration with Bof Arkitekten of Hamburg. Environmental conditions at Neumayer are:

- Temperature extremes: 36°F to -58°F
- Annual mean: -56°F
- Average high: 28°F Jan (midsummer) -7-6°F July (midwinter)
- Average low: 20°F Jan (midsummer) -21°F July (midwinter)
- Average wind speed: 19 knots (22 mph)
- Peak gust: 100 knots (116 mph) July 2013
- Sunshine hours: 1430 per annum

Standard cold store systems are manufactured by mainstream construction companies such as Kingspan. Panels are generally around 4' wide, based on standard metal coil widths with lengths determined by building design and anticipated winds during construction. The core material is selected to be fire resisting and self-extinguishing and can offer excellent thermal resistance at the appropriate thickness. Panels can be fixed to the steel structure using brackets, allowing for tolerance and movement. Panels are fixed to the brackets using single stainless steel or nylon bolts or using separate stainless steel fixings for inner and outer fixing of skins into a continuous polyamide sleeve, creating a thermal break and reducing cold bridging effect. The precise specification and number of fixings used will depend on wind load on the building.

Joints between panels are commonly tongued and grooved with a double scarf joint for improved fire and thermal resistance and joints are sealed with butyl sealing compound added on site. A jointing cover strip can be applied for additional weather protection. Outer facings can be specified to suit the location with options for coatings to prevent corrosion on more humid sites close to the sea.

At Bharati temperatures range from 41°F to -40°F and winds can gust up to 180 mph. Micro-profiled steel skin cold store panels were finished with PVDF enamel and joints were covered with a 8 ½" x 1" aluminum strip. Joints were sealed with neoprene strips, although the successful sealing between panels proved one of the greatest technical challenges of the project. Insulation was provided by a 6 5/8" polyurethane core.

Advantages

Metal Composite Systems

- Single stage installation process – the outer face provides the architectural finish
- Very durable and strong
- Good fire resistance can be achieved
- System can be prefabricated to include glazing and doors etc. with the benefit of single sourcing
- Proven at Neumayer 3, Bharati and other Antarctic projects
- Standardized system proven to -40°F throughout food and beverage industries
- Economic as long as system is not too bespoke

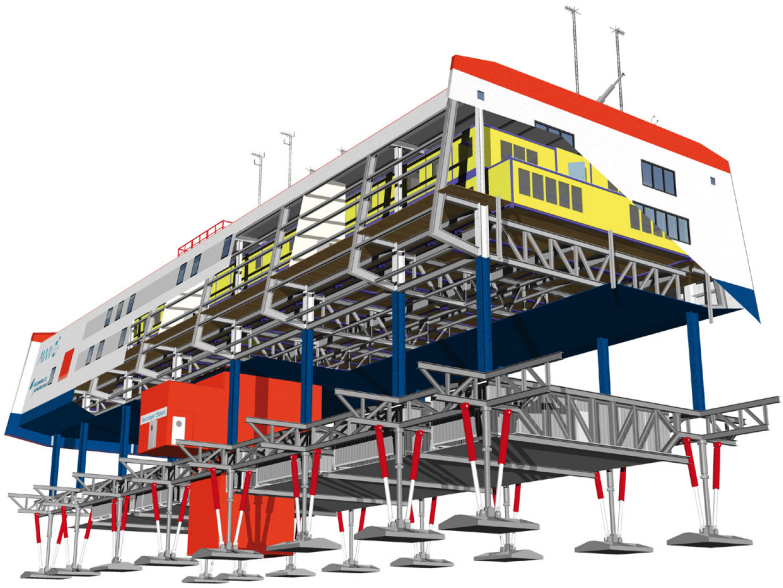
Disadvantages

- Panels cannot be cut or easily adapted on site. Future installation of science equipment and services, especially the introduction of service penetrations, is not easy.
- Panel sizes dictated by standard metal coil widths, creating more panels, more fixings and more time in installation
- Nylon fixing bolts are required to hold the layers of the panel together to prevent delamination of panels under wind suction loads. Concerns over the use of nylon fixing bolts: work hardening, fracture, cold bridging, UV degradation
- Panels are made using metal components with risks of cold bridging, thermal expansion and contraction. We understand that panels moved apart after time at Neumayer III due to expansion and contraction, leading to freeze: thaw action of condensation and eventually leading to ice penetration of the building envelope
- If joints do open up the thermal integrity and air tightness of the system could be compromised
- Complex corners and curved geometries are hard to form so it is harder to create aerodynamic shapes, although at Nuemayer and Bharati panels are designed to create chamfered edges to improve aerodynamics
- Panels are heavier and can be difficult to move in higher winds
- Concerns over aesthetics because of visible bolt heads and edge details
- Cold store panel design life might not meet the requirements of the project program

Benchmarking

Metal Composite Systems

Neumayer Station, Germany, 2006

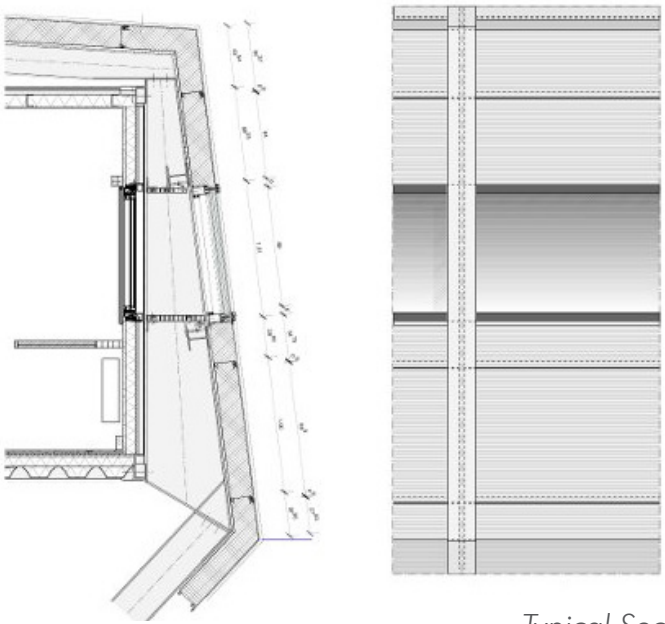


Typical Section

Neumayer station is comprised of pre-manufactured modules that are then protected by an envelope of a 9" composite prefinished metal panel. The outer and inner metal skin serves as the wind and vapor barrier, respectively.

Metal Composite Systems

Bharathi Station, India, 2014



Typical Section

Similar to Neumayer, the Bharathi station is comprised of 134 shipping containers that are then enclosed by an outer, protective envelope. This envelope consists of a composite prefinished metal panel. The outer and inner metal skin serves as the wind and vapor barrier, respectively.

Metal Composite Systems

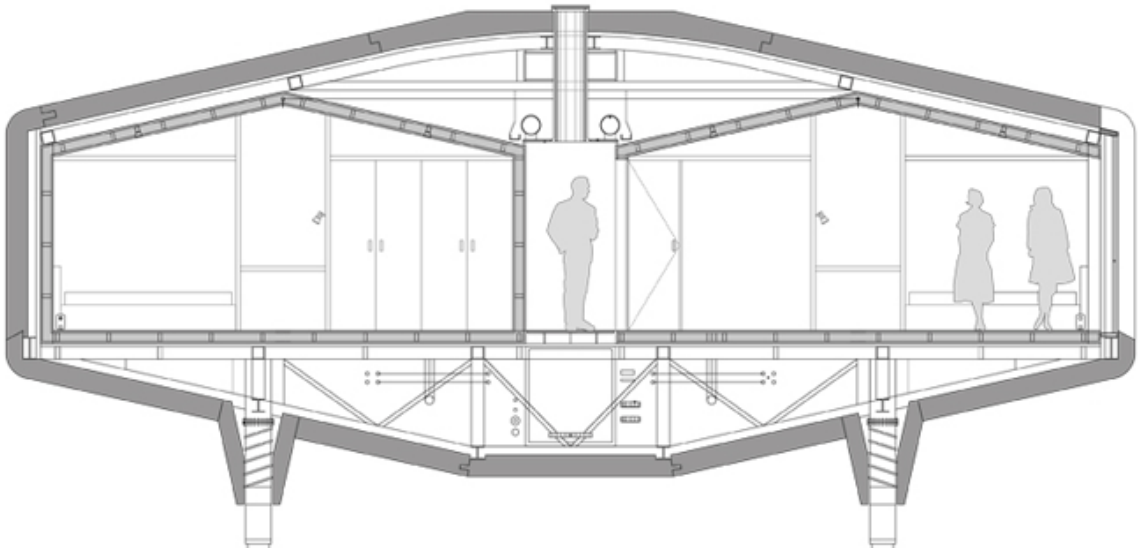
Jang Bogo Station, Korea, 2015

Typical Section

Jang Bogo station is comprised of pre-manufactured modules that are then protected by an envelope of a composite prefinished metal panel. The outer and inner metal skin serves as the wind and vapor barrier, respectively.

Metal Composite Systems

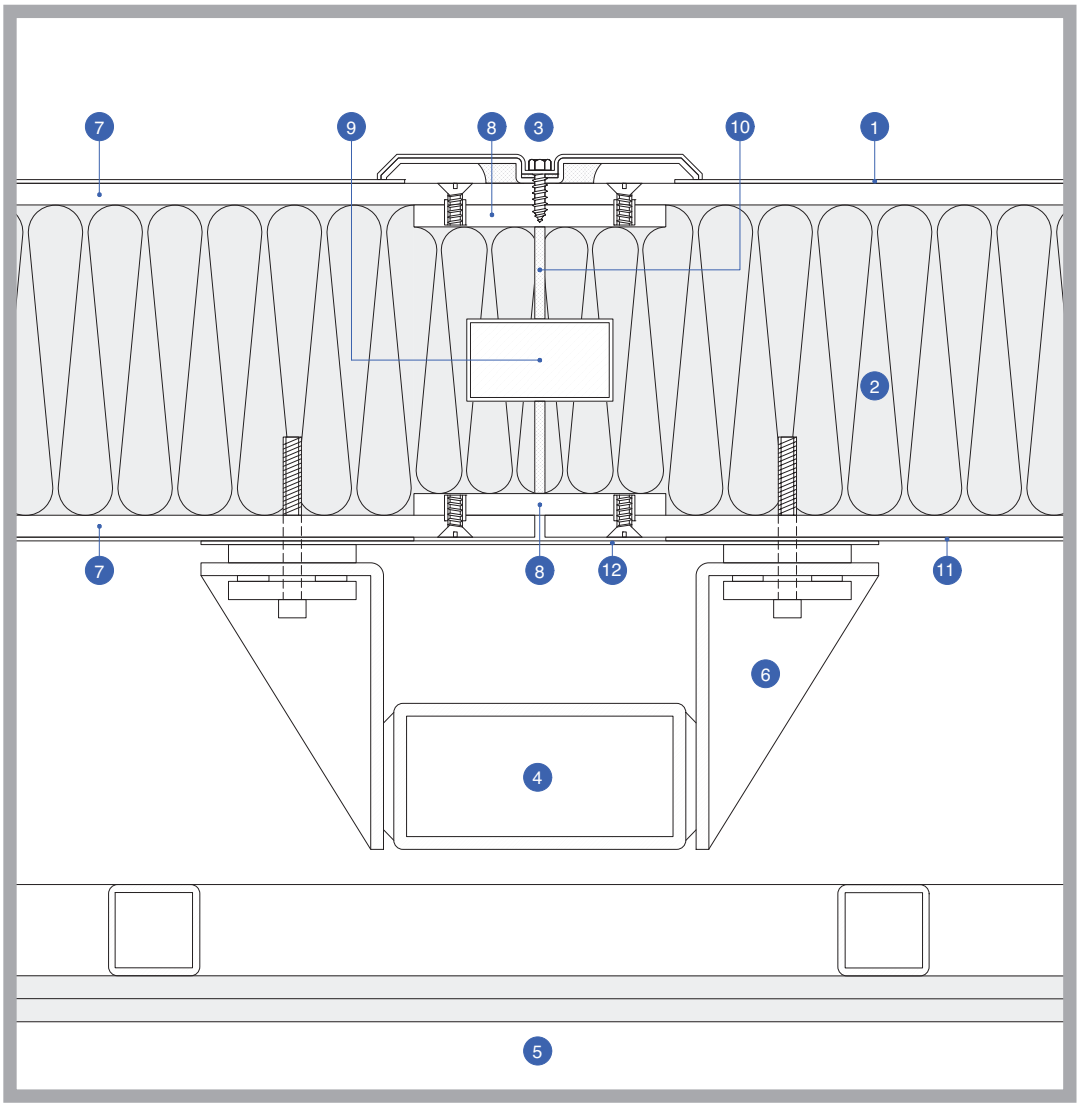
Commandre Ferraz Station, Brazil, 2016-2018



Typical Section

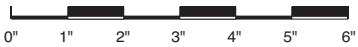
Brazil's Ferraz station is comprised of pre-manufactured modules that are then protected by an envelope of a 9" composite prefinished metal panel. This panel is separated from the interior walls by a 20" "Buffer Zone" that is held to approximately 50F. Glazing from the inner wall to the outer wall through this buffer zone is surrounded by a continuous 'jamb.'

Structural Insulated Panels



Key

1 Color coated aluminum architectural facing
2 SIP panel with 6 11/16" extruded polystyrene insulation core
3 Aluminum cover strip and sealing system
4 Steel super structure
5 Inner linings
6 Fixing bracket
7 7/16" OSB board
8 OSB spline
9 EPS spline
10 Field applied foam
11 Factory applied vapor barrier
12 Field applied vapor barrier



McMurdo Station Envelope

Cladding detail study

Amundsen Scott US Antarctic Research Station

Scale: 6" = 1'0" @ ANSI B

Structural insulated panels (SIPs) consist of an insulating layer of a rigid core sandwiched between two layers of structural board. Most commonly they are made of Oriented Strand Board (OSB) sandwiching a foam core made of expanded polystyrene (EPS), extruded polystyrene (XPS) or rigid polyurethane foam. SIP cladding systems can also incorporate several other components such as studs and joists, additional internal insulation, external waterproof membrane, vapor barrier and air barrier. Crucial to the successful application of SIPs in Polar Regions is the design of the spline or connector piece. Maintaining insulation values through the spline can be achieved with a rigid foam core, which fits between panels, and overlapping OSB splines, which span between one panel and the next and help draw the panels together, improving weather resistance. The spline needs to be designed to minimize frictional resistance when panels are pulled together. Typically SIPs tend to come in sizes from 4 feet to 24 feet in width with the largest panels achieving the best levels of insulation (the spline connection being the weakest thermal point in the system).

Structural Insulated Panels

SIPs have been regularly used in Polar Regions for cladding buildings, the best example being the Elevated Station at South Pole, which has to operate within the following climatic parameters:

- Temperature extremes: 7.5° F to -117° F
- Annual mean: -56° F
- Monthly mean: -8° F Dec (midsummer) -76° F July (midwinter)
- Average wind speed: 10.7 knots (12.3 mph)
- Peak gust: 48 knots (55 mph) Aug 1989
- Elevation: 2,835 meters (9,306 feet) – note altitude effects equalization of air density between glazing cavities and exterior, impacting on feasibility of gas filling

The cladding system at South Pole was developed by Ferraro Choi Architects and manufactured by Enercept of Water Down, South Dakota. The system is formed with SIP panels comprising a 15" core of Extruded Polystyrene with 7/16" sheets of Oriented Strand Board (OSB) forming the inner and outer face. The three parts create a stress skin panel, an engineered assembly that is stronger than the sum of its parts. Panels typically come in four-foot wide sections with custom lengths of up to sixteen feet. Panels are fixed back to a steel frame using continuous clips. Connections between panels are formed with internal splines of EPS and external splines of OSB, with the joint sealed using field-applied foam. We understand that frictional resistance between EPS splines and EPS cores created issues during construction leading to air infiltration and development of freeze thaw cycles in cladding joints ("A model for freeze-thaw cycling of the South Pole Station exterior sheathing", Phetteplace and Weale, CRELL, 2007). This can now be overcome by encasing splines with PTFE (polytetrafluoroethylene or Teflon) to reduce frictional resistance during installation (easy factory process) or by adding an additional layer of ply to the inner face of the cladding to reduce air infiltration (labor intensive on site).

Vapor barriers were factory applied to panels, with an on site application over joints. An external waterproof membrane was not installed because the temperature is so low and air so dry that there was no risk of water penetration through the outer board. If this were perceived as a risk the outer board can be specified at a suitable water-resisting grade or an additional bitumen impregnated board can be added to the panel. At South Pole the SIP panels are over clad with alternating 4' and 2'5" wide aluminum facings screw fixed to the SIPs. We understand that the entire system provides thermal resistance of R-70.

Advantages

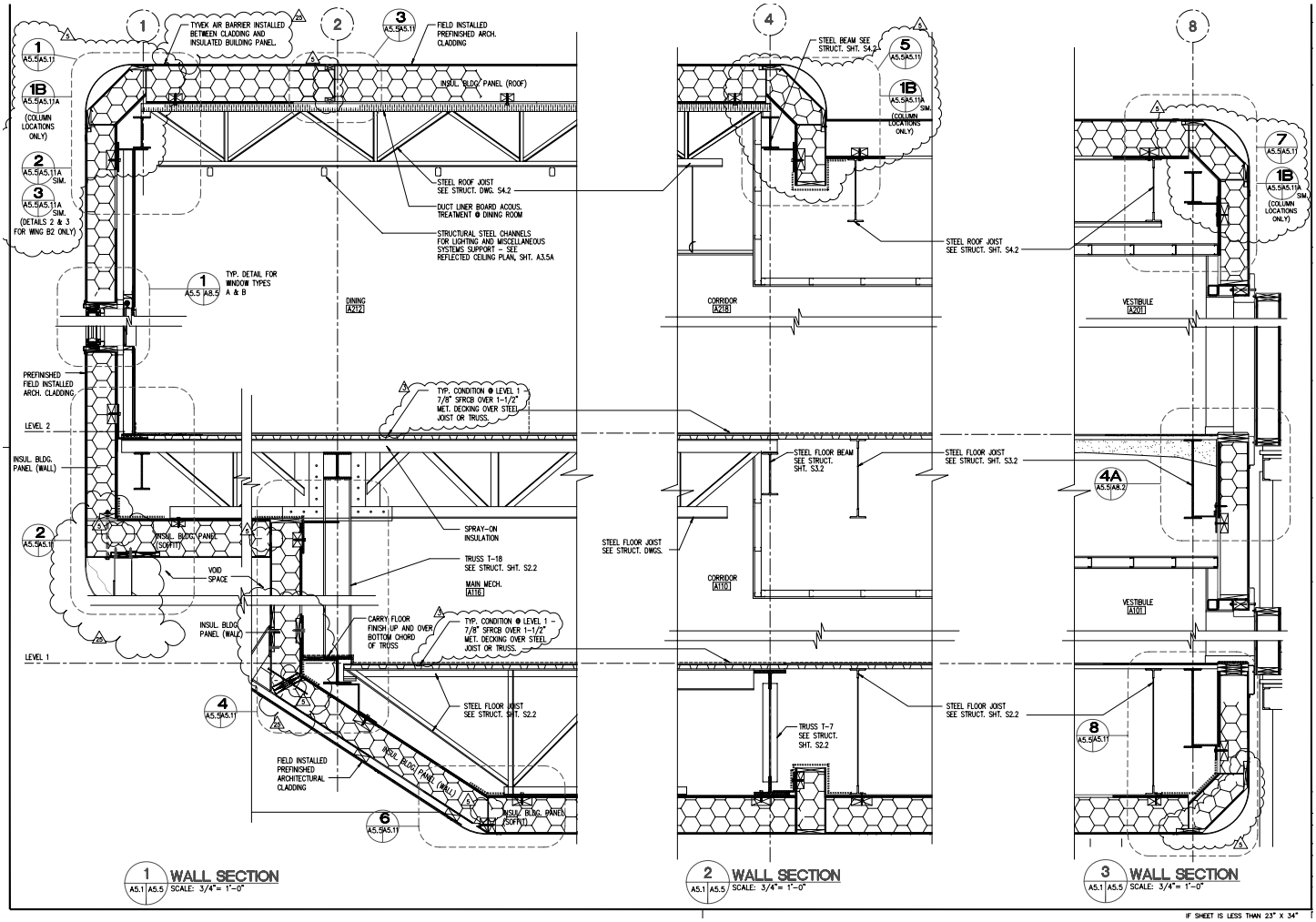
- With finishing panels separate from SIPs, joints can be staggered to help prevent water and spin drift ingress
- Standard SIP junctions regularly used in the US construction industry can be adopted. The use of PTFE (polytetrafluoroethylene or Teflon) to reduce friction when drawing panels together can ease installation.
- Junctions are standardized to simple square end connections wherever possible, using prefabricated chamfered panels and formed outer cladding profiles to form any shapes needed for aerodynamics, e.g. the curved form of the windward face of South Pole Station. Curved SIP panels are also possible to manufacture using ply outer sheets and injection molded insulation.
- Panels can be easily adjusted on site as they are a joinery item
- Science equipment can be relatively easily installed in the future using e.g. Brattberg ports
- Limited R&D required as system is well established within US construction market and was used

Structural Insulated Panels

extensively at South Pole.
- Involves relatively simple adaptation of off the shelf systems and components
- Less stoppage time from high wind as panels are smaller, weigh less and therefore move around less in high wind. A typical SIP panel might measure 4' by 8' and weigh around 10lbs per square foot (at 10" thickness)
- Multiple options for finishing panels are available. The outer skin of the SIP panel could also be pre-finished in aluminum, coated steel, timber boarding or GRP, further reducing time on site
- System is tried and tested at the South Pole and other Antarctic stations (e.g. New Bransfield House, Rothera British Antarctic Research Station, 2011)
- Cost effective

Disadvantages

- If larger, heavier panels are used, they will impose greater load on building structure
- Risk of delamination of the panels under high suction loads – structural integrity relies on the bond between OSB boards and insulating core. The risk can be reduced by incorporation of internal studs and battens but these increase risk of cold bridging – see photo of Halley V.
- Fire risk using EPS – British Antarctic Survey have forbidden use of EPS as a core insulation material following a fire at their Rothera Station Bonner Laboratory. This was caused by an electrical short in the EPS causing fire to spread through the cladding system.
- If elements are separately sourced (e.g.. SIPs, outer facing, windows, doors etc.), it will require greater co-ordination and control during prefabrication. There will also be many more components to install and fix on site requiring more time and greater site accuracy
- The installation of many smaller panels and components might lead to accumulative error during installation
- Large number of small external panels need face fixing with small screws – difficult in cold weather, although this might be mitigated with installation of external skin in factory, so only splines and cover strips need to be installed on site
- Installation is a multiple stage process with SIPs fixed from inside and finishing panels fixed from the outside with access equipment and windows and doors installed after
- Slower installation process does not lend itself as well to the cold climate as other systems which have larger panels, fewer fixings and fewer stages of installation
- Access equipment would need to be repositioned more often as panels are smaller
- The smaller components still require a crane so the work rate on site cannot be increased with larger number of teams unless there are more cranes available
- Problems of friction when drawing panels together. The use of PTFE coated splines to reduce friction when drawing panels together can ease installation.
- Smaller components might require more regular adjustment on site for tightness of fit
- Resolution required on how to accommodate thermal movement within the cladding and between the cladding and the steelwork
- Maintenance, future adjustment or replacement of the panels might prove complicated if the system is made of multiple layers with staggered joints
- Larger number of panels means a larger number of brackets fixing back to primary structure
- Site application of wet sealants to fix site applied waterproof membranes to the exterior skin and vapor barriers internally in an environment, which lacks moisture and with ice covered surfaces can be difficult. Careful consideration will need to be made to the specification of wet sealants on site



Typical Section

Structural Insulated Panels

South Pole Elevated Station, USA, 2006

The envelope at the South Pole Elevated station consists of Pre-finished aluminum panels, wind barrier, 12"-wide SIPS panels and vapor barrier.

Timber Engineered Panels

While Mass Timber is relatively new to the continent, wood construction has been often used in Polar Regions for the primary structural and framing system. The example for using Mass Timber in Antarctica is the Belgium station, Princess Elizabeth. The station, located on the Utsteinen Ridge, has to operate within the following climatic parameters:

- Temperature extremes: 23° F to -58° F
- Average wind speed: 10.9 knots (12.5 mph)
- Peak gust: 134.7 knots (155 mph)
- Elevation: 1,382 meters (4,534 feet)

Key

1 Wall covering in woolen felt
2 Heavy duty Kraft paper with a thick continuous aluminum vapor barrier
3 2 15/16"multiplex wooden panel
4 15 3/4" lightweight expanded polystyrene insulation
5 1 5/8" multiplex wooden panel - linked to the lower board by means of 2 3/8" diameter cylindrical beech wood posts, fitted precisely into cylindrical holes in the polystyrene
6 1/16" EPDM waterproofing membrane
7 3/16" closed-cell polyethylene foam mat
8 1/16" stainless steel sheet
9 1/16" stainless steel cover plate bolted to multiplex wooden panel
10 Steel fixing plate
11 Timber structure
12 Field applied foam
13 2 3/8" diameter cylindrical beech wood posts link multiplex panels

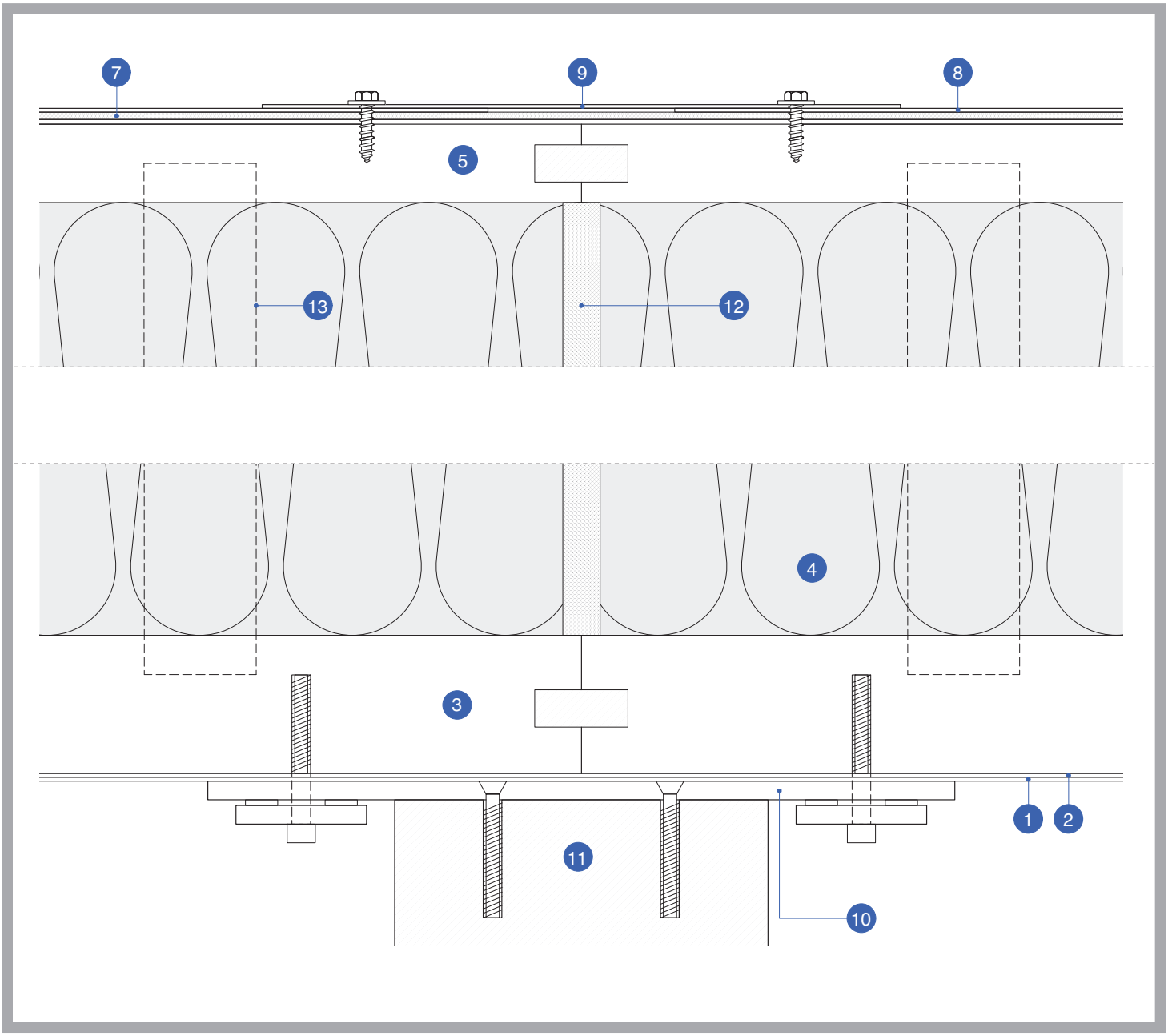
McMurdo Station Envelope

Cladding detail study

Princess Elisabeth Belgian Antarctic Base

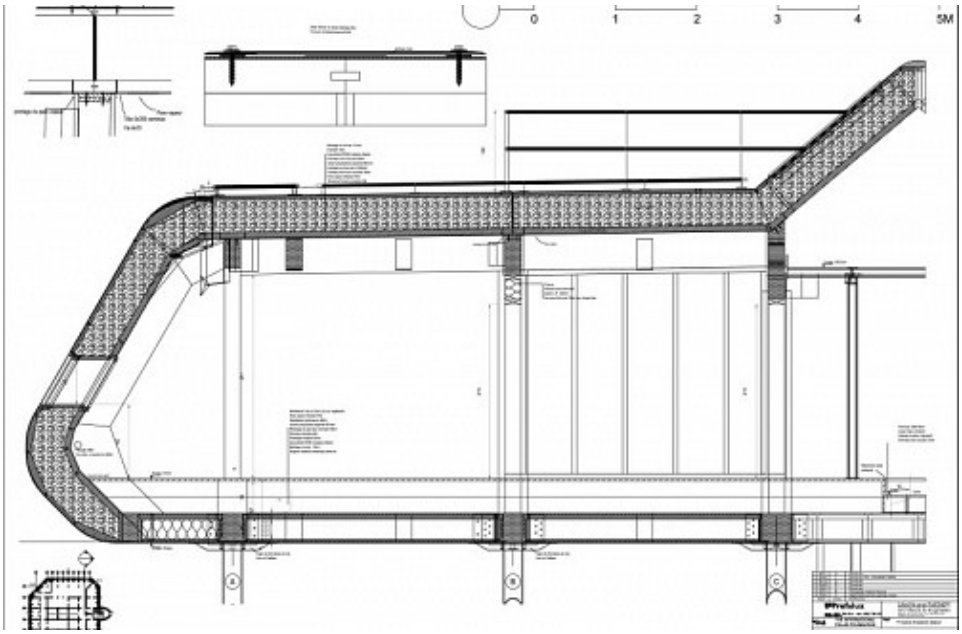
Scale: 6" = 1'0" @ ANSI B

Timber Engineered Panels



Timber Engineered Panels

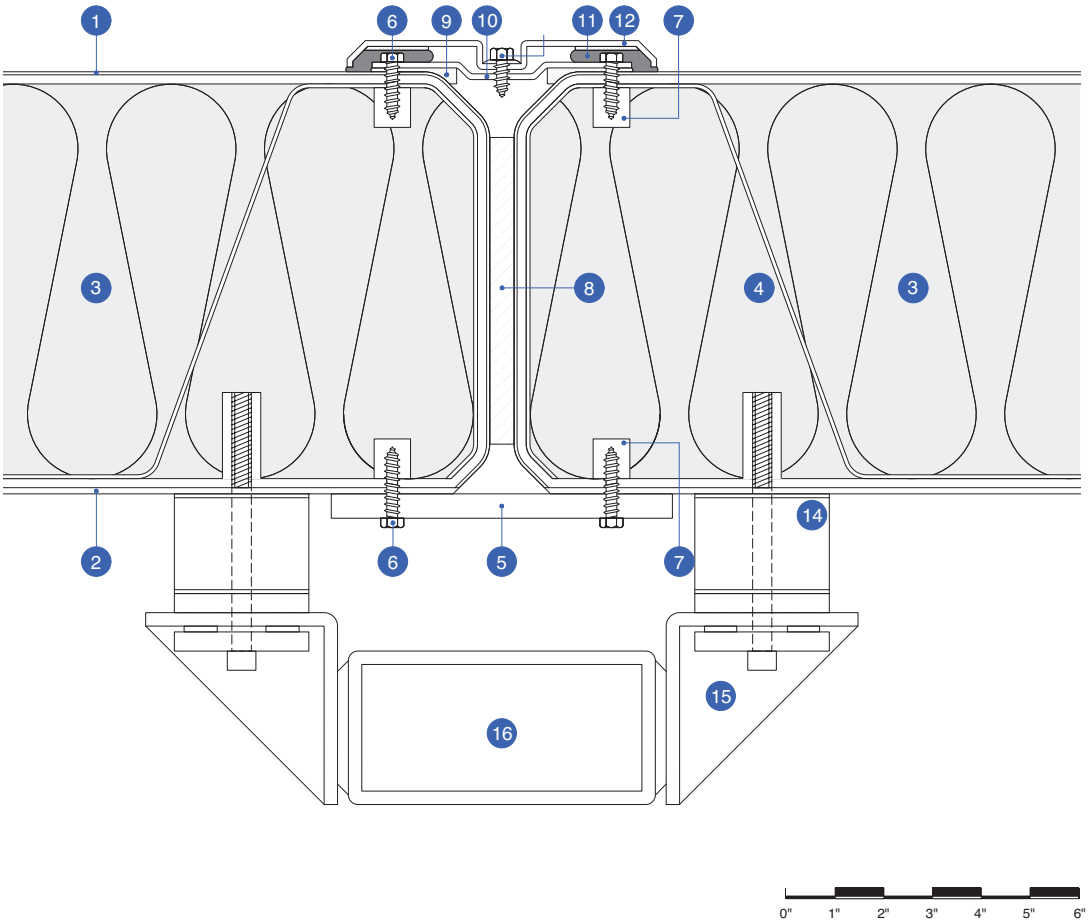
Princess Elizabeth Station, Belgium, 2013



Typical Section

The 9-layer envelope at the Princess Elizabeth station consists of 1.5mm stainless steel panels, 400mm of graphite-infused Expanded Polystyrene, and aluminum vapor barrier,an internal air barrier of craft paper, and an interior finish layer of wood felt.

GRP Composite Systems



Key

1 Outer skin of GRP cladding panel with UV resistant paint system on 260g/m2 (0.05lb/ft2) satin weave glass cloth protective layer on 50g/m2 (0.01lb/ft2) Ni-coated Carbon veil on 2 x 1080g/m2 (0.22lb/ft2) plain glass woven roving. Outer face spray-painted in factory with semi matt polyurethane acrylic paint and primer, Color - International Orange (Aerospace) RGB 255, 79, 0.
2 Inner skin of GRP cladding with 2 x 1080g/m2 (0.22lbs/ft2) plain weave glass woven roving finished with intumescent paint.
3 50kg/m3 (3.12lb/ft3) pentane blown closed cell polyurethane insulation, to achieve R-65.
4 1 x 1080g/m2 (0.22lb/ft2) plain weave glass woven roving ribbing as a continuous ribbon to bond inner and outer
5 Pre-manufactured & pre-drilled GRP joining strip
6 Coach screw
7 Pre-manufactured hard point for fixing
8 Compressed foamed EPDM (Ethylene Propylene Diene Monomer) gasket lined with PTFE (Polytetrafluoroethylene) coated fabric on outer surface of gasket and on both outer surfaces of cladding panels in contact with gasket
9 Compressed foamed EPDM gasket
10 Pre-drilled extruded aluminum joining strip, 1/8" gauge
11 Compressed foamed EPDM gasket with Neoprene backing, to suit sealing over coach screws
12 Pre-drilled extruded aluminum cover strip, 1/8" gauge, spray painted in factory with semi matt polyurethane acrylic paint and primer, color to match outer face of cladding panels
13 Self-tapping screw with self sealing washer at approximately 6" O.C.
14 Flexible elastic silicone cladding mounting screwed into FRP 'hard points' cast into panels
15 Steel cladding brackets welded to primary steel superstructure
16 Steel superstructure finished in intumescent coating to achieve 1-hour fire resistance. Steel grade selected for performance at extreme low temperature

McMurdo Station Envelope

Cladding detail study

Atmosheric Watch Observatory
Summit Station, Greenland

Scale: 6" = 1'0" @ ANSI B

GRP (glass reinforced plastic) is an ideal material for use in cold regions and has been successfully proven in use in Antarctica. Stations clad in GRP include SANAE IV (South African base), Concordia (French-Italian base), Halley VI (British base), Juan Carlos 1 (Spanish base) and Marion Island (South African sub-Antarctic base). Throughout Antarctica it is also used to clad numerous satellite domes and small buildings used both on station and in the field.

GRP Composite Systems

One of the earlier stations to be clad in GRP panels on a steel frame was the French – Italian Base at Concordia, completed in 1998. The panels comprised a 5mm fiber and resin skin with 150m polyurethane core. A timber joint was designed between the panels, which were then covered with an aluminum cover strip. Windows were pre-installed in the factory.

More recently, Halley VI and the Spanish Base Juan Carlos 1 were also clad in GRP panels fixed to a steel frame. Conditions at Halley are:

- Temperature extremes: 39°F to -67.5°F
- Annual mean -1.3°F
- Monthly mean: -18°F
- July (midwinter): -11.2°F
- Jan (midsummer): 28°F
- Average wind speed: 13.3 knots (15.3 mph)
- Peak gust: 80 knots (92 mph)

The cladding was formed by laying glass fiber fabric within plywood formers. 10" milled rigid closed cell CFC free structural polyisocyanurate insulation was then laid over the outer skin of fabric. Insulation was selected for its fire performance and structural integrity. In our project designing the AWO for NSF, the off gas properties of the insulation and their impact on the clean air sector science were also key issues to be considered and led to the choice of a polyurethane closed cell insulation core. The closed cell structure of the selected insulation was considered crucial because it prevents moisture forming in the insulation, which could otherwise freeze.

The inner layer of fabric is laid over the insulation with glass fiber webs included to tie together the inner and outer skins. The ties ensure resistance of panels to wind suction loads. The GRP resin is then vacuum infused through the fabric and insulation assembly and the whole panel allowed to cure.

The exterior (visible) face of the panels was finished with a gel coat and then over-spray painted with a high performance polyester urethane top coat paint system, commonly used on yachts and aircraft with excellent performance under conditions of high UV exposure and where panels are exposed to high thermal shock. The internal face of the panels was finished with two coats of intumescent latex, manufactured by Contigo International of Rochester, Indiana and achieved a Class 0 Surface Spread of Flame resistance.

Panels are bolted together through flanges internally and fixed with a gasket race and aluminum pressure plate externally to form a rigid stressed skin. The external joint is also further protected by an aluminum cover strip fixed through the joint with stainless steel coach screws. Connections between panels are sealed with an aluminum and flexible EPDM foam gasket sealed with an aluminum cover strip, which prevents ingress of spindrift or moisture. The panel construction achieved an R-value of R-65.

Advantages

- The panel forms both the outer weather resistant layer and the internal vapor barrier. Installation is therefore a single stage process, reducing time on site. By contrast a structural insulated timber panel system is a two-stage process with installation of SIPs followed by installation of architectural cladding (e.g. aluminum panels). At Halley VI the entire station was completely clad in GRP panels in a 9-week period
- The panels are relatively light – around 7.2lbs/sq.ft - and yet very strong so large panels can be manufactured (within logistic constraints), ensuring high levels of quality control and reducing time on site.

GRP Composite Systems

- GRP has very low thermal conductivity, typically 100 times less than steel, so is dimensionally very stable at extreme low temperatures. GRP is often used in cryogenic applications below -310°F. Most modern aircraft wings are fabricated in GRP components working at very high stress and fatigue levels well below the lowest Antarctic temperatures.
- Inner and outer skins of GRP panels can be linked together with resin infused fiber webs. These prevent delamination under extreme wind load without cold bridging, which can be significant with metal or timber panels.
- GRP resins can achieve high levels of structural fire resistance, which is vital in remote locations. The highest levels of fire resistance are achieved using phenolic or filled polyester resins. Using these resins the panels achieve 30-minute fire resistance from outside to inside and 30 minutes resistance from inside to outside, when tested to ASTM E119-10a,b for fire resistance of non-load bearing elements.
- The surface finish of the panels achieves ASTM E84-10, class 1 for Surface Spread of Flame on the outside and ASTM E84-10, class 0 for Surface Spread of Flame on the inside. The higher inside performance is intended to further reduce risk of fire and is achieved with the spray application of an intumescent latex over the panel. This paint is commonly used within the aircraft industry.
- Fire integrity of the envelope is maintained even where there are penetrations for building services using special high performance flexible cable transits, common in ships and manufactured by MCT Brattberg Inc. These can either be cast into the panels or machine fitted in the future, ensuring flexibility for future science needs. The ports can of course be used with all the systems reviewed in this report.
- GRP panels allow easy manufacture of more complex geometric forms as the panels are manufactured using molds. This means that three-dimensional aerodynamic forms can easily be formed in the factory as prefabricated components.
- No wet fixings or sealants used on site
- Larger panels mean less junctions on site, therefore fewer on-site installation problems and less risk of heat loss through joints. The roof panels at Halley VI measured 33' x 33' and were pre-glazed with roof lights. The wall panels measured 10' x 33' and were also pre-glazed. Bigger panels and less junctions also mean less points at which water or spindrift ingress can occur. Joints are sealed with compressible neoprene to maintain thermal performance.
- No scaffolding required. Scissor lifts moved less often.
- Tried and tested in Antarctica at Halley, SANAE IV, Juan Carlos 1 and Concordia as well as numerous smaller buildings and satellite domes etc which have been in use for up to 40 years.

Disadvantages

- Installation relies on a crane. There is no scope for multiple teams unless there are multiple cranes on site.
- Larger panels might be problematic with wind borne movement
- On site damage is hard to deal with
- Geometry of panel-to-panel joints needs to be carefully designed to avoid resin rich zones, which can be effected by thermal shock, an issue that occurred with the first panels installed at Halley.
- Process involves screw fixing of cover strips, pressure plates and gasket races on site. Difficult in a cold weather situation and time consuming
- Significant R&D may be necessary
- Probably more expensive than a timber or cold store based system, although this will depend on geometric complexity.
- Panels can be made by US companies, particularly from the marine and transport sector but the manufacture is a specialism and there are fewer fabricators than the other systems. An international supplier may be needed.

GRP Composite Systems

SANEA Station, South Africa, 2004

The SANEA station, now in its 12th year of service, is protected by a composite GRP envelope, consisting of __mm outer shell, ___" of Polyurathane foam insulation and a ___mm-thick inner shell. This system achieves an R-value of ___.

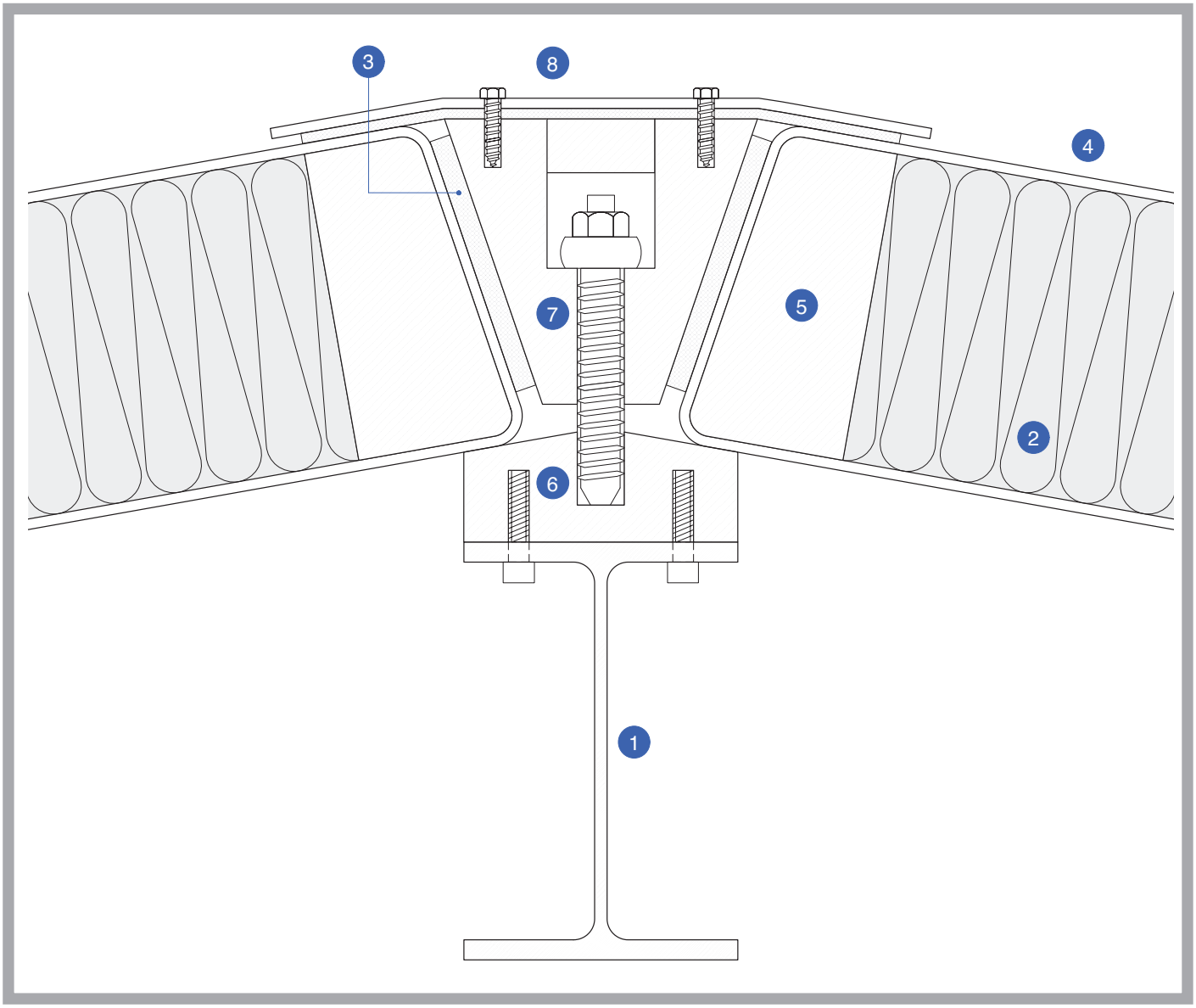
GRP Composite Systems

Concordia Station, France and Italy, 2005

Typical Section

The Concordia station is protected by a composite GRP envelope, consisting of __mm outer shell, ___" of Polyurathane foam insulation and a ___mm-thick inner shell. This system achieves an R-value of ___.

GRP Composite Systems



Key

1 Steel structure
2 6" polyurethane core
3 Compressible silicone foam joint
4 3/16" GRP skin
5 Timber framework within GRP panel
6 Timber furring fixed to primary steel structure
7 Secondary timber structure fixed to timber furring
8 Aluminum cover strip fixed to secondary timber structure

0" 1" 2" 3" 4" 5" 6"

McMurdo Station Envelope

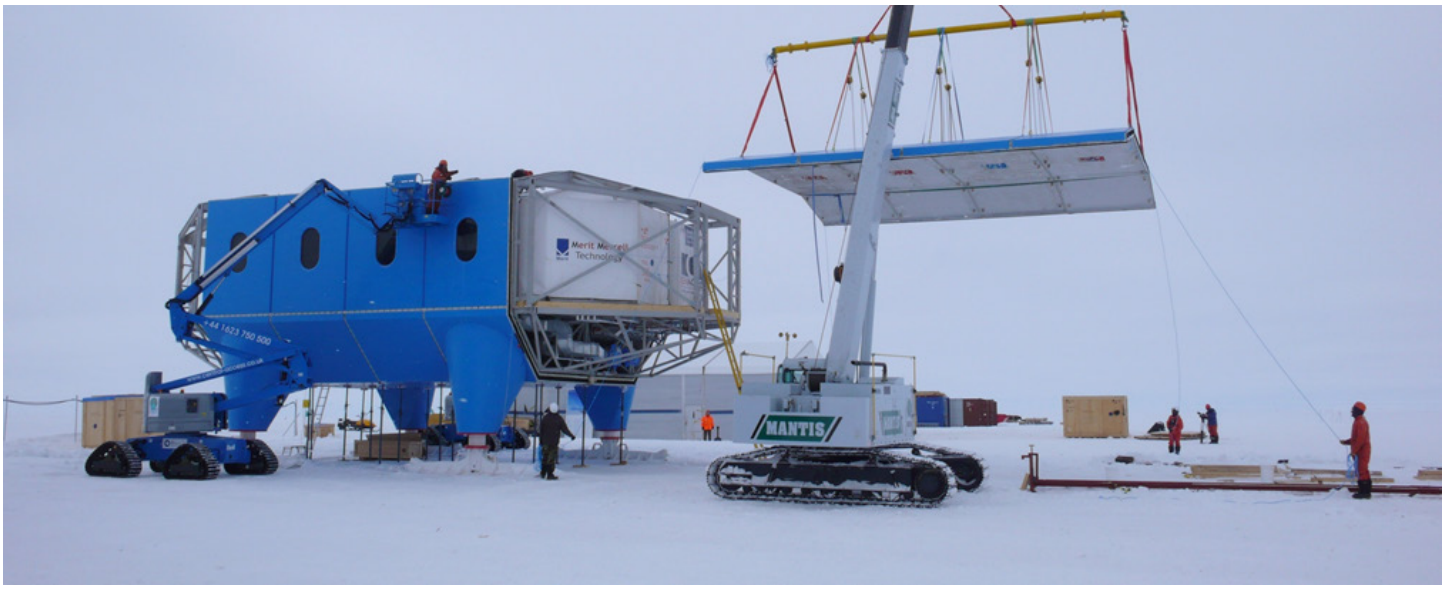
Cladding detail study

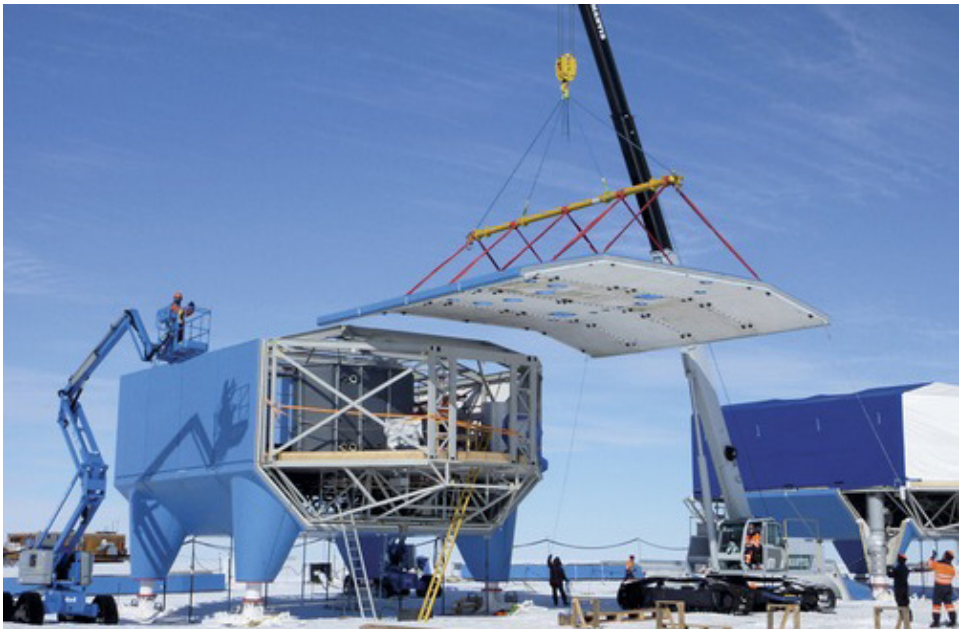
Concordia French - Italian Research Station

Scale: 6" = 1'0" @ ANSI B

GRP Composite Systems

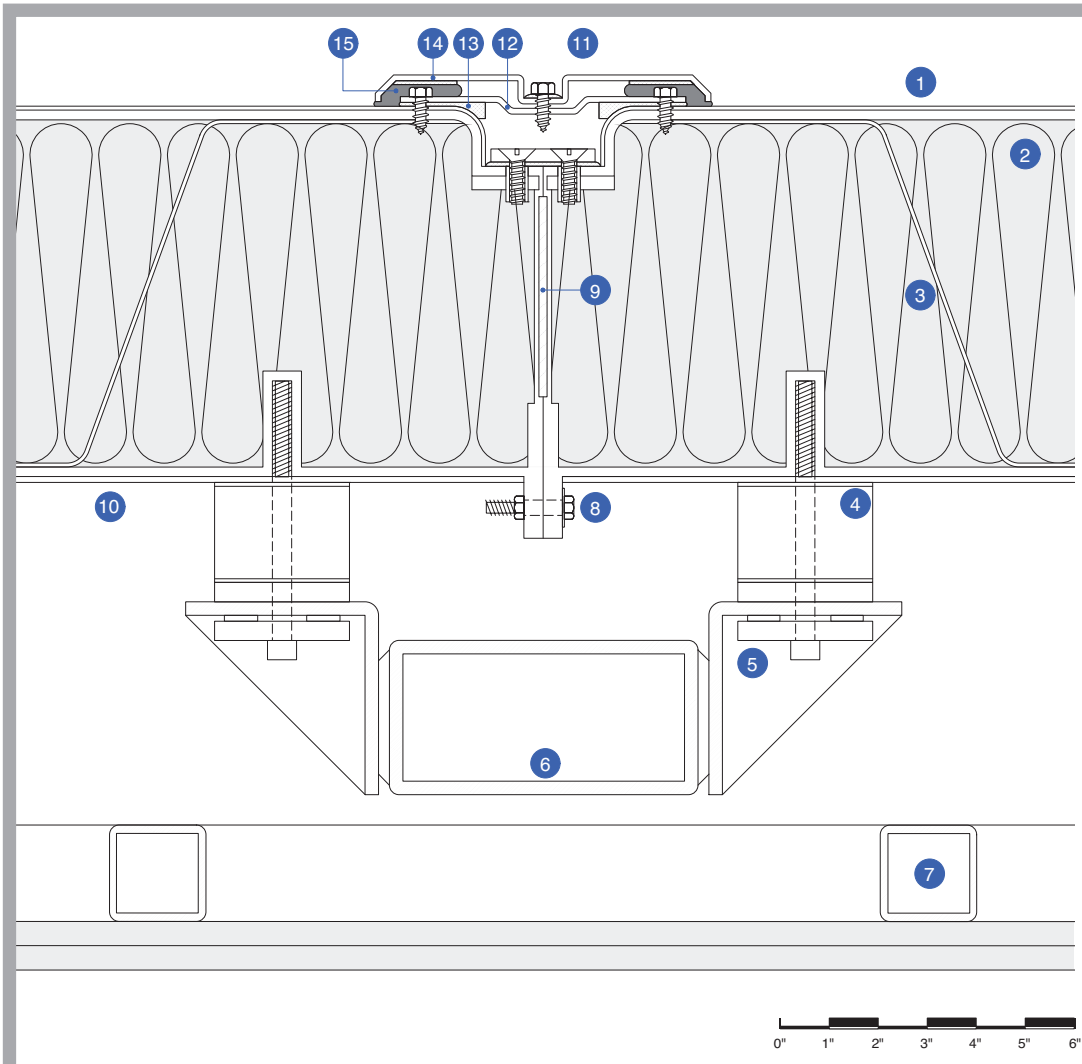
Halley VI, Great Britain, 2014





Typical Section

GRP Composite Systems



Key

1 Fiber reinforced polymer (FRP) outer skin to panels finished with gel coat and overspayed with polyurethane acrylic automotive paint to ensure UV stability. Filled polyesther resin used to achieve 30 minutes fire resistance
2 7 1/2" polyisocyanurate (PIR) closed cell foam insulation to give U-value of 0.113WsqmK
3 Resin infused cross fibres prevent delamination under wind load
4 Flexible elastic silicone cladding mounting screwed into FRP 'hard points' cast into panels
5 Steel cladding brackets welded to primary steel superstructure
6 Steel superstructure finished in intumescent coating to achieve 1-hour fire resistance. Steel grade selected for performance at extreme low temperature
7 Steel structure to prefabricated room pods (bedrooms, bathrooms, offices etc). Pods lined in Fermacell board selected for rigidity and acoustic performance
8 Panels bolted together through FRP flanges using stainless steel fixings
9 Continuous compressible neoprene insulation maintains thermal performance at joints. Insulation finished with PTFE to reduce friction during installation
10 Fiber reinforced polymer inner skin to panels finished with intumescent paint to achieve C-s3d2 (Class 0) surface spread of flame characteristics
11 Panels jointed with FRP jointing strip fixed with countersunk M10 stainless steel cap screws through compressed foam neoprene gasket
12 Extruded aluminum internal cover mounting strip
13 Aluminum mounting strip fixed with coach screws. Foamed EPDM compressed gasket seal between mounting strip and panel.
14 Extruded aluminum external cover strip finished with polyurethane acrylic automotive paint to match panel finish, fixed to internal aluminum mounting strip with self-drilling stainless steel fasteners
15 Junction cover gasket formed in foamed EPDM

McMurdo Station Envelope

Cladding detail study

Halley VI Antarctic Research Station

Scale: 6" = 1'0" @ ANSI B

ARCTIC PRECEDENTS

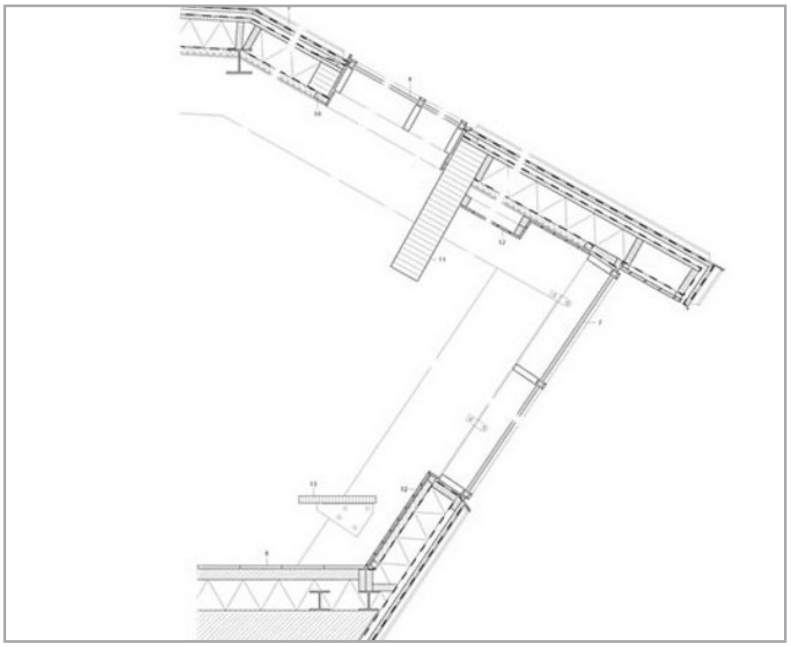
Having considered Antarctic Station precedents, it is also useful to study examples of recent architecture built in the Arctic, specifically in Longyearbyen in Svarlbad and Nuuk in Greenland. In both locations, notable public buildings located on permafrost have been constructed in recent years.

In both locations it is also important to note that the climate is far milder than at McMurdo due to the warming effects of the North Atlantic Drift. In Longyearbyen daily mean temperatures of -2.3°F in January rise to 41°F in July. Average lows are -5.8°F and average highs reach 44°F. The climate in Nuuk has cold, snowy winters and cool summers. Average lows are 14°F in January with average highs of 50°F in July. The city is the capital of Greenland and has a population of around 17,000.

Administration Building for the Governor of Svalbard, Longyearbyen, Svarlbard, 1998

This is a multi-purpose building designed by Jarmund Vigsnaes and which includes offices, dwellings and a prison. It is 19,000 square feet in area. The building has a timber structure, which is clearly expressed internally. Allied with internal timber boarded walls, this creates a warm, cocoon like feel. The exterior is clad in a standing seam metal skin (presumed to be zinc) with extensive glazing on the east façade, overlooking the bay and spectacular mountain scenery. Facades are inclined to improve aerodynamics. The building is elevated on small steel columns with precast concrete foundations, minimizing risk of heat warming the permafrost.

Svalbard Science Centre, Longyearbyen, Svarlbard, 2005



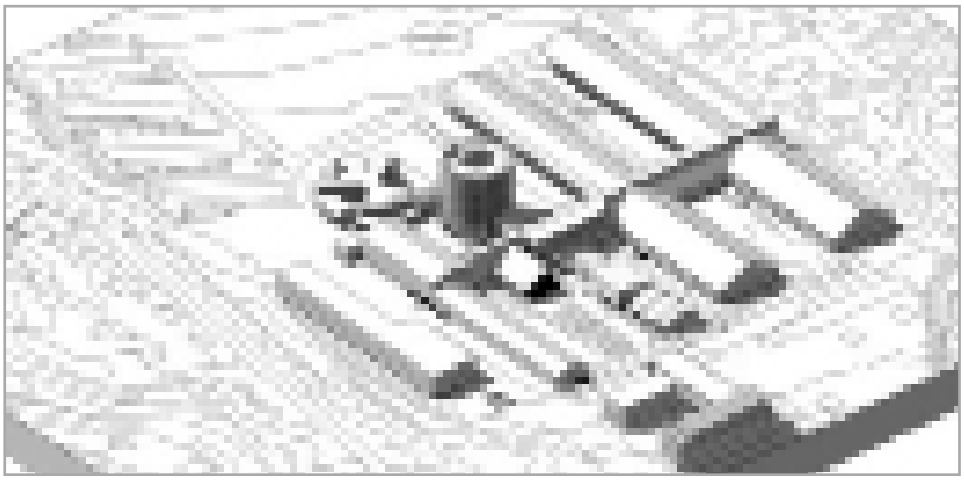
Typical Section

Also designed by Jarmund Visgnaes, the university science building has an area of 22,500 square feet. Climactic 3D simulations were conducted to understand the wind and snow movements as they pass through and around the site. This helped determine the form of the copper clad building and ensures there will be no accumulation of snow in front of doors or windows. The building is elevated on 390 steel columns. The gap under the building allows snow and winds to pass freely underneath and prevents the absorption of any heat into ground, preserving the permafrost. The architects chose pine and bold colors to bring a strong sense of warmth to the interior. The facility includes space for the Norwegian Polar Institute, a cultural and historic archive for the Governor of Svalbard and a new museum.

Cultural Centre of Greenland, Nuuk, Greenland, 1997

Designed by Schmidt Hammer Lassen, the 51,600 square feet cultural centre's design was inspired by Greenland's dramatic scenery of icebergs, snowfields and mountains. The principal façade is sheathed by an undulating screen of larch with the accommodation behind clad in profiled black metal faced panels. The screen was conceived as an architectural metaphor for the Northern Lights. Daylight penetrates the large foyer through roof lights and vertical glazing set into the larch external screen. The foyer serves as an indoor public piazza for the city and is divided into separate areas by three free-standing geometric structures housing the main facilities of the Cultural Centre: a square box for the television studio, a triangular structure for the café and a circular form for the multi-purpose auditorium which has seating for 550 people and can also be used as a cinema, a concert venue or conference hall.

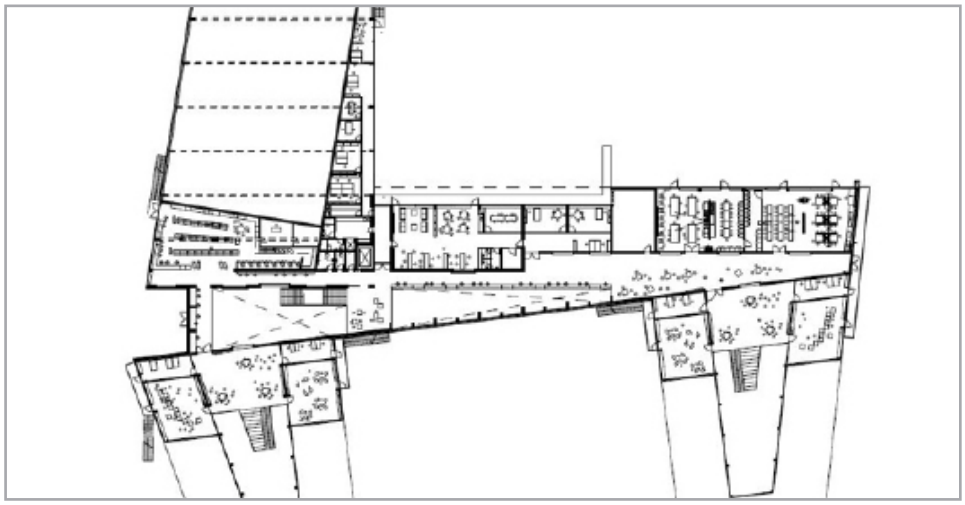
The Queen Ingrid Health Centre at Dronning Ingrids Hospital, Nuuk, Greenland, 2011



Campus Plan

The new 16,000 square feet health centre and national pharmacy form the first phase of a masterplan to renew the Dronning Ingrids Hospital. The building was designed by Schmidt Hammer Lassen. The designers drew inspiration from the ice floes that float around in the Godthåbsfjord and the building does appear to grow out of the ground just like a block of ice. Both the inclined facades and the roof are clad in copper giving a feel of strength. The unifying copper skin is appropriate for the building's inclined form and makes it stand out as a public building in contrast to the timber clad domestic stock. The texture of the copper, its patina and its ability to withstand the extreme climatic conditions of Greenland, were all important factors in determining the specification of the facing material.

Atuarfik Hans Lynge School, Nuuk, Greenland, 2013



Floor Plan

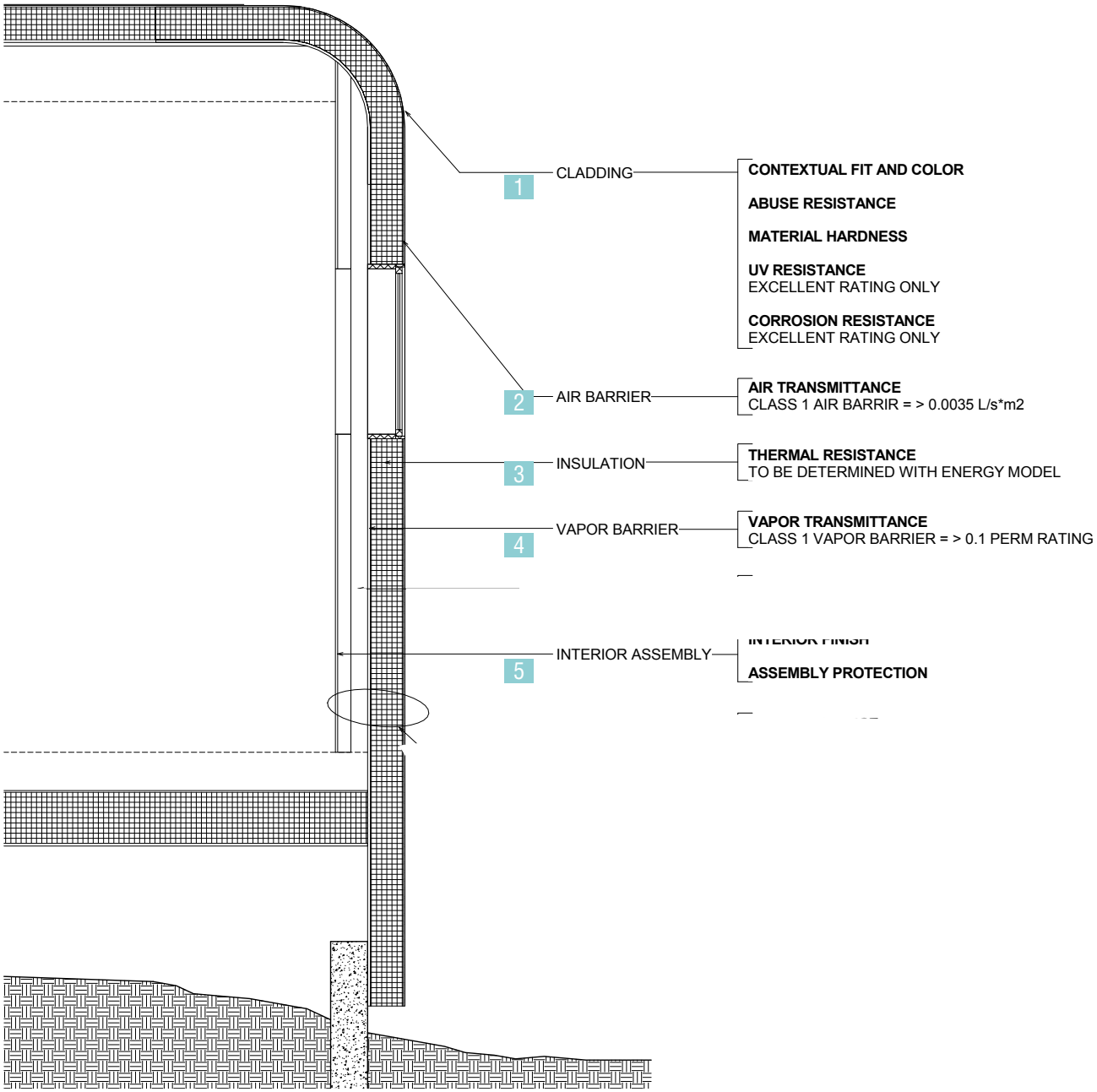
The 19,685 square feet school was designed by KHR Arkitektur (who also designed the larger University of Greenland in 2009). The building is set in a rugged location at the foot of mountains. A series of staggered classrooms branch off from a main school building in the centre, taking full advantage of views out to the harbour. Due to the topography of the site, the building is vulnerable to severe winds and influxes of snow and melting water. Large eaves have therefore been incorporated to protect the structure with a longitudinal stone gutter to defend the northern façade against rushes of water. Carefully angled roofs direct strong winds up over the building. The building is clad in timber. Internally the building is lined with acoustic panels, which give a natural feel alongside high sound absorption, high durability, natural breathability and low cost life cycle performance. The facades incorporate significant expanses of glazing to draw in natural light.

SECTION 2
TECHNICAL INVESTIGATION & RESEARCH

Components

The Design Criteria from the previous section are used to evaluate the components and collective assemblies that define the building envelope. The envelope assembly consists of multiple layers of components which each performing a specific function in protecting the interior from the exterior environment. These components, and their location in the wall assembly, are illustrated in the diagram below and include:

1. Exterior cladding
2. Air barrier
3. Thermal barrier (Insulation)
4. Vapor barrier
5. Interior finish assembly



METALS

A common cladding material used in both Antarctic and Arctic environments is metal, including carbon steel, stainless steel, copper, and aluminum.

General Description of metals

Metals are described as a hard and opaque material that can be formed into a sheet or plate. The properties of metals allow it to be pressed and bent without breaking. It can be fused (melted together) and exhibits the ability to be molded or shaped without exceeding its breaking point. Metals are described in terms of their physical properties.

"Those physical properties are strength, ductility, thermal conductivity, electrical resistance and conductivity, opacity and luster." [1]

Strength is defined as the ability of a material to resist deformation from its original shape when a stress is applied. It is typically measured in units of pressure or ksi (thousands of pounds per square inch).

Plasticity describes the materials ability to deform without fracturing and can be subdivided into two categories. Ductility is the solid material's ability to deform under tensile stress and malleability is the ability to deform under compressive stress.

Thermal Conductivity is the measure of a material's ability to conduct heat. It is measured in watts per meter kelvin (W/(m·K) or BTU-in/hr-ft^2-°F) . Variables of mass, temperature, time and length affect the way in which thermal conductivity is measured. Conductivity is referred to as the U-Value of a material. The inverse of conductivity is resistance. It is measured in kelvin-meters per watt (K·m·W−1) and is commonly referred to as an R-value.

Electrical resistance and conductivity are "the measure of a materials ability to conduct electrical current." Resistance is measured in ohm.metre (Ω.m) . Conductivity is represented by the Greek letter σ (sigma), but k (kappa) (especially in electrical engineering) or y (gamma) are sometimes used." [2]

Opacity is the measure of a materials ability to not be penetrated by visible light. Opaque objects will not let light pass through them. They are neither transparent nor translucent. An opaque surface does not transmit light it can only reflect, scatter or absorb all the light that falls upon it.

Luster is the way light interacts with the surface of a crystal, rock, or mineral.

Corrosion

One factor that impacts the physical properties of a metal is corrosion. "Corrosion is a natural process, which converts a refined metal to a more stable form, such as its oxide. It is the gradual destruction of materials (usually metals) by chemical reaction with their environment." [3]

All metals, except a few, are susceptible to oxidation. Oxidation is the chemical process by which an ionic chemical reaction occurs at the surface of a metal when in the presence of oxygen. This can happen in air or when metal is exposed to water or acids. The most common example is the corrosion of steel, which is a transformation of the iron molecules on the surface of the steel into iron oxides, most commonly Fe2O3 and Fe3O4.4 This is also referred to as rusting. When rust occurs, the metal forms a protective coating at the surface to hinder further oxidation from occurring and impacting the material's useful properties.

In order to resist corrosion, different steps can be taken to prevent it from occurring. Applied coatings can be painted or plated onto metals forming a protective coating that provides a barrier to corrosion. This type of protection is susceptible to chipping and cracking, which leaves the bare metal exposed to corrosion if a chip or crack occurs. Reactive coatings can be added to the surface of a metal and they form a chemically impermeable coating on the metal's exposed surface. With this type of treatment, extra inhibitors from a chemical reaction can help protect an exposed area that has become damaged by a scratch or impact. Anodization is the electrochemical treatment of metals (typically Aluminum) where the pores of the metal are densified and form a very thick and hard surface layer of the metal's oxide. If the surface is scratched, then the metals natural oxidation process takes over and repairs the mediate area around the scratch.

Components

Alloys

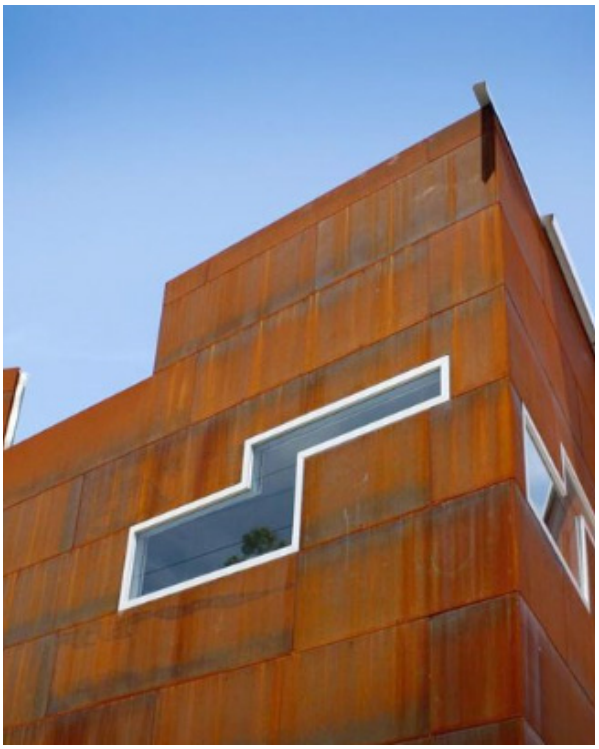
Metals can be combined to form a new material. An alloy is created when a base metal is combined with another metal or element to form a mixture of those materials. The metal must be in a molten state when the other metal or element is added. When they are combined, they become soluble and dissolve into the mixture forming the new alloy. An alloy allows for the physical properties of a metal to be changed so that its hardness, toughness, ductility or other characteristics are enhanced to make a better performing metal. Alloys can result in metals with higher strength to weight ratios, better corrosion resistance, or increased ductility.
Metal can also be heat treated to change their physical properties. "Heat treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve a desired result such as hardening or softening of a material. Heat treatment techniques include annealing, case hardening, precipitation strengthening, tempering, normalizing and quenching. It is noteworthy that while the term heat treatment applies only to processes where the heating and cooling are done for the specific purpose of altering properties intentionally, heating and cooling often occur incidentally during other manufacturing processes such as hot forming or welding." [4]
Metals are commonly referred to as either ferrous or non-ferrous. Ferrous metals contain iron. Non-ferrous metals do not contain iron.

Metals are typically formed or extruded into shapes which can be further shaped for an intended purpose. For this report, metal plate and sheet metal were investigated. Metal plates are metals that are formed into thin flat plates usually greater than 1/16" thick. There is more material and weight associated with plate and it is much stronger and resistant to impact than sheet metal. They can be used for structural purposes and also as a cladding material. Sheet metal is usually referred to as a thinner metal material and cannot be used for structural applications. Its thickness is usually measured in a gauge. Sheet metal only serves as a barrier to the environment. It ranges from the 32 ga (thinnest) down to 10 ga (thickest).

The different types of metals which were researched for this report were aluminum, copper, stainless steel, carbon steels, titanium, and zinc. All of these materials are typically used in the construction industry and applied in various ways to enclose a building. The individual metals were researched to determine their ability to standup to the environment, deal with the thermal stresses of very cold temperatures, their individual strength and rigidity, durability, and if they were aesthetically pleasing.

Components

1. Cladding



CARBON STEEL

Physical Properties – According to the American Iron and Steel Institute, Carbon steel is:

"...considered to be carbon steel when no minimum content is specified or required for chromium, cobalt, molybdenum, nickel, niobium, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 percent;or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60." [5]

Carbon steel is further subdivided into low-carbon steel, mid-carbon steel, and high carbon steel. As the percentage of carbon increases, a decrease in ductility occurs while the alloy's strength is increased.

- Low Carbon Steels/Mild Steels contain up to 0.3% carbon
- Medium Carbon Steels contain 0.3 – 0.6% carbon
- High Carbon Steels contain more than 0.6% carbon

Corrosion Resistance – Carbon steels will be affected by corrosion. Any humidity or water will cause the metal to rust or oxidize. The alloy of the steel does affect the corrosion rate of the metal. A carbon steel can be protected from corrosion using passive barrier protection, active protection, sacrificial protection, cathodic or galvanic protection, metallic coatings, organic coatings, and powder coatings.

Thermal conductance, electrical conductance & resistivity – Carbon steels typically have a mid-level of thermal conductance in comparison to more conductive copper or aluminum. Its electrical conductance is also characterized as mid-level. It exhibits a higher level of resistivity when compared with copper and aluminum.

Physical Appearance – Steel is usually coated or treated to have an opaque finish to protect it from oxidizing. Some steel alloys are formulated to be weathered, those are typically A606 steels (referred to commonly as Corten (trade name) or weathering steels. They are allowed to "rust" and the sacrificial layer of rust protects the steel below from further oxidation.

Constructibility and Workability – Carbon steel's use in many panel systems and other cladding materials is very common. It is readily available in the market place and comes in a variety of shapes and sizes. It can be manipulated easily with common tools. Its ductility allows for thinner gauges to be used. Steels typically can be worked easily using a lighter stronger material when compared to copper or aluminum.

Recyclability – "Steel is one of the world's most-recycled materials, with a recycling rate of over 60% globally." [6]

1. Cladding

STAINLESS STEEL

Physical Properties – Stainless Steel is an alloy of steel with a minimum of 10% chromium content by mass and other elements added to the metal. The material compared to mild steel has a higher strength and high ductility. The only metal with higher strength is titanium. Stainless steels are available in several different families, those are Austenitic, Ferritic, Martensitic and Duplex stainless steels. Stainless has a very good hardness and toughness. It can have its hardness increased further by additional processes, such as heat treating.

Corrosion Resistance – With the addition of the chromium to the material, it will not easily corrode like ordinary carbon steel. The chromium forms a chromium oxide and becomes a passive film protecting the surface from further corrosion by oxygen diffusion. It is susceptible to galvanic corrosion if it comes into contact with a dissimiliar metal.

Thermal conductance, electrical conductance & resistivity – Stainless steel has a very low thermal conductivity. It also had a very low electrical conductance and high resistivity.

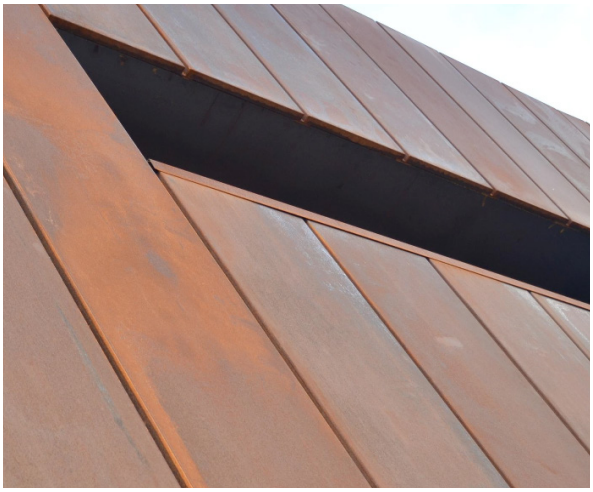
Physical Appearance – Stainless Steel does not need a protective coating due to the protective coating that the metal forms naturally. It can be polished, embossed, annealed, or coated to produce a finish different than the original metal. Finishes can be applied to stainless (polishing and brushing) that control the reflectivity of the metal's surface. Stainless steel can maintain its finish for a very long time requiring little or no maintenance. The material has good abrasion resistance and minor abrasions will have little to no impact.

Constructibility and Workability – Due to the hardness of stainless steel, it requires tools which can cut or manipulate the harder material when compared to other metals. Since its use is common, working with the material does not require a high level of specialized labor. Due to its molecular structure, welding is more difficult with stainless steel then carbon steel.

Recyclability – Very recyclable, 100% of the material that is recycled is put back into use.

1. Cladding

COPPER



Physical Properties – Copper is traditionally thought of as a "soft" metal with low mechanical strength, but high ductility. It is a non-ferous metal. It can be alloyed with brass and bronze to increase its hardness. Copper is light weight and has a mid level thermal expansion coefficient.

Corrosion Resistance – Copper does oxidize in the presence of oxygen and water. When copper oxidizes, a protective layer forms to protect the metal below from additional corrosion. The oxidation will turn blackish-brown and will eventually turn green with enough time. Copper is also susceptible to sulfides. It will tarnish if sulfides are present. Special attention needs to be paid to dissimilar metals, such as steel, being in contact with copper. Galvanic corrosion can occur. It is also anti-microbial.

Thermal conductance, electrical conductance & resistivity – Copper has a high thermal conductance, second highest of all the metals. It has a high electrical conductance and lowest resistivity of the metals considered in this report.

Physical Appearance – An additional coating is not needed to protect it from oxidation; it forms its own durable protective coating. The natural green patina of copper is considered to be attractive and can be left to weather on its on without any maintenance. Minor abbrasions will "heal" themselves once the oxidation of the exposed material occurs.

Constructibility and Workability – Coppers high ductility lends itself to easy workability during installation. It also can be fused together are lower temperatures and with alloying, it can be made to achieve a higher level of hardness.

Recyclability – easily recyclable. "Third most recyclable material. 80% of the copper ever mined is still in use today. Copper is 100% recyclable without any loss of quality, regardless of whether it is in a raw state or contained in a manufactured product." [7]

Common alloys

Data from Wikipedia, https://en.wikipedia.org/wiki/Copper_in_architecture

Copper alloy	Common term	Composition	Natural color	Weathered color
C11000 / C12500	Copper	99.90% copper	Salmon red	Reddish-brown to gray-green patina
C12200	Copper	99.90% copper; 0.02% phosphorus	Salmon red	Reddish-brown to gray-green patina
C22000	Commercial bronze	90% copper; 10% zinc	Red gold	Brown to gray-green patina in six years
C23000	Red brass	85% copper; 15% zinc	Reddish yellow	Chocolate brown to gray-green patina
C26000	Cartridge brass	70% copper; 30% zinc	Yellow	Yellowish, gray-green
C28000	Muntz metal	60% copper; 40% zinc	Reddish yellow	Red-brown to gray-brown
C38500	Architectural bronze	57% copper; 3% lead; 40% zinc	Reddish yellow	Russet brown to dark brown
C65500	Silicon bronze	97% copper; 3% silicon	Reddish old gold	Russet brown to finely mottled gray-brown
C74500	Nickel silver	65% copper; 25% zinc; 10% nickel	Warm silver	Gray-brown to finely mottled gray-green
C79600	Leaded nickel silver	45% copper; 42% zinc; 10% nickel; 2% manganese; 1% lead	Warm silver	Gray-brown to finely mottled gray-green

Components

1. Cladding

ZINC

Physical Properties – Zinc is very soft in comparison to other metals, it also become very brittle in temperatures below 0 degrees F. Typically used to coat other metals. The material also has a high thermal expansion rate. Its tensile strength is only half that of mild steel. Its toughness is low, but it has a high impact resistance.

Corrosion Resistance – Very corrosion resistant. The surface of zinc oxidizes quickly and forms a protective barrier preventing further corrosion. It is often used as an anti-corrosion coating and is used as a sacrificial anode. It forms a natural patina as part of the oxidation process.

Thermal conductance, electrical conductance & resistivity – Zinc has a moderate thermal and electrical conductivity. It has a high level of resistivity.

Physical Appearance – Due to the nature of the oxidation process, zinc changes from shiny silver to a matte bluish-grey in its natural state.

Constructibility and Workability – Zinc is very workable at normal temperatures, once temperatures get below freezing it becomes brittle and its workability will decrease. At tempaeratures below freezing the material could be suspetable to fracturing when bent Limited in-field forming or working of the metal would be possible. Special precations for in-field working of the material would have to be taken into consideration.

Recyclability – "Architectural grade zinc is 90 to 95% recycled. Replacement costs are negligible with a long lifetime of 80 to 100 years for zinc roofing and 200 to 300 years for wall systems." [8]

[8] *"Zinc". www.metaltech-usa.com. Retrieved 20 August 2014.*

Components

1. Cladding

TITANIUM

Physical Properties – Titanium has the highest strength to weight ratio of all the metals considered in this report. Its density is very low and it is as strong or stronger than most heat treated steels without the density associated with steel. Titanium is 60% denser than aluminum, but more than twice as strong. The material is also very ductile when in the presence of oxygen. Titanium has a very high fatigue limit that allows the material to perform very well in almost any environment. It can be alloyed to alter the performance of the base material. Currently 50 grades of the material are in production. Its stiffness and tensile strength are naturally high, due to the properties of the material.

Corrosion Resistance – Titanium is highly resistant to corrosion from chlorines, salts and in a marine environment.

Thermal conductance, electrical conductance & resistivity – Titanium has a very low electrical and thermal conductivity. Titanium's resistivity is higher than other metals in this report, approximately 3 times that of mild steel. It is also non-magnetic.

Physical Appearance – In its natural state, titanium appears silver and is very opaque. Various finishes can be applied to its surface to change its appearance. It can be anodized to change its surface appearance and color. It is most commonly left in its natural finish.

Constructibility and Workability – Harder than other metals and will require some specialization for fabrication. Limited in its ability to be cold worked.

Recyclability – It is recyclable.

Components

1. Cladding

ALUMINUM

Physical Properties – Aluminum is a non-ferrous metal that has a lower mechanical strength than that of steel or titanium, but is stronger than zinc. It has a good strength to weight ratio and excellent ductility. Its mechanical strength can be increased by alloying it with other elements and heat treating. Aluminum can be heat treated which affects its corrosion resistance, workability, formability, strength. It is almost always alloyed. As temperatures decrease, it becomes more brittle and can become more susceptible to stress.

Corrosion Resistance – Aluminum typically forms a protective coating on its exterior surface through oxidation (passivation). This process occurs naturally. The surface of aluminum can be made to be harder and more corrosion and abrasion resistant through anodization. Anodization is the electrolytic passivation process that increases the aluminum's surface thickness and hardness. Aluminum can also be painted or have other coatings applied to its surface in order to protect it from the elements. The material is unaffected by UV radiation, but the coatings may be affected.

Thermal conductance, electrical conductance & resistivity – Aluminum has a high thermal conductance of thermal energy. It also has a high electrical conductance and the second to lowest electrical resistivity, copper being the lowest in this report.

Physical Appearance – It is completely opaque and can be painted, powder coated, anodized, left in its mill finished state, or have a brushed finish applied to it. It can be extruded into shapes and panels which vary in shape, thickness and size.

Constructibility and Workability – Aluminum can be worked easily due to its high ductility, but at lower temperatures the material becomes more susceptible to stress cracking. In order to overcome that limitation, thinner gauges of material can be used. Aluminum's softness allows it to be worked with common tools and requires little specialized labor. Aluminum can be fastened in a variety of ways and can be welded.

Recyclability – Easily recyclable second to copper in comparison.

Common alloys:

NON-HEAT TREATABLE (COMMON) ALLOYS

3003 is alloyed with 1.2% manganese to provide a tensile strength range of 17 to 30 KSI. Excellent workability, weldability, and corrosion resistance. Used for drawing, spinning, fuel tanks, sheet metal work and other applications where slightly higher strength than 1100 is required. Conforms to AMS QQ-A-250/2 and ASTM B209.
5005 is alloyed with .8% magnesium. Tensile strength range is 18 to 30 KSI. Excellent workability, weldability, and corrosion resistance. Specified for applications comparable to 1100 and 3003 – where anodizing is required. Anodized finish matches that of architectural alloy 6063. Conforms to Federal specifications ASTM B209.

HEAT TREATABLE ALLOYS

6061 is alloyed with 1.0% magnesium and .6% silicon. Tensile strength range 20 to 42 KSI. Good formability, weldability and corrosion resistance. Used for engineering and structural applications, boats, furniture, transportation equipment, etc. Conforms to AMS QQ-A-250/11 and ASTM B209.

Data from Erickson Metals Website, http://ericksonmetals.com/aluminum-products/aluminum-coil/

1. Cladding

FIBER REINFORCED PLASTICS

Fiber-reinforced plastic (FRP) is a composite material made of a polymer matrix reinforced with some type of fiber. The fibers can be glass, carbon, aramid, or basalt. Other fibers such as paper or wood or asbestos have been used, but are very uncommon. The polymer is usually an epoxy, vinylester or polyester thermosetting plastic. Some phenol formaldehyde resins are still being used for some types of plastics.

A polymer is generally manufactured by Step-growth polymerization or addition polymerization. When combined with various agents to enhance or in any way alter the material properties of polymers the result is referred to as a plastic. Composite plastics refer to those types of plastics that result from bonding two or more homogeneous materials with different material properties to derive a final product with certain desired material and mechanical properties. "Fiber-reinforced plastics are a category of composite plastics that specifically use fiber materials to mechanically enhance the strength and elasticity of plastics. The original plastic material without fiber reinforcement is known as the matrix. The matrix is a tough but relatively weak plastic that is reinforced by stronger stiffer reinforcing filaments or fibers. The extent that strength and elasticity are enhanced in a fiber-reinforced plastic depends on the mechanical properties of the fiber and matrix, their volume relative to one another, and the fiber length and orientation within the matrix." [9] "Reinforcement of the matrix occurs by definition when the FRP material exhibits increased strength or elasticity relative to the strength and elasticity of the matrix alone." [10]

Physical Properties – Fiber reinforced polymers are made of fibers and a polymer matrix forming a composite material. This structure gives completely different chemical and physical properties than the individual materials. The primary role of fibers is to provide strength and stiffness to the composite material. The glass fibers by themselves are very brittle so to increase their strength, they are cased in a polymer coating material. The polymer binder distributes the load to the glass fibers and increases its strength. The material has a high strength to weight ratio due their low density.

"The fibers used in composite are as follows; E-glass, S-glass, Quartz, Aramid (Kevlar 49), Spectra 1000, Carbon (AS4), Carbon (IM-7), Graphite (P-100), and Boron. Polyesters, Vinyl Esters, Epoxies, Bismaleimides, Polyimides, and Phenolics are the polymers used. Each polymer has different chemical and physical properties; therefore, contribute differently to the composite structure. As a result, the composite properties are also different based on the polymer." [11]

Corrosion Resistance – Most FRP's are highly corrosive resistant to chemical corrosion. Careful choice of the resin and reinforcing fibers has to be considered based upon contaminates found in the environment. UV degradation can affect polymers if left exposed to sunlight for an extended duration of time. Polymers can have other chemicals (UV stabilizers) added to them that help prevent the attack on the polymer from ultra-violet light. The factors which determine the susceptibility to UV degradation are time the extent and degree of exposure.

Thermal conductance, electrical conductance & resistivity – Has a very low rate of thermal conductivity. FRP's do not conduct electricity. It has a low conductivity and high resistivity. Both of these are determined by the type of

1. Cladding

fibers used for the material. They are used as electrical insulators. They can be made to conduction electricity if a conductive additive is used in the composite.

Physical Appearance – FRP's can be made into any shape because they are formed into or over a mold. The manufacturing process of FRP allows for complex forms and curves to be made. The material is typically covered with a coating so color is applied to the material and is not integral.

Constructibility and Workability – Panels are formed into a shape using a mold. Once the panel is manufactured, some minor manipulation of the panel can be made. Major modifications are limited. Exact tolerances during the manufacturing process must be monitored due to the nature of the material.

Recyclability – Very limited. FRP can be recycled. The process of reclaiming the materials does shorten the fibers and they effectively are down cycled. Meaning that they cannot be used to the same potential as the previous material.

Components

1. Cladding

PHENOLIC RESIN PANELS

Physical Properties – uses thermosetting resins using formaldehyde and phenol to bind fiber together forming a highly impact resistant sheet with good flexural strength and elasticity. Panels are manufactured under high pressures and temperatures yielding a highly stable and dense panel with a good strength-to-weight ratio. Material does not burn, only chars. It has a very high fire resistance.

Corrosion Resistance – highly corrosive resistant.

Thermal conductance, electrical conductance & resistivity – Very low thermal conductivity. It does not conduct electricity and has a very high resistance to electricity.

Physical Appearance – Can be altered by color and texture to fit the desired aesthetic. Due to the panel surface having a closed structure, contaminants have a harder time clinging to it , making it very easy to clean. Required maintenance is reduced significantly due to the nature of the material.

Constructibility and Workability – the material is factory cut and finished to a high standard of accuracy. Field modifcations can de done, but will require more specialized labor to make modifciations. Curves and complex forms are achievable with the material. Cutting of the material can be performed with basic carpentry tools.

Recyclability – Phenolic resin panels are made from recycling wood products and combining them with a phenolic resin to form a hard flat surface. Once this product is manufactured, it can be down-cycled and is suitable for themal recycling.

1. Cladding

SINGLE PLY MEMBRANES

A membrane system that uses a polymer-based synthetic material installed as a liquid or as a flexible sheet. These systems are made using a variety of bitumens, polymers, fillers, plasticizers, stabilizers and other additives. Single-ply products can be applied over an insulating material and are typically secured using a mechanical fastening system or are adhered to a substrate using an adhesive.

EPDM rubber (ethylene propylene diene monomer)

Physical Properties – EPDM is a type of synthetic rubber. It has exceptional elongation properties and is very stable in a wide range of temperature extremes. The material retains its flexibility over a wide temperature range. It has exceptional resistance to thermal shock.

Corrosion Resistance – EPDM is resistant to acids, alkalis, and oxygenated solvents (ketones, esters, and alcohols). It is affected by petroleum based products.

Thermal conductance, electrical conductance & resistivity – EPDM has a very low thermal conductance and very low electrical conductance. It has a very high resistivity.

Physical Appearance – EPDM typically comes in White or Black, based on the ingredients added to the material. It can be coated using acrylics and has a smooth monolithic appearance.

Constructibility and Workability – Easily applied in the field. 30% of the roofs in the US currently are EPDM roofing membranes. Can be ballasted, mechanically fastened or self-adhered to a substrate. The nature of the material allows for easy modifications and repairs. Relies of liquid adhesive to join seams.

Recyclability – can be recycled and reused in other products.

TPO (Thermoplastic polyolefin)

Physical Properties – TPO roofing membrane is composite membrane that is manufactured using polypropylene and EP (ethylene-propylene) rubber polymers joined together using a polymer manufacturing process. It remains flexible at low temperatures without the use of polymeric or liquid plasticizers. The combination of the fabric and TPO plies provide reinforced membranes with high breaking and tearing strength and puncture resistance. It performs well in low temperatures.

Corrosion Resistance – Good corrosion resistance and good UV resistance

Thermal conductance, electrical conductance & resistivity –

Physical Appearance – TPO typically comes in white, tan or gray, based on the ingredients added to the material.

Constructibility and Workability – Similar to EPDM in the installation of the product. All seams are heat welded instead of bonded by using an adhesive.

Recyclability – 100% recyclable. The membrane can be ground into "rework" and this material can be used as the bottom ply for a new TPO roofing membrane.

2. Air Barrier

Located between the cladding and thermal barrier, or as the cladding itself, and air barrier's role is to reduce air infiltration through the building envelope. In the Antarctic environment, it is specifically critical that this air barrier work to minimize the migration of wind and moisture into the envelope, while allowing the release of any moisture trapped in the envelope to escape to the exterior of the building. This means the building will require a vapor-permeable, air-barrier membrane.1

The Air Barrier Association or America recognizes five types of air barriers. Many barriers have the same chemical structure with the only difference being how it is applied. For instance, Henry's Air-Bloc system can be applied with a trowel, rolled like paint, or sprayed onto a surface. This product's capacity to be applied differently is not alone in the industry. Therefore, the industry has standardized the types of barriers based on their application process. The categories of application are Self-Adhered Air Barriers, Liquid Applied Membranes, Sprayed Polyurethane Foam, Mechanically Fastened Building Wrap, and Insulated Boardstock. Each type has its own list of tests that it must meet to qualify as an air barrier. However, all barrier types are tested for air permanence and water vapor permanence.2

Most Self Adhered Air Barriers have similar physical characteristics to each other. These include a cross laminated polyethylene that is relatively thick (40mil), tacky, almost always black, and a semi fluid like substance. This is bonded to a sheet of modified asphalt. The construction of these barriers have a protective sheet on the tacky surface that is pulled off as it is being applied. These barriers offer excellent resistance to punctures, has self-healing characteristics, and they can also be applied to all types of substrates. A major positive, is there a few membranes that can serve in subzero temperatures and remain pliable and strong. A drawback is that the application of the barrier must be monitored and controlled to ensure proper adhesion to the surface. It is recommended the air barrier be applied in a factory or assembly plant.

Tests:

air permanence, water permanence, resistance to puncture, tensile strength, water resistance, stripping strength of adhesive bonds, lap adhesion, low temperature flexibility, nail sealability, pull adhesion,tear initiation, tear propagation, and crack bridging

2. Air Barrier

Liquid Applied Membranes can be an alternative to self-adhered air barriers. There are many liquid applied barriers on the market based on their binder. Binders include acrylic-based, asphaltic-based, or polymers. New polymer based barriers have exceptional elongation and resistance to cracking that is lacking in other binder types. Many can equal the performance of self-adhered air barriers. The biggest drawback is all liquid applied membranes cannot be installed or service deep subzero temperatures with the reliability of the best self-adhered air barriers. This eliminates liquid applied membranes for exterior weather barriers.

Tests: air permanence, water permanence, nail sealability, pull adhesion, and crack bridging

Sprayed Polyurethane Foam is a closed cell foam as defined in this report. It acts as both an air barrier and insulation. (The insulating values are described in the subsequent section of this report.) While a few can be used in subzero temperatures, on average, spray foams do not perform as well as an air barrier as self-adhered and liquid applied membranes. While advantagous insulating properties require the team to look into polyurethane as the primary air barrier, it is recognized other barriers perform better in this capacity. Therefore, other barriers will be recommended ahead of polyurethane spray foams.

Tests: air permanence, water permanence, flame spread characteristics, thermal insulation, compressive strength, density, tensile strength, dimensional stability, water absorption, open cell

Mechanically Fastened materials is the most common type of air barrier used in construction. Usually mechanically fastened materials require several accessories for penetrations, terminations, and joints that add to labor costs that other types of barriers do not require. Additionally, since the membrane is mechanically attached, focus on air tightness at the seams is exaggerated. Failure at the seams means air can get behind the membrane and find its way across the wall with ease. Due to this concern over quality control and its additional in-field labor, mechanically fastened barriers will not be recommended.

Tests: air permanence, water permanence, dry tensile strength, pliability, and water resistance

2. Air Barrier

The last type of barrier is board stock. This category includes gypsum board, OSB, plywood, rigid foam boards, and other like materials in board form. Some of these materials, do not meet the performance standards that other barriers can achieved, additionally, board stock produces joints and seams that must be taped to ensure air does not find its way through at the seams. Since, one of the main concpets is to reduce the amount of seams, board stock should not be used as the primary air barrier.

Tests: air permanence, water permanence, compressive strength, flexural strength, water absorption, dimensional stability, and tensile strength

Following is a chart of the most common high performing air barriers. The matrix shows the air permanence and vapor permanence. These two characteristics are the two most important when determining barrier. In addition, the installation and service temperatures are critical as the exterior barrier will be subjected to extreme cold. Since the air barrier will be installed outside the thermal envelope, products that do not meet service temperature will not be used. The ability for the product to remain flexible in subzero temperatures is essential. This is measured in terms of pliability as tested to ASTM D 412. Membranes that do not pass pliability standards at -40F (-40C) shall not be considered, and membranes that have incomplete data down to -40F (-40C) will be under greater scrutiny until the product is determined acceptable.2

Data provided by the Air Barrier Association of America

		Pliability	**Water Vapor Trans**	**Water Vapor Trans**	**Air Leakage**
	Install Temp	*Service Temp*	*water method*	*desiccant method*	*cfm/ft2 @ 75Pa*
Barrier Type		*ASTM D412*	*ASTM E96-B / perms*	*ASTM E96-A*	*ASTM E2178*
Sheet Materials					
Grace: Perm-A-Barrier Wall Mem	25F (-4C)	-45F (-43C)	0.05		0.0002
Henry: Blueskin	41F	-40F (-40C)	0.86	0.03	0.0001
Soprema: SopreSEAL Stick 1100T	14F (-10C)	-49F (-45C)	0.031		0.00001
Meadows: Air Shield	20F (-7C)	-40F (-40C)	0.035		0.0004
Fluid Applied					
Grace: Perm-A-Barrier VP	40F (4C)	32F (0C)	11.2		
Henry: Air Bloc 33MR	40F (4C)	-40F (-40C)		11.6	0.0016
Meadows: Air Shield LMP	40F (4C)	-15F (-26C)	12		0.004
Sprayed Poly					
BASF: Walltite	30F	interior only	1.39		0.0003
Henry: Permax 2.0	30F	interior only	0.8		0.004

3. Thermal Barrier (Insulation)

The heart of the enclosure is the insulation. The other components protect it and allow it to optimize its value. Insulation has several performance criteria that it needs to meet. The primary function is thermal insulating performance. Additionally, thermal stability, shear capacity, structural capacity, cell structure, fire resistance, global warming potential, and ozone depletion are taken into consideration for some of the materials considering the materials abilities and compatibilities.

The materials are categorized into four groups: Open Cell, Closed Cell Rigid Foams, In-Field Spray Foams, and Advanced Technologies.

Thermal Insulating Performance is defined as the ability of a material to resist thermal transmittance. Thermal transmittance is the rate of transfer of heat through a material over a given thickness. This thermal transmittance rate is called a U-Value, and the resistance of this heat transfer is the reciprocal of the U-Value, called an R-Value. For this project R-Value will be described in terms of US units (ft2·°F·hr/Btu). All insulating components will be measured to this unit.

Thermal Stability is defined as the ability of a material to maintain its performance requirements over time and over temperature change. In recent years, research into thermal stability has been completed for some materials. Much of this research is proprietary and not available to the public. However, the research that is public has been reviewed.

As the research for this project progresses, it has been discovered that, while important, choosing the right insulation is not as important as joint detailing, cladding, and barriers. The best assembly with the highest R-Value can quickly be compromised by insufficient detailing. The R-Value per inch, at McMurdo Station, is not as critical as it would be in the aerospace industry or other projects where space and weight are importance considerations. So the difference between an insulation that offers R4.5/in is nearly equal to those that have an R5/in. Applied to an R-40 wall panel, there is little impact between an 10.5" thick panel and an 8" thick panel.

Insulation Material	R-value R/inch	Density lb/ft³	Emb. E MJ/kg	Emb. Carbon $kgCO_2/kg$	Emb. Carbon $kgCO_2/ft^2 \cdot R$	Blowing Agent (GWP)	Bl. Agent kg/kg foam	Blowing Agent GWP/ bd-ft	Lifetime GWP/ $ft^2 \cdot R$
Cellulose (dense-pack)	3.7	3.0	2.1	0.106	0.0033	None	0	N/A	0.0033
Fiberglass batt	3.3	1.0	28	1.44	0.0165	None	0	N/A	0.0165
Rigid mineral wool	4.0	4.0	17	1.2	0.0455	None	0	N/A	0.0455
Polyisocyanurate	6.0	1.5	72	3.0	0.0284	Pentane (GWP=7)	0.05	0.02	0.0317
Spray polyurethane foam (SPF) – closed-cell (HFC-blown)	6.0	2.0	72	3.0	0.0379	HFC-245fa (GWP=1,030)	0.11	8.68	1.48
SPF – closed-cell (water-blown)	5.0	2.0	72	3.0	0.0455	Water (CO_2) (GWP=1)	0	0	0.0455
SPF – open-cell (water-blown)	3.7	0.5	72	3.0	0.0154	Water (CO_2) (GWP=1)	0	0	0.0154
Expanded polystyrene (EPS)	3.9	1.0	89	2.5	0.0307	Pentane (GWP=7)	0.06	0.02	0.036
Extruded polystyrene (XPS)	5.0	2.0	89	2.5	0.0379	HFC-134a[1] (GWP=1,430)	0.08	8.67	1.77

1. XPS manufacturers have not divulged their post-HCFC blowing agent, and MSDS data have not been updated. The blowing agent is assumed here to be HFC-134a.

3. Thermal Barrier (Insulation)

OPEN CELL

The Open Cell category refers to the cellular structure of a material. Any open celled insulation will fall into this category, including Cellulose, Fiberglass Batts, Mineral Wools, and Natural Wools. Many spray foams also come with the option of an open-celled type. Generally, open cell insulations have a reduced R-Value, reduced cost, and better fire resistance. However, they have no structural capability and many would be inappropriate for use in prefabrication methods due to their inability to hold space and maintain tolerances.

All loose fill insulations are determined inappropriate for this application because open cell insulations are much more likely to fail to keep cold air out due to its permanence and loose fills will eventually compress and leave uninsulated cavities within the wall. These insulations include cellulose, fiberglass, and mineral wools.

Batts and blankets are made of fiberglass, mineral wool, and plastic or natural fibers. These are usually fitted in between studs to hold it into place, but can be manufactured in greater widths. There is no structural capability with batt insulations. Using batts as an exterior insulation requires additional studs for attachments. This creates thermal bridges between the exterior and interior environments.

Plastic fibers of polyethylene terephthalate typically requires treatment with a fire retardant. However, plastic fibers do have a higher R-value than other batt insulations. Natural fibers include cotton, sheep's wool, straw, and hemp. They all have a similar R-value between 2.5 and 3.5 per inch. Sheep's wool is the only natural fire resistant product; the other natural fibers need to be treated in order to have any fire resistance.

The last open celled option is spray foam. Many spray foams do have an open celled option. While the cost of open cell foams are significantly less than closed celled options, both require the same installation process and labor. Additionally, the R-value per inch is significantly less than closed cell spray foams, therefore most of the material costs would be balanced by the fact that more material would need to be used in the wall assembly.

Unlike closed cell insulations, open celled insulations cannot be used as a barrier against vapor drive, a key parameter of the wall assembly. The designer of the Halley VI station refused to consider open celled insulations. His reasoning is there is concern that if moisture does enter the assembly, water could freeze within the open cells of insulating material. While open celled insulation may have a place in interior walls, it does not appear these insulation options are appropriate as a part of the exterior building envelope.

LOOSE FILL INSULATIONS - CELLULOSE

FIBER GLASS BATTS

MINERAL WOOL

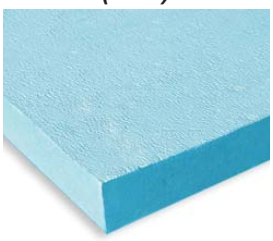
WOOL

3. Thermal Barrier (Insulation)

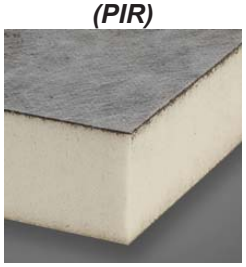
RIGID FOAMS

EXPENDED POLYSTYRENE (EPS)

EXTRUDED POLYSTYRENE (XPS)



POLYISOCYANURATE (PIR)



PHENOLIC FOAM

NEOPOR FOAM

The next three categories focus on closed cell options. The first, most common category, is rigid foams. Examples in this category include Expanded Polystyrene (EPS), Extruded Polystyrene (XPS), Polyisocyanurate (PIR), Polyurethane (PUR), and Phenolic Foams.

Generally, rigid foams can be injected into a mold or made into boards that can then be installed on a building wall. Both are viable options as both can be manipulated to take almost any shape, but injected foams need a completely enclosed form or panel to be injected into.

Rigid foams do have a certain amount of structural stability and the ability resist projectile impact. All rigid foams can hold its own weight and many have the capacity to withstand compression forces. Therefore, rigid foams are often used as a continuous insulation because it will not fall down or sag, and it can hold up to impact forces.

Rigid foam has an environmental impact. Due to its blowing agents, the process of producing rigid foams have a high value of Global Warming Potential and Ozone Depletion substances. However, as the article by the Huntsman noted:

> *"Because of their lower ODP (Ozone Depletion Potential), HCFCs have been an established intermediate alternative to CFCs. In regions such as the European Union or the United States of America, the use of HCFC141b in foam applications has been banned for almost a decade… For developing countries, as of 1st January 2013, the consumption of HCFC141b will be capped and 2 years later, as of 1st January 2015, it will be gradually reduced until 2030."*

Due to this recognition that manufacturers within the United States are already switching from ozone depleting materials, a blowing agent requirement can specify low Global Warming Impact and zero Ozone Depletion Potential.

3. Thermal Barrier (Insulation)

RIGID FOAMS

EPS

Expanded Polystyrene is a versatile insulating material. EPS can be injected into a mold or formed into boards. Therefore it can be used in prefabricated panels. While it has a lower R-value than other closed cell insulations, it outperforms most open cell insulations. Physically, it is white with small beads creating the structure. One of the primary benefits with using EPS is it structural stability. In the event of wind blown projectiles, EPS has great flexural strength to resist breaking. However, product density should be considered under building movement. Stresses over time can compromise the material. "Design professionals should recall that greater strength properties are available from EPS foam by increasing density."

One of the drawbacks for EPS is its lack of flame resistance. It melts if exposed to high temperatures. EPS in its standard composition is combustible, and requires a fire retardant added to the material to make it noncombustible. However, it will still melt when it gets above 100°C. The International Building Code (IBC) does allow EPS on exterior walls as long as the product is protected or sheathed. Allowing the structure of the building and its occupants to be protected. A European Manufacturers of EPS study noted, "It is strongly recommended that expanded polystyrene should always be protected by a facing material, or by complete encapsulation. Taking these factors into consideration it can be concluded that expanded polystyrene products do not present an undue fire hazard or lead to an increased risk of smoke density when installed correctly in recommended applications."

GPS

Graphite Polystyrene (GPS) is EPS which has been infused with graphite in its formula. A common GPS product is the BASF product, Neopor.

GPS is a re-formulates EPS. It has increased R-values and stronger compressive and flexural strength. The R-value is significantly higher than EPS, and like EPS, performs better in cold conditions.

XPS

Extruded Polystyrene (XPS) is another rigid foam. It is very similar to EPS in terms of flame combustion, environmental impact, and structural strength. Additioanlly, both are made from a polystyrene resin having high compressive strength, and increases in R-value as the temperature drops. However, there are several differences to consider.

One key difference is XPS has a higher R-value. This difference can be significant over several inches and may sway the design toward XPS over EPS. However, EPS is used more by manufacturers of prefabricated panels, such as metal composite panels and SIPS. The manufacturing process also gives EPS an advantage in thickness. This is due to how it is manufactured. EPS is a resin that is expanded, then molded, whereas XPS is liquefied, then extruded. Another difference is cost. XPS generally costs 10 to 30% more than EPS, but usually this is mitigated by the fact less XPS material is needed to provide the same R-value of EPS.

The significant difference between EPS and XPS may be in its application. EPS is better if injected into in a prefabricated shell, whereas XPS is better if multiple rigid boards are layered on top of each other and sandwiched between panels

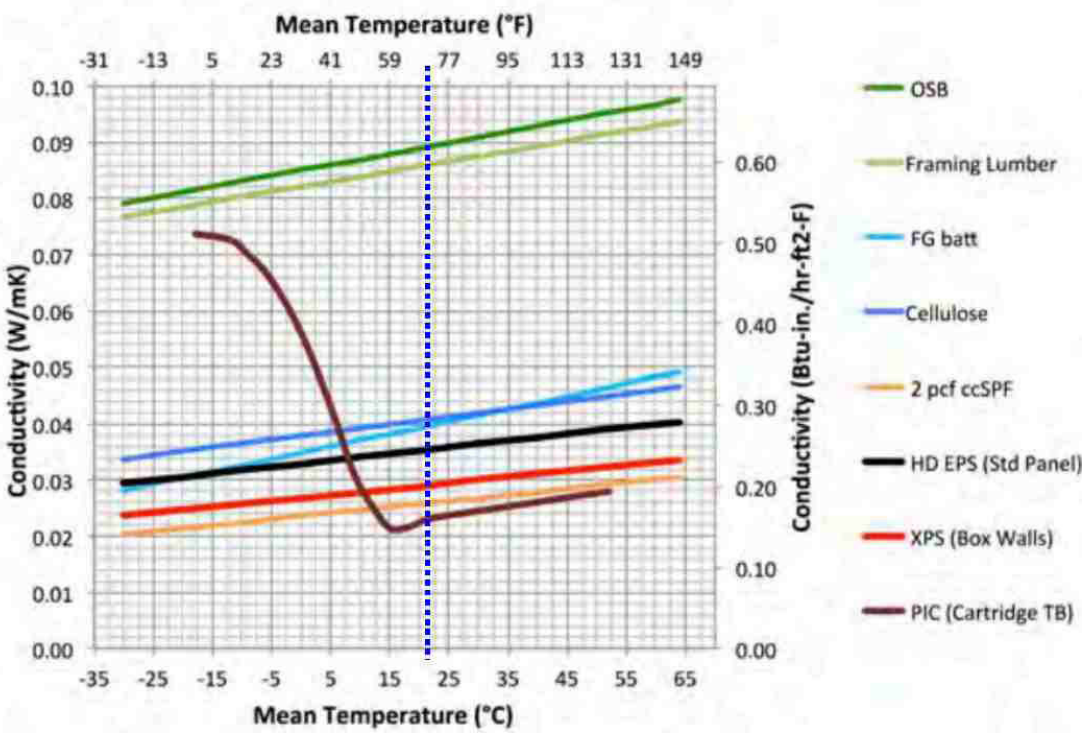
3. Thermal Barrier (Insulation)

RIGID FOAMS

Polyisocyanurate (PIR)

In recent years, PIR is increasing in popularity. Like EPS and XPS, PIR is a rigid foam that is fabricated in board form. While published R-values are superior to polystyrenes, recent research indicates that PIR's thermal qualities may diminish as temperature decreases.

> *"All of the samples show a decrease in R-value as "outside" temperatures go below freezing. It appears that the "peak" R-value for all samples occurs when outdoor temperatures are closer to the indoor temperature (i.e. between 36°F or 2.2°C and 108°F or 42.2°C). Winter temperatures (i.e. less than 32°F or 0°C) and solar heated roof temperatures (i.e. greater than 113°F or 45°C) result in lower R-values."*



PIR Performance Drops as Tempurature Drops

Due to the inconsistency and unknown performance at very cold temperatures, PIR is not an appropriate thermal barrier for McMurdo Station.

Polyurethane (PUR)

Like EPS and XPS, the differences between Polyisocyanurate and Polyurethane insulation are minor due to their similar cellular makeup and composition. Chemically, the difference between PUR and PIR is the amount of isocyanate used in the manufacturing process. Standard PUR nearly equal part polyol and isocyanate. PIR has more than double the amount of isocyanate to polyol. This produces a product where there are some differences, but fire performance is similar.

3. Thermal Barrier (Insulation)

RIGID FOAMS

> *"...the resultant product of PIR gives greater heat stability, increased flame resistance, chemical resistance and dimensional stability, than that of a PUR foam. Both PUR and PIR carry a Factory Mutual FM 4880 - Class 1 Standard for Fire performance as measured by today's standards."*

Polyurethane is mostly produced as a spray foam, but it produces a closed cell rigid insulation that could be used as rigid boards in SIPS panels and other enclosed sandwich panels.

> *"Polyurethane foams have some of the highest insulating values of any conventional foam insulation commercially available today. They contain very low conductivity gases trapped in a closed-cellular structure, which reduces heat transfer by conduction. The small cell size practically eliminates heat transfer by convection, another source of energy transfer. Polyurethane foams can be used in a wide range of service temperatures, generally from -100°F to 200°F."*

The structural capacity of polyurethane foams is matches closely with EPS, and may be even better.

> *"High compressive and shear strengths allow low density insulating cores to be faced with relatively thin steel or aluminum and yet span long distances unsupported. For example, the foam can hold together many of the components in a refrigerator or hot water heater while it continues to perform as thermal insulation."*

A benefit for using polyurethane is they melt at a much higher point than polystyrenes, and they are noncombustible. Therefore, they are safer to use in a building than polystyrenes. Much of the construction industry in Europe favors polyurethane for this very reason.

Because polyurethane is similar to PIR, the same concern over loss of R-value in cold temperatures applies. However, due to a new recognition that this is occurring in PIR, the same reports have not found the drop in R-Value shown in PIR does not occur in PUR.

Currently, the industry is using an R-value of 5.7, which is said to be more honest than the R-7 manufacturers were stating previously. At such extreme low temperatures, PIR and polyurethanes perform similarly to polystyrenes.

Phenolic Foam

Phenolic foam boards were once very popular in the United States, but their use has significantly declined in recent years due to its lack of dimensional stability and its noted possibility to increase corrosion at metal decks. However, it can perform better than EPS for insulating values, and it has much better fire resistance properties.

It is not known specifically why phenolic foams may be the probable cause for building deterioration, but it is thought to be chemicals within the foam moving with moisture laden air onto other building materials. While this problem may be reduced or eliminated by the below freezing environmental conditions, it is not without risk.

3. Thermal Barrier (Insulation)

SPRAY FOAMS

Spray foams have become very popular in recent years as a way to seal exterior walls and act as a vapor barrier, especially in residential projects. Depending on project parameters, spray foams usually have closed and open cell options. Any liquid foam insulation can be sprayed. These include cementitious, phenolic, polyiso, and polyurethane foams. There are also other types that include Icyene and Tripolymer foam. The most common type is polyurethane.

All spray foams are mixed with a foaming agent that is sprayed into place; the mixture then expands and hardens. They can be sprayed onto irregular shapes and hard to reach places before expanding. However, its flexibility also means it can have quality control concerns for in-field construction. There have been occasions where the foam may be sprayed on with less thickness than specified and the insulation used may not be as dense as specified, and while these concerns can be managed, other issues, as noted below, are not so easily resolved.

On top of control issues, another in-field concern would be environmental. Not only does the cold temperature create a problem, but so does wind. The sprays need a little to no wind condition to apply it properly. Again, this can be resolved, but may be impractical for in-field installation.

Spray foams can have higher quailty control when applied as a part of a premanufactured system where environmental conditions are stable. However, some of the benefits of spray foam, like its ability to be without joints, would be compromised by the fact it will have joints in the prefabricated panel, thus making it similar in construction to EPS.

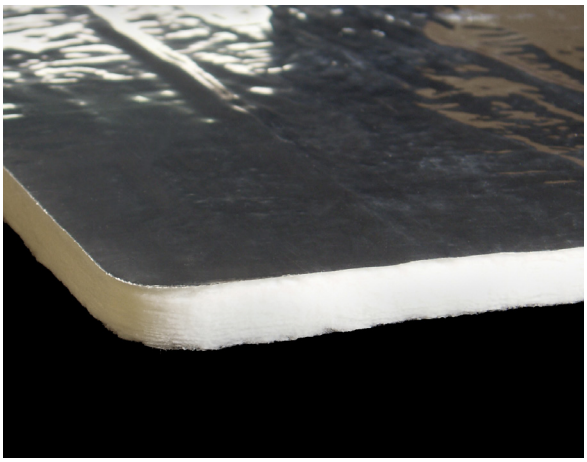
Polyurethanes and phenolic insulations can be used as a spray foam application. Their properties are the same as the rigid materials as described above. Cement spray foams are very unique as a spray foam. Since it is cement, it is non-flammable. However, its insulating properties are not as good as EPS, and its weight could be problematic if additional inches of material are needed to meet the envelope performance requirements.

Icynene is similar to all other spray foams in its application, but the biggest differences are it can be sprayed or injected and an open celled option is available. Icynene is a good option if the insulation needs to breathe and air should pass through the insulation, but at McMurdo, air permeability is not desired. Additionally, the insulting value is smaller than EPS, and thus a large section of the material would need to be installed. Furthermore, due to its open cell nature, there is concern that moisture will condense within the insulation and cause moisture troubles within the assembly.

3. Thermal Barrier (Insulation)

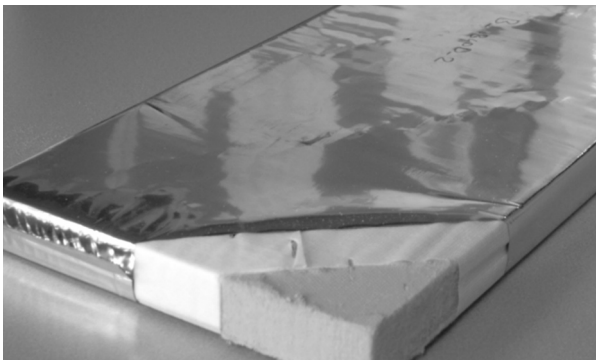
ADVANCED TECHNOLOGIES

While the previous examples of insulation types are common in the construction industry, there are significant advances of insulating products that should not be ignored. Many of these advances are not currently fully understood. However, these advances will become more familiar among manufacturers and contractors and will have increasing market share as time progresses.



AEROGELS

The first such technology are aerogels originally designed for the aircraft industry. This is a very new technology and only a handful of companies in the United States supply aerogel as an insulating material. Despite this, aerogels continue to advance and may become an important tool for insulating buildings.
Aerogels are not rigid, but flexible. They are porous, but hydrophobic. They are fire resistant and perform well in extreme cold conditions, and the biggest impact they will have is their insulating abilities. Aspen Aerogels notes, "...aerogel is a lightweight silica solid derived from gel in which the liquid component of the gel has been replaced with gas. When the liquid is removed, what remains is "puffed-up sand", with up to 99% porosity. The result is an extremely low density solid with several remarkable properties, most notably its effectiveness as a thermal insulator."
Despite all their positive qualities, areogel has yet to be placed in a building as the primary insulating material. Most applications, for today's building uses, are at joints and insulating very small spaces. For instance, Dow Corning currently has a product made of aerogel that is used as insulating material for curtain wall applications. Currently, areogel is supplied in blankets and needs a backer to make it rigid. It is, also, much more costly per square foot compared to other materials.

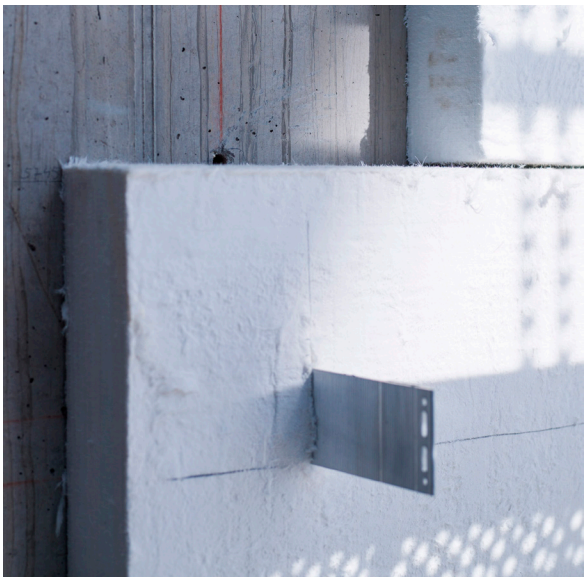


VACUUM INSULATED PANELS

Another promising technology is vacuum insulated panels, or VIPs. VIPs have been a useful technology for many years in the cryo and refrigeration industries due to its high thermal properties. In fact, VIPs usually have higher performance rating than all the common materials, and even areogels. VIPs are common in residential freezer doors. However, VIPs as a primary building insulation have proven to be impractical.

Among these impracticalities, VIPs cannot be punctured without losing insulating value, they have limited life cycle, they inability to be used as continuous insulation; and cost. VIPs are simply insulation stuffed into a pouch, and vacuum sealed. If the vacuum is penetrated and looses its air tightness, then the panel loses all its added insulating properties. Even if the panel can be protected from being punctured, these panels have only been proven to about 20 years, and at this point it could be the pouch material that starts to allow air transmittance. Additionally, VIPs cannot support cladding. This is very different than the rigid insulations that can be used to hold substrates and cladding. For this application, since continuous insulation is a given, VIPs would need girts to hold cladding, thus creating thermal bridging.

3. Thermal Barrier (Insulation)



ANORGANIC AEROGEL

Lastly, several companies are experimenting with silicon based aerogels. This is a material, used throughout Europe, that acts like rockwool but has much higher thermal performance than traditional rockwool. It is non-combustible, and is formed into semi-flexible boards. The good R-values enable the envelope to be thinner, and unlike some other advanced technologies, has been used as a primary building insulation. It is also much more cost effective than the other advanced technologies.

Negatively, it does need clips or girts to hold cladding as it is technically an open celled insulation, and because of this air is allowed to transfer through the material. In an application which needs to stop air transmittance, this material may not be well suited for an exterior application. However, it can very well be considered as an interior insulation, especially when considering its fire resistant properties.

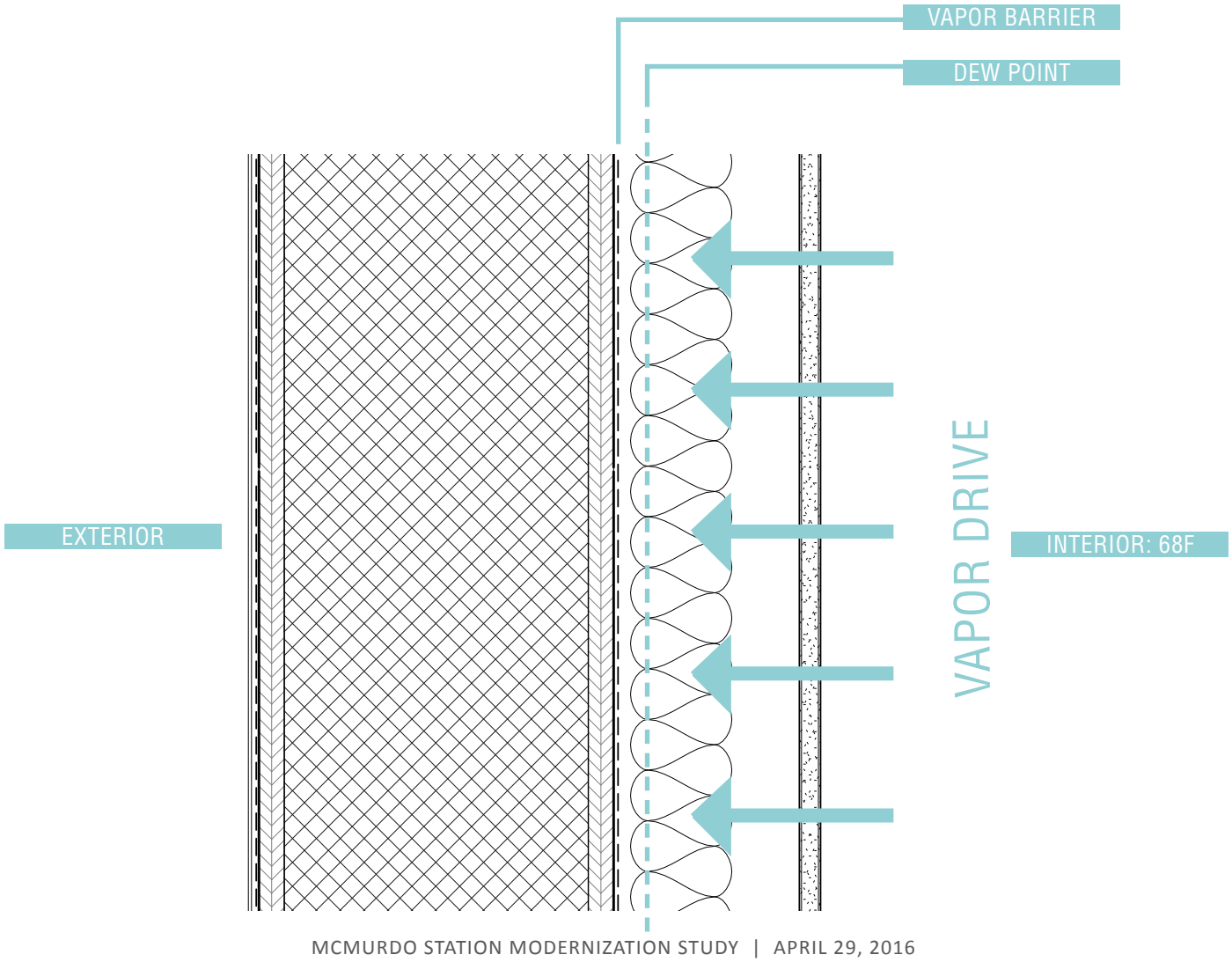
4. Vapor Barrier

Moisture protection from the interior is critical, as moisture and vapor migration into the panel will condense and freeze within the wall or roof assembly. Since liquid water is not a factor at McMurdo Station, there is no recommendation to provide a rain screen that allows water to flow out of the assembly. Instead, the assembly focuses on keeping solid water (ice and snow) out and water vapor out. Controlling ice and snow is relatively simple through cladding and tight construction, but controlling water vapor is more complicated.

Water vapor moves from the warm side of the wall to the cold side of the wall. In Antarctica, vapor will always travel from the interior of the building to the exterior. The best strategy is to keep any vapor out of the wall assembly. For the McMurdo environment, where the outside humidity is extremely low, a vapor barrier is required on the interior side of the thermal envelope to block interior moisture. If moisture condenses and freezes within the envelope, the assembly will fail as seen at the German station Neumayer III and McMurdo's Crary Lab.

Stressing the importance for controlling the moisture, Joseph Lstiburek notes:

"Moisture flow by air leakage and vapor diffusion from the inside to the outside is a huge concern. Even tiny gaps leaking air can lead to substantial icicles and frost boles. There is no argument that an actual air barrier is essential. The vapor drive when it is 40 degrees below zero outside is formidable. This is one climate that needs



4. Vapor Barrier

Mr. Lstiburek continues to recommend a vapor barrier that is less than 0.1 permanence, or a Class I rating as tested under ASTM E2357 Standard Method for Determining Air Leakage of Air Barrier Assemblies.

Following is a list of Class 1 Vapor Barriers:

Glass	0 Perm
Sheet Metal	0 Perm
Rubber Membrane	0 Perm
0.002in Polyethylene Sheet	0.16 Perm
0.0004in Polyethylene Sheet	0.08 Perm
0.0006in Polyethylene Sheet	0.06 Perm
0.00035in Aluminum Foil	0.05 Perm
0.001in Aluminum Foil	0.01 Perm

While glass, sheet metal, and rubber membranes provide an imperious barrier against moisture, it is impractical to assume an entire building would be lined with one of these products. What is acceptable are some of the barrier types listed in the Air Barrier section of this report. All barrier types are tested to the same set of tests to determine the rating of each material for air permanence and water permanence. In this way, many vapor barriers are air barriers, some air barriers also block moisture, and some barriers do great at blocking both air and moisture. These tests are listed in the Air Barrier section of this report.

From the reporting of these tests, we find self-adhered sheets have superior average performance over any other type of barrier. Within the self-adhered sheets, about 7 commercially available membranes meet the Class 1 requirements. Of all the other types of barriers, only one specific product can be categorized as a Class 1 Vapor Barrier. This happens to be a liquid applied barrier. Spray foam product (1 inch) and mechanically fastened barriers do not meet Class 1 requirements.

Below is the list of Class 1 Vapor Barriers:

Carlisle, Fire Resist 705 FR-A	0.01 Perm	Self-Adhered
Tremco, ExoAir10	0.02 Perm	Self-Adhered
SompremaSEAL, Stick 1100T	0.031 Perm	Self-Adhered
Tremco, ExoAir11	0.04 Perm	Self-Adhered
W.R. Meadows, Air_Shield Sheet	0.047 Perm	Self-Adhered
Grace, Perm-A-Barrier Wall Membrane	0.05 Perm	Self-Adhered
Grace, Perm-A-Barrier Liquid	0.09 Perm	Liquid Applied
Carlisle, CCW-705	0.10 Perm	Self-Adhered

4. Vapor Barrier

Since the vapor barrier will be subjected to subzero temperatures during construction1, it is important to filter through these barriers with their ability to resist loss of performance from cold temperatures. The liquid barrier does not perform in the cold, and the two Carlisle products have been tested only down to -25F. All other membranes have been tested between -32F and -43F. Of these, SopraSeal Stick 1100T has a good balance between cold temperature performance and peel and lap strength. The Grace Wall Membrane and the W.R. Meadows Air Shield also have good deep cold performance.

For the McMurdo Station wall assembly, peel strength (ASTM D903) and lap strength (ASTM D1876) is essential as the use of mechanical fasteners are discouraged because they could create a cold bridge. Instead, adhesives are used. However, these adhesives have their own set of requirements. They must be able to withstand building movement as the membranes are pulled and the lap strength and peel strength is tested. The membranes must withstand building movement. By far, the highest performing membrane in the SopraSeal Stick 1100T with the W.R. Meadows membrane coming up next.

Through analyzing the membranes and their performance characteristics, only a handful are capable of achieving the performance required and ligistical considerations, and construction methods.

5. Interior Finish Assembly

Interior assemblies may not be traditionally a part of the building envelope, but the interior lining and finish of the exterior walls is important to this discussion for several reasons.

- Interior furring walls can be insulated.
- The interior wall can protect the vapor barrier.
- An air cavity can exist between the thermal envelop and the interior walls creating a service chase.
- The exterior panel could be the interior finish.

While it is not important to discuss the interior finish for this shell and fenestration study, it is important to understand the logic behind the key design concepts described above.

In many of the newer stations, such as India's Bharathi station, a large cavity exists between the exterior thermal envelope and the interior walls. This allows the station to create a buffer zone between the outdoor environment to the interior living spaces. This buffer zone would be a warmed environment, but it may not be as conditioned as the interior living spaces. These spaces have the advantage of allowing maintenance to the exterior envelope to fix joint failures or penetrations. Also, utilities and structure could be run through these chases and be hidden from the interior environment but still have the ability to be inspected and not interfere with the vapor barrier.

The interior walls provide a surface for the occupants to attach cabinets, shelving, or other objects. The interior wall can be punctured through the wall without potentially causing a failure of the envelope.

Many of the exterior envelope types may not look appropriate for the station's interior. Many systems have raw steel panels or steel framing with a black vapor barrier. An interior furring wall allows any finish to be applied and hide the unsightly vapor barrier or other exterior envelope walls. Mass timber construction has the advantage of concealed vapor barrier and thus does not need an interior cover. The assembly would reduce the amount of interior furring needed, plus enhancing the environment with wood finishes.

Example of Mass Timber Interior Finish

Structural Support

While not a part of the thermal envelope, the structure does have a direct impact into what system is eventually chosen. Due to the long spacs required at McMurdo, all cladding and envelope systems need additional structural support. Even systems that could act as their own structural system, such as SIPs, are shown to be supported by a building superstructure. Additionally, some structural systems have inherent thermal breaks which can potentially enhance the thermal performance of the entire assembly.

The vast majority of newer buildings' structure across the continent is steel. Steel is relatively easy to erect, simple to store, and non-combustible. Concrete needs to be precast which requires heavier erection equipment. Cast in place concrete has the issues of pouring and curing concrete in cold temperatures. Likewise, dimensional lumber framing is combustible and may not be able to withstand the forces exerted on the building.

Steel will need to be designed differently depending on the envelope attaching to it. SIPs will act differently from metal insulated panels will act differently from GFRP. Because each panel has a different modulus of elasticity, the amount, weight, and detailing of steel will differ between each system. It is not anticipated this difference will have much of a cost delta between each system.

While steel may have many advantages, there are a few key drawbacks. Due to the metal having a high heat transmittance, awareness and special detailing will need to be considered when introducing thermal breaks. Additionally, steel inherently would need to be erected prior to adding the thermal envelope, requiring a two step process. The first step would be the steel structure, and the second step would be the envelop panels. Whereas structural panels, such as mass timber, could be put into place in one step.

One such alternative would be to use ***mass timber*** as the primary structure. While made out of a combustible material, mass timber construction is considered heavy timber in the code which does have fire resistant qualities. Recent code updates have recognized these traits and CLT and other mass timber offerings is becoming more common in construction across North America. Another benefit with using mass timber is that, unlike steel, it can be used as a panel. Insulation could be directly applied to the mass timber frame and have a one step thermal envelope. However, construction crews may need to apply cladding around the facility as it may be difficult attach cladding to the panels and keep them protected during shipping and construction. Additionally, the mass timber is low in heat transmittance. This means insulations and cladding can be directly mounted to the panel with heat loss occurring from the wood and through each subsequent material.

The third option is ***precast concrete*** panels. Concrete has the significant advantage of being its own air barrier and very durable and long lasting. The advantages of concrete end there. While it makes sense to use concrete on the exterior, this means the insulation will be on the interior. The weight of the system will be also need to be considered during shipping and on site. Due to the greater tolerances required for concrete, the joints are necessarily larger, more varied, and may not be able to be completely and precisely stitched together.

General Description

For the envelope of McMurdo Station, all six sides of the building will be clad in a material which can stand up to the specific requirements of its application. We are attempting to isolate the interior of the building from the exterior by providing a barrier to the environment. In order to achieve this goal we are relying on the envelope to stop all environmental factors from infiltrating the envelope and interior of the building. The requirements for wall performance were defined by N.B.Huthcheon published in *Canadian Building Digests (48). Requirements for Exterior Walls*:

1. Control heat flow
2. Control air flow
3. Control water vapor flow
4. Control rain penetration
5. Control light, solar and other radiation
6. Control noise
7. Control fire
8. Provide strength and rigidity
9. Be durable
10. Be aesthetically pleasing
11. Be economical

He goes on to describe how these are to be used in context to each other. Items 1-7 give specific definition to how a wall acts as a barrier from the indoor environment to the outdoor environment. As the difference between those two environments increases, there is more stress that the materials of the wall must be able to tolerate. He goes on to discuss the priorities associated with these requirements and the relationship requirements each has upon the other. Specific attention must be paid to various factors and a high level of understanding is needed to evaluate selections of materials. Items 8-11 then expand the discussion of requirements to a level of the general or overall requirements. These principles are relevant and applicable to the way we make selections of materials. Additional requirements have been added to this list in consideration of the impacts building methods and materials have on the environment. Risk assessment is now informing the robustness of materials and technology is changing the way we interact with a building. Using this as a reference point helped to establish the envelope criteria explained earlier in the report.

To apply these principles to each building surface (roofs, walls and floors), different strategies should be employed to deliver a high performing envelope that will withstand the environmental conditions of Antarctica.

Walls

The common elements of a wall assembly are:

- Exterior Cladding
- Drainage Plane(s)
- Air Barrier System(s)
- Vapor Retarder(s)
- Insulating Element(s)
- Structural Elements (referenced only)

Exterior cladding is defined as protective layer or finish which is attached to the outermost portion of the building and controls how the environmental elements reach the other components of the wall assembly beyond. The exterior cladding can control the environmental elements in many different ways. For this report, we focused on the approaches of using the exterior cladding in a either a barrier wall or a cavity wall system.

The central concept of the barrier wall is a wall that is a complete barrier to anything penetrating its exterior. In order to achieve this, the exterior cladding functions both as finish and drainage plane for rain, snow, or other airborne particulates. The exterior barrier depends upon a weather-tight seal. These systems rely on a sealed joint between panels to maintain their weather tightness. Barrier walls are commonly used in precast concrete, certain types of composites, and insulated metal panel wall systems. They can be load bearing or attached to a structure and non-load bearing. In this environment, the concern is any imperfection in the barrier would allow snow to get behind the cladding and compromise the wall assembly through freeze-thaw cycles.

With barrier walls, exterior finish acts as an air barrier, the interior side of the exterior finish must account for vapor migration from the interior allowing it to be dispursed to the exterior or allowed to dry out from the inside without accumulating behind the exterior finish.

With barrier walls, exterior finish acts as an air barrier, the interior side of the exterior finish must account for vapor migration from the interior allowing it to be dispursed to the exterior or allowed to dry out from the inside without accumulating behind the exterior finish.

Walls

Cavity wall systems are created by using an exterior finish separated by an air space from the supporting structure of the wall. The finish is typically non-structural and is solely supported by the structural system of the building. Cavity walls typically have an exterior finish which protects, but it designed to accept moisture intrusion into the air space. This air space allows for drainage and drying of any moisture. In the environment at McMurdo Station with blowing snow, the principle of a drainable cavity wall will allow snow and ice to build up within the cavity. This is not an acceptable use of a cavity wall in this environment.

A modification to the cavity wall concept uses the principle of an impermeable exterior finish fastened to an extruded framing system that holds the exterior finish away from the other wall components allowing an air space to be created. These are typically referred to as a pressure-equalized dry joint system. It is based on the traditional rout and return system and does not rely on a gasket to seal the edge of the panel. The key benefit to this type of system is that as wind driven snow strikes the surface of the exterior finish and if it does penetrate into the cavity, it doesn't have pressure from wind or the influence of capillary action drawing it into any joint or open penetration. With the air barrier serving as a secondary barrier, water or snow can't infiltrate the wall cavity but has the potential of collecting within the cavity. The potential for collection of snow inside the cavity can present the potential for thawing to occur and refreezing of the liquid water. This would prove to be problematic for the wall system.

At McMurdo Station, the typical pressure-equalized system may not be applicable, but the concept of an air space can improve the performance of the exterior cladding. A small air space can be used to alleviate the potential for major amounts of snow or vapor collecting behind the exterior cladding. A review of the wall assemblies by a building science expert recommends a very small air space (between 1/4" to 1/2") which will allow drying of any condensatoin or moisture behind the cladding. In order to incorporate the airspace sugggested, the use of a drainboard material applied behind the exterior caldding will provide the airspace suggested and help manage snow infiltration into the cavity.

Walls

METAL INSULATED PANELS WITH STEEL STRUCTURE

MIPs, or Metal Insulated Panel, could be characterized as the most utilized construction assembly in Antarctica. In fact, despite the common use of GRP and SIPs, MIPs are still being designed into the newest stations. The panels are simply a metal shell wrapped around closed cell insulation. Usually this insulation is polyurethane. Since MIPs have been used in freezers and coolers to keep cold inside, it seems natural to use the walls to keep the cold out. Metal panels are very common in the construction industry and easy to install. Therefore, this construction method offers certain economies.

Like GRP, the panel is the cladding, insulation, and air and vapor barrier. Unlike GRP, the metal cladding can resist human activity and UV better without the high initial cost. The simplicity of the construction also assists with the on site construction process.

These panels have evolved to provide basic enclosure for a worldwide market. They are less suited to the harsh climate at McMurdo. The failures of the panel have been observed and documented. The panels can only be made at 4 foot widths, the smallest limit of all the panel types. This means there are more joints, and more opportunities for failure as a thermal envelope. In an attempt to prevent the joint from failing, the seams at the panel joints are an interlocking weave of insulation and metal. However, as the panels move due to thermal expansion or structural settlement, the panels will no longer maintain a perfect fit. This allows the ice and snow to enter any opening, and over time will cause a separation at the joint. Additionally, the metal panels need to be directly connected from the outside, though the panel, and fastened to the structure. This creates a thermal bridge. Nylon fasteners have been attempted, but these fasteners have shown wear, and more confidence would be place in metal fasteners.
Due to these failures, joint covers have been added to reduce the possibility of failure. However, these joints can be complicated and add on site labor during the stitching process at the seams.

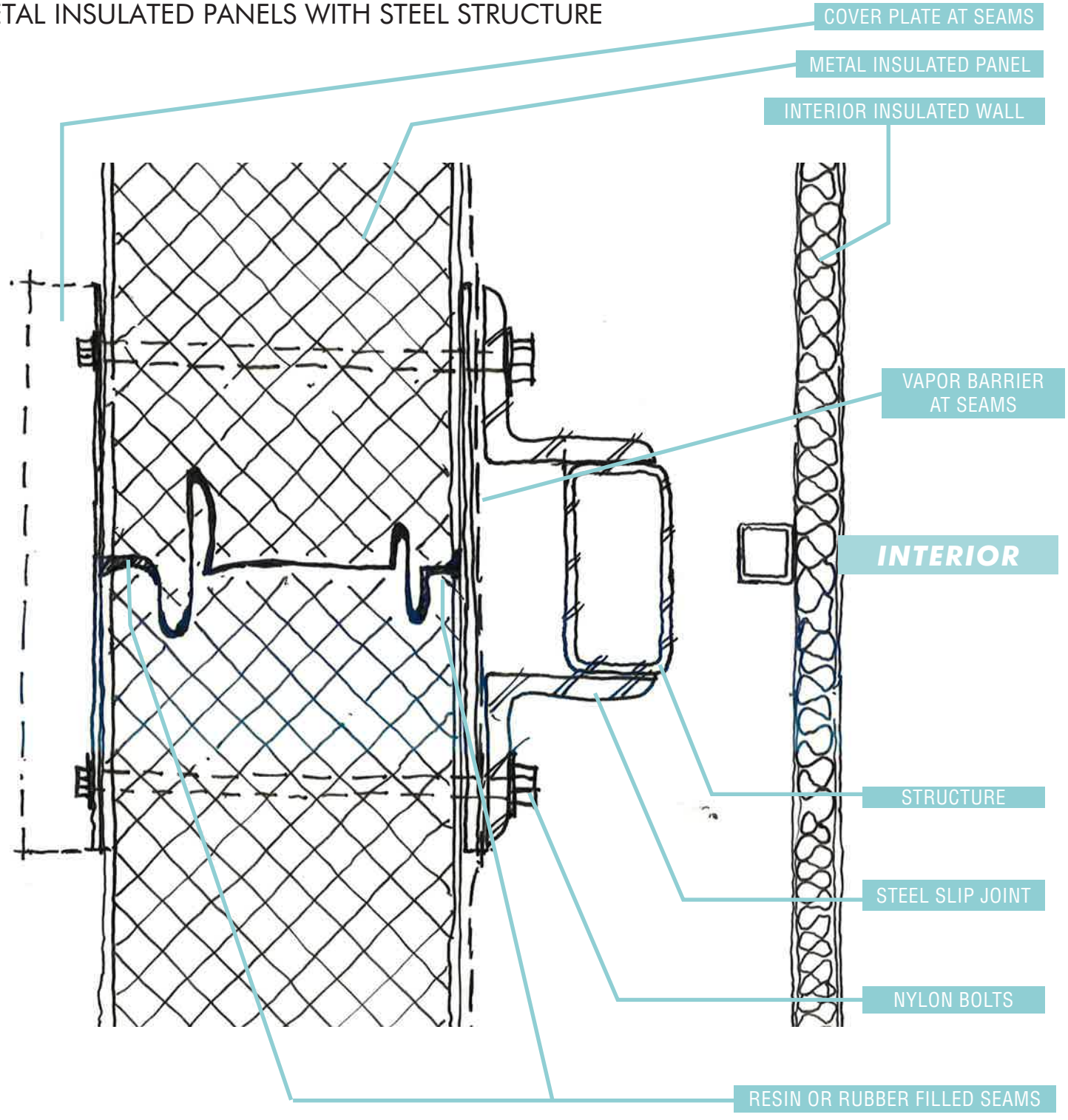
Like GRPs, the entire panel is the complete thermal envelope assembly acting as the cladding, insulation, and air and vapor barrier. Completing the system requires only clips to the steel superstructure and joint covers.

Because of this, IMPs are very simple and fast to put in place. In fact, the stitching process may take longer to finish than the actual process of putting the panels in place.

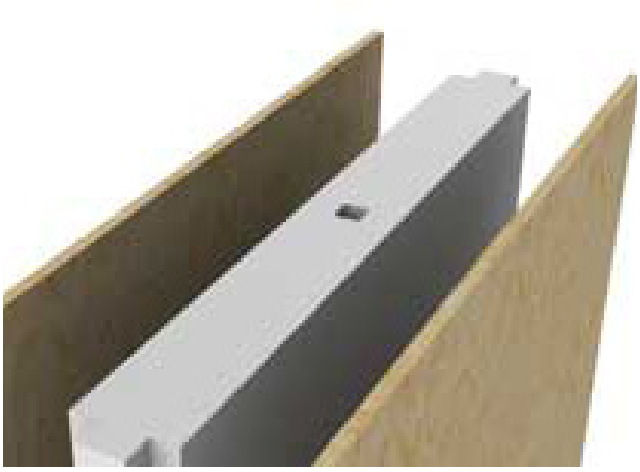
With this assembly it is recommended to have interior walls to protect the exterior envelope walls. As with many other stations, these interior walls could be insulated to further add thermal resistance to the assembly. A cavity between the exterior and interior walls would be used to run utilities, and possibly used as a strategy to pre-warm the environment before it gets to the interior thermal wall.

Walls

METAL INSULATED PANELS WITH STEEL STRUCTURE



Walls



SIPS WITH STRUCTURAL FRAME

Structural Insulated Panels (SIPs) is a sandwich panel defined as extruded insulation sandwiched between two layers of OSB. While there are other ways to produce SIPs, for the purposes of this report, SIPs will be defined this way. SIPs panels can be constructed with several types of insulation, including polyurethane, EPS, and XPS. EPS and polyurethane as the most common.

SIPs can be used in a variety of ways, but for a subzero environment and a facility of this size, the panels will be attached to a superstructure. The superstructure would be steel or wood with the SIPs panels connected by slotted clips to allow for panel movement.
Inside the SIPs, there would need to be an applied vapor barrier to stop any vapor drive into the insulation. All vapor would go from the interior, where humans occupy and create the humidity, to the exterior, where the cold environment would be dry and low relative humidity. This vapor barrier would be directly applied to the SIPs panel, and field-applied or preapplied before the panels are shipped.

SIPs panels are constructed from OSB or plywood and insulation. While the wood sheathing is straightforward, the insulation can be constructed out any type of rigid insulation. This report evaluates EPS, XPS, polyurethane, and more advanced EPS, such as graphite infused EPS. The choice of insulation determines the thickness of the panel as it meets the required thermal performance. For instance, to achieve an R-60, EPS would need to be 13-1/2". EPS, that is infused with graphite, could be 11-1/2". Polyurethane would need to be 10". At the time of this report, Polyurethane has a maximum limited thickness of 9" due to press sizes. In the future, there may be more advanced presses in the marketplace, but the number is, at best, limited.

On the exterior side of the SIPs panel, an air barrier is applied to minimize the cold air penetrating to the insulation. Finally, cladding would be installed on the assembly to protect the building from ice, sand, snow, UV, and wind. The cladding will need to be tough and durable.

Construction using SIPs is a very common and familiar construction technique. Over the past several years, SIPs construction has grown in market share. What makes SIPs so appealing is its intrinsic quality to panelize, hold thermal insulation, and its ease of transportation.Because of all these positives, SIPs tends to be a cost effective construction process.

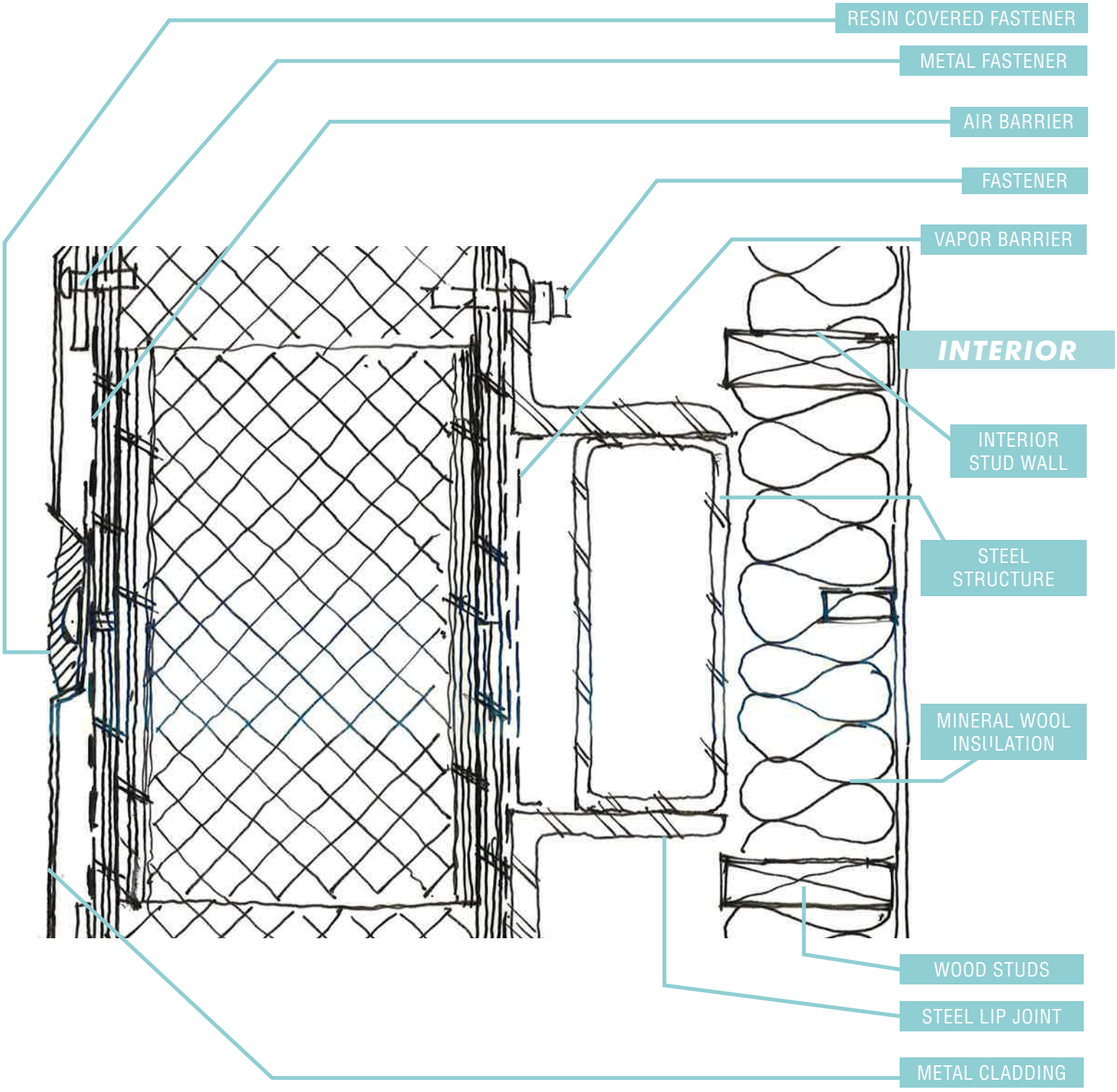
One of the reasons for its value is SIP's ability to be the structural system. Many homes across the United States use SIPs in this way. However, the application of SIPS for this large of a facility may not make sense. Therefore, SIPS's value would be reduced if the panels need to be attached to a superstructure. The current thinking is that the SIPS panels would be connected to a superstructure because this concept offers the great benefits of panelization, greater joint control, and ease and pace of construction.

SIPS are, by nature, panels and are lightweight compared to other panel types. These panels can be moved easily by construction crews due to its reduced weight. The panels also offer better joint control because the ends can be fitted with insulation, effectively shorting any thermal bridge.

However, this application would require a three stage construction process. First, the superstructure needs to be constructed. Second, the SIPS panels would be installed. Finally, cladding would be added. So, while SIPS may be faster than traditional constructions methods, it may not be any faster than other panelized processes.

Walls

SIPS WITH STRUCTURAL FRAME



SIPS WALL DETAIL

Walls

MASS TIMBER

CLT is defined as traditional wood product laminated together into panels, with each layer turned 90 degrees to the next layer. This gives the panel immense strength, and has been used in several multi-story structures. Because they are developed from cross laminations, the panels can stretch up to 65' long x 8' wide. This enables the structure to have fewer joints and possibly a tighter fit. When the fit is not perfect, since it is wood, field corrections can easily be made. The larger panels would also allow the structure to be erected quickly, which is crucial to reduce labor hours on site.

One of the benefits of using mass timber (CLT) is the resulting interior environment, as the interior layer in CLT Structure is wood.

As with SIPs, vapor can penetrate through the wood an into the insulation. Thus, the insulation needs to be protected by a vapor barrier. This would be applied outside the CLT. The insulation would then be applied directly to the barrier covered wood.

Insulation can vary dramatically depending the application. While the generic assembly shows a single layer of insulation, it is recommended to have two overlapping layers for more thermal breaks. Furthermore, the insulation could be applied prior to field installation or during field installation. If the installation is installed in the field, rigid boards could be used. However, it is highly recommended insulation be applied prior to shipping. In this case, a layer of substrate is recommended to protect the panel as well as act as the cladding substrate during field installation. Before the cladding, an air barrier can be added.

CLT, or cross-laminated timber, has been around for decades, but has only started to become popular recently. Like SIPs, its market share has been steadily increasing over recent years. Unlike SIPs, CLT is the structural system and it is not the thermal envelope. Its benefits range from being used as a structural system, as an interior finish surface, and also being used as a floor deck (CLT has strong fire resistance capabilities).

As a environmental product, CLT, or any mass timber product, is superior. It uses scrap or salvaged wood to create the timbers. Therefore, the embodied energy and the pollution created to produce a panel are much lower than steel structure.

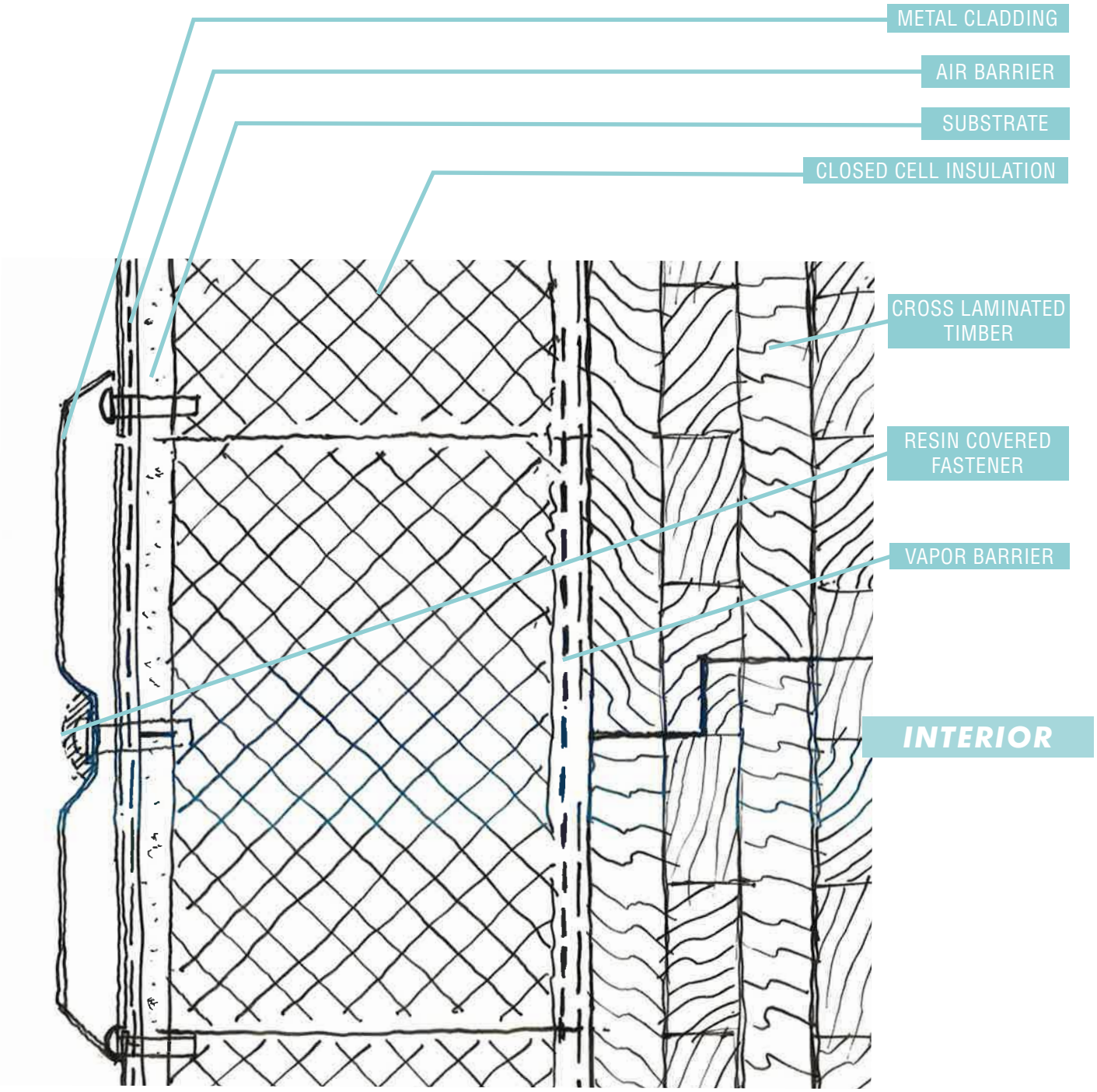
One of the reasons CLT was not popular for several years was because it is wood, and wood is combustible. For large buildings, wood was virtually eliminated due to codes restricting its use. However, as research has proven, CLT should be considered as heavy timber. CLT, and all mass timber types have very good fire resistance. They can withstand several hours of direct burn and only char.

As mentioned previously, CLT has very little thermal qualities. Therefore it would need a thermal envelope and cladding. Like SIPs, this means there would be multiple stages in the construction process. However, the number of stages could be reduced as the insulation is preapplied to the panel. First, the CLT with insulation would be erected; then, the cladding would be applied.

Walls

Since CLT is constituted of wood, one of the main concerns with CLT is fire spread and smoke spread. CLT is perceived to add fuel to a compartmentalized fire. Within a compartment, CLT can add to the fuel. However, CLT does have excellence fire resistance which stops the spread of fire and smoke. The CLT Handbook noted Frangi tested a CLT building and detemirned that the room with the fire, after one hour, had a minimum amount of char of the wood and that no smoke was shown in the rooms above the room with the fire. Structural integrity of the CLT remained intact throughout the fire.

CLT should follow all the building code provisions for fire safety. It is anticipated CLT would follow Type IV construction.



MASS TIMBER WALL DETAIL

Walls

GRP WITH STEEL STRUCTURE

GRP construction is simple in concept, but not yet in the mass marketplace. Currently, manufacturers who produce GRP walls are usually in maritime or aerospace industries. However, these manufacturers have been able to accomplish the task. It is highly recommended that the project designer and contractor will need to coordinate closely with the manufacturer of the panel.

Like the metal panels, GRP is the entire panel without additional components. In this system the panel acts as the vapor and air barrier, the insulation is added into the cavity of the panel, and it acts as the cladding. The panel does need to be painted with a very durable and resistant paint, similar to automotive paints. This enables the plastic to be more resistant against UV.

The only added items the GRP panels needs is a superstructure, detailed clips for attachment, and joint covers at the seams.

GRP, or glass reinforced plastics, is not a familiar or highly used building construction method and material in the United States. However, plastics have been used on several stations in Antarctica as mentioned previously in this report, and seem to be a viable option for construction in extreme cold environments.

One positive would be the speed of on site construction. Large complex panels can be manufactured off site and brought to the site in large pieces. Since they are lightweight, fitting them into place is much easier than concrete, and the allowed complexity of panels would make this option superior to CLT and SIPs.

An additional positive would be the lack of thermal bridges and reduced number of joints. This ensures a more controllable on-site construction joint and significantly reduced on-site labor. Like SIPs and IMPs, the thermal insulation is infused into the plastic form. Once the insulation is in the plastic, it could be its own structure. The panels are structurally strong and create a continuous thermal envelope on all six sides.

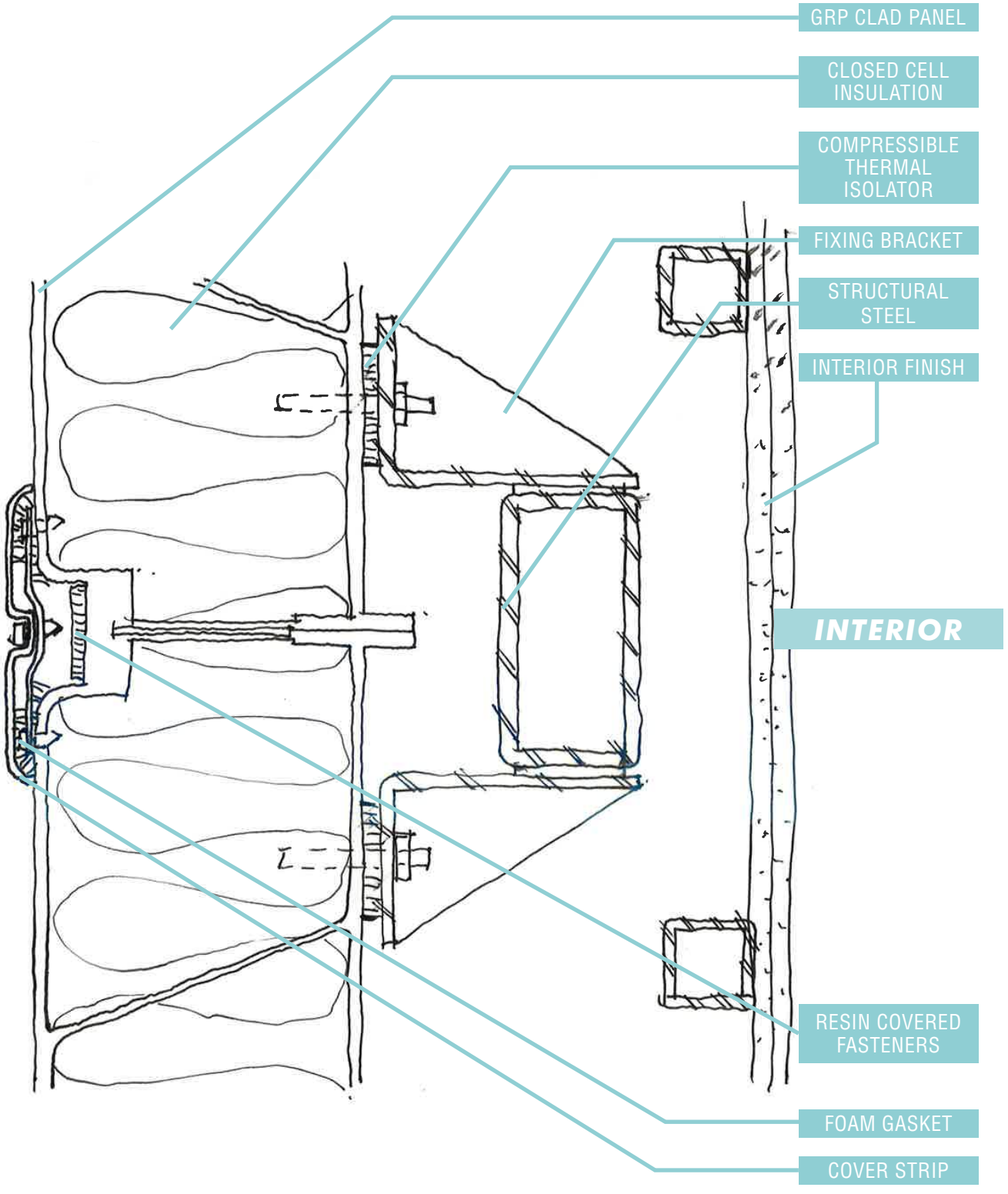
It cannot be stressed enough that the GRP panels produce a superior joint that can more reliably maintain a tighter seam over time. Many other types of panels and materials expand and move – thus joints have the potential to fail either by separating, or joint materials break or fall out. GRP panels, if detailed correctly, can reduce the potential for failure.

By many accounts, GRP is superior to other building types. However, there are a few drawbacks. First, GRP needs to be precisely coordinated during the manufacturing process. This can take additional pre-planning by the designer, manufacturer, and contractor. This is necessary to ensure the panels are exactly what needs to be manufactured for a precise fit during on-site construction. If a panel does not fit, there is no way for a field correction, so the panel needs to be re-manufactured. This could cause delay and complications.

Along these same lines, it would be difficult to repair a plastic panel during the life of the building. Some of the other buildings using GRP panels are much smaller in scale, and are not sited in areas with a potential for human abuse.

Additionally, the plastic walls cannot be penetrated. Therefore, interior systems would need a separate wall and cavity to run through. Plus, this interior wall would be useful for protecting the GRP.

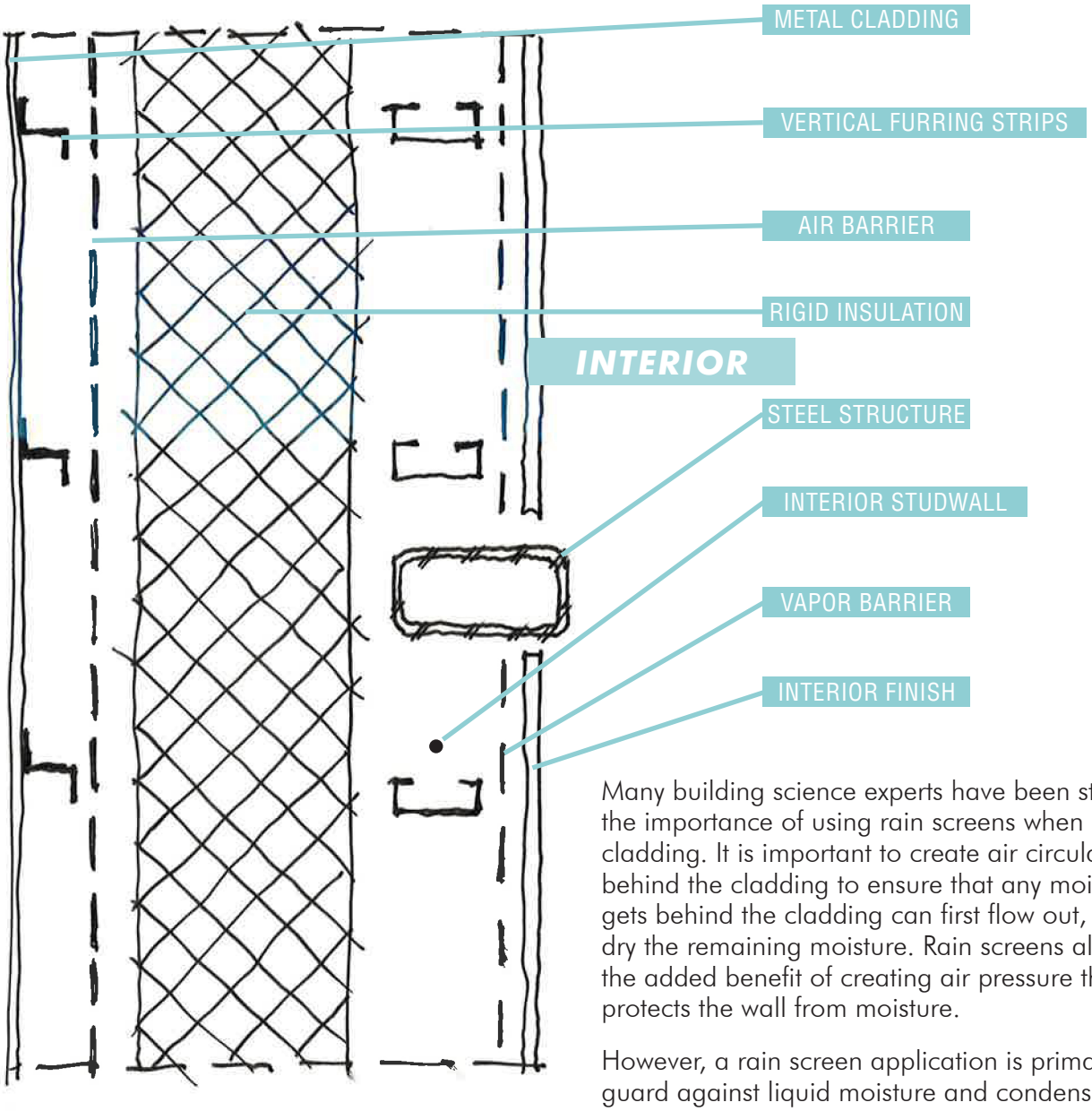
Walls

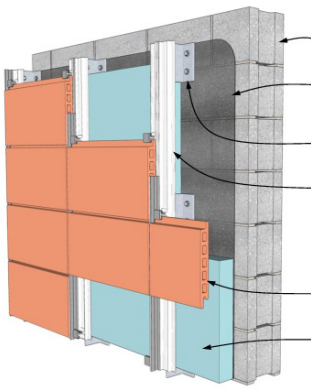


GRP WALL DETAIL

Walls

RAIN SCREEN



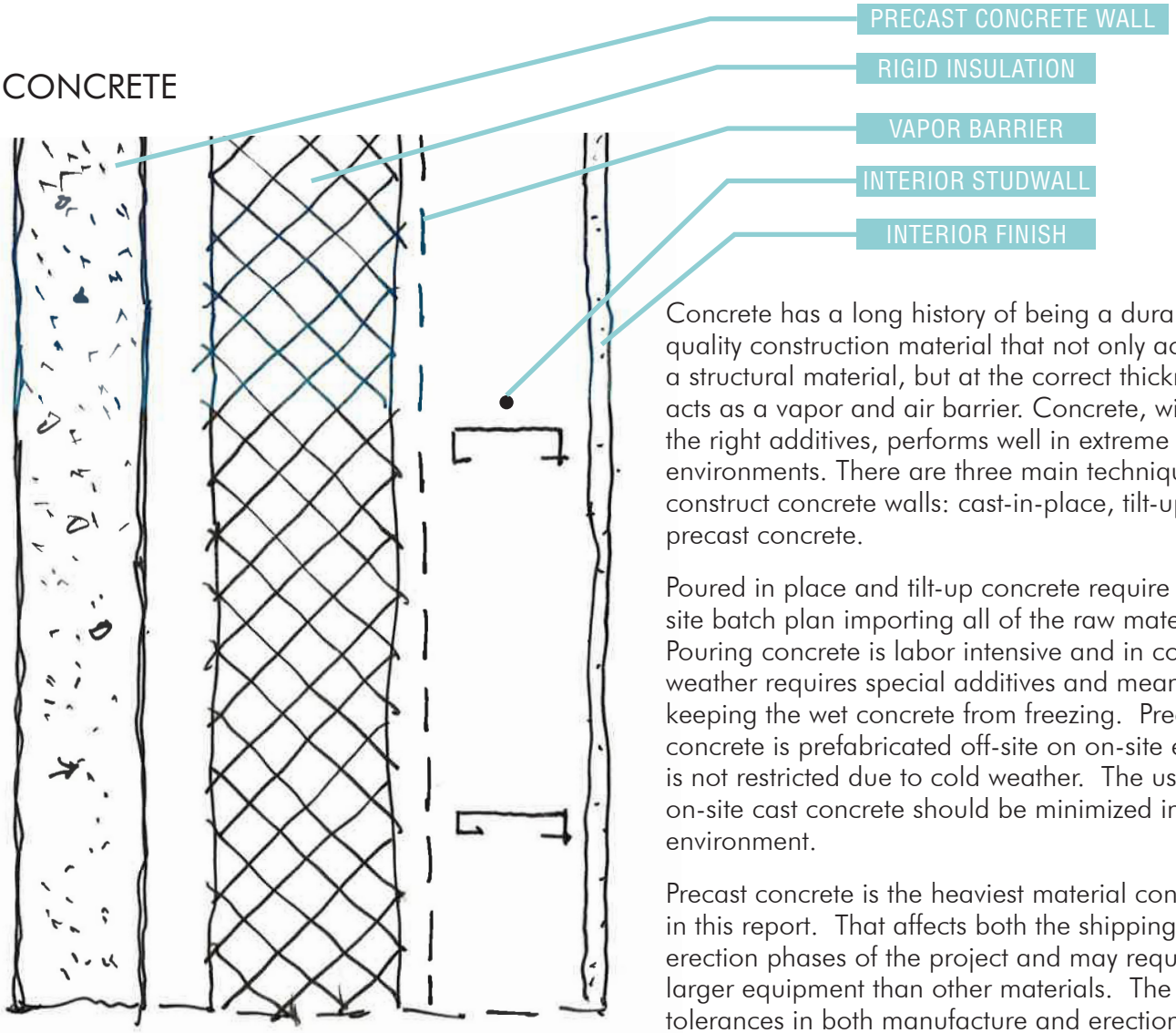


Many building science experts have been stressing the importance of using rain screens when applying cladding. It is important to create air circulation behind the cladding to ensure that any moisture that gets behind the cladding can first flow out, then air dry the remaining moisture. Rain screens also have the added benefit of creating air pressure that further protects the wall from moisture.

However, a rain screen application is primarily to guard against liquid moisture and condensation. In Antarctica, there is no liquid moisture and any condensation would freeze. Furthermore, a rain screen may unintentionally allow ice and snow to build up in the cavity and cause failures at the cladding installation. It may be possible to construct a rain screen where ice and snow do not build up, but the reasons to use a rain screen do not exist, therefore it is not practical in this environment. While worthwhile to mention, this report will not produce much research suggestions for a rain screen as a possible solution.

Walls

CONCRETE



Concrete has a long history of being a durable quality construction material that not only acts as a structural material, but at the correct thickness, acts as a vapor and air barrier. Concrete, with using the right additives, performs well in extreme cold environments. There are three main techniques to construct concrete walls: cast-in-place, tilt-up, and precast concrete.

Poured in place and tilt-up concrete require an on-site batch plan importing all of the raw materials. Pouring concrete is labor intensive and in cold weather requires special additives and means of keeping the wet concrete from freezing. Precast concrete is prefabricated off-site on on-site erection is not restricted due to cold weather. The use of on-site cast concrete should be minimized in this environment.

Precast concrete is the heaviest material considered in this report. That affects both the shipping and erection phases of the project and may require larger equipment than other materials. The standard tolerances in both manufacture and erection are greater than other materials greatly relying on the joint for a tight system that has to be flexible and adaptable to a wide range of widths.

Roofs

The common elements that comprise a roof assembly are:

- Roofing Material
- Air Barrier System(s)
- Vapor Retarder(s)
- Insulating Element(s)
- Attachment to Structural System

Multiple forms of roof assemblies were investigated in different shapes to withstand shedding water, snow, and wind. We examined flat roofs, single pitched roofs, multi-pitched roofs, arched roofs and troughed roofs. As a result of these investigations, due to the long spans an wind analysis, the roof system configuration that seemed most applicable for McMurdo Station is a low slope roof.

Liquid applied membranes, single-ply membranes, and metal roofing assemblies were researched as low slope roofs. A low roof is defined as a roof with 0-3" per foot of slope. It provides just enough slope to drain water away or allow wind to scour the snow off of it's surface.

Other than roof slope and shape, research and analysis determined making the roof assembly the same as the wall assembly. Untraditional for moderate climates, Antartica presents a unique environment where sun exposure on the roof is nearly equal with the walls. Several stations in Antarctica have the same assembly for walls and roofs. A key advantage is this reduces the number of joint types by ensuring the joint used for walls, is the same joint for roofs, and the transition between walls and roofs does not involve trims or battens that would add complexity at this intersection. It is highly recommended to have the same wall and roof assemblies due to the possibility of creating ice dams or icicles at the transition from roof to wall.

The major determining environmental factors for a successful roof are extremely cold temperatures and high winds. The higher humidity on the interior of the building will be continuously trying to drive to the exterior where there is relatively no humidity. There will need to be limited access to the roof for servicing and monitoring of roof top equipment (mechanical, satellites, etc.). Durability for those activities factors into the selection of the roofing system. The risk tolerance for the roof needs to be as fail safe as possible. Damage due to wind or other environmental factors will be a constant test of the roofing system. A system that can resist these factors and can be easily repaired in adverse conditions if a leak is discovered. The service life expectancy for the roof should also be for a period of 20 years at minimum requiring a replacement of the wear surface during the life of the structure.

The roof must be able to control several factors. Those are:

1. Control the environment (snow, water)
2. Control Airflow
3. Control Heat Flow
4. Control Vapor Diffusion
5. Control Fire

3 BSD-149: Unvented Roof Assemblies for All Climates, Christopher Schumacher, http://buildingscience.com/documents/digests/bsd-149-unvented-roof-assemblies-for-all-climates

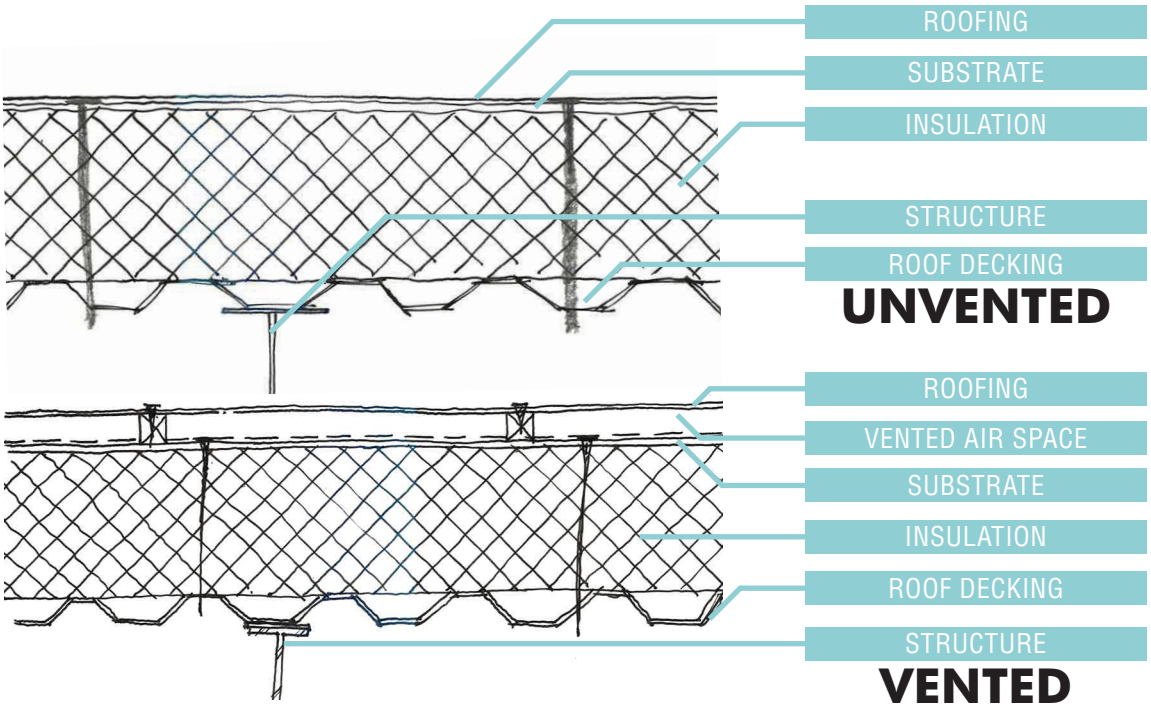
Roofs

Two types of roof construction were researched for this report: unventilated roofs and a ventilated roofs. An ***unventilated roof*** does not allow air to be circulated through any part of the roof assembly. It takes the thermal, moisture and air controls and moves them to the exterior of the assembly. In order to do this the roof assembly responds to the roof requirements by doing the following:

1. The weather barrier does not allow snow or water to enter the assembly. It is completely sealed.
2. Moisture in the air is prevented from reaching the dew point within the assembly where it can condense by an impermeable barrier.
3. Heat flow is controlled by an insulation that meets the required thermal performance of the assembly.
4. Vapor diffusion is managed at the insulation controlling any vapor moving through the assembly at a rate low enough so that moisture cannot collect and condense.
5. Fire resistance is a function of the assembly and the components it is constructed of.

A ***ventilated roof*** system takes a different approach to dealing with how the assembly is put together. A ventilated roof uses an air cavity to separate the weather barrier from the air barrier and thermal insulation. It allows air to circulate over the surface of the insulation and carry away any warm moist air that does make its way through the roof assembly. The roof surface (weather barrier) is allowed to remain the same temperature as the surrounding air. This can help prevent the possibly of water melting and refreezing creating ice damming. A vented roof assembly responds to the roof requirements by doing the following:

1. The weather barrier does not allow snow or water to enter the assembly. It acts as the first barrier to snow or water penetration.
2. Air is circulated between the weather barrier and the air barrier/ thermal components. This cavity is open on both ends using vents.
3. Heat flow is controlled by an insulation that meets the required thermal performance of the assembly, similar to an unventilated roof.
4. Vapor diffusion is managed by allowing the air cavity below the weather barrier to collect any moist humid air and carry it away to the exterior through vents.
5. Fire resistance is a function of the assembly and the components it is constructed of.



Floors

The common elements in a floor assembly are:

- Elevated Floor Assembly
- Weather Barrier
- Air Barrier System(s)
- Vapor Retarder(s)`
- Insulating Element(s)
- Plenum/ Interstitial Airspace
- Insulated Floor Decking attached to Structural System

Slab on Grade Floor Assembly over Permafrost

- Slab on Grade with Single Phase Closed Thermal Tube (Thermosyphoning)
- Insulating Element(s)
- Floor Decking

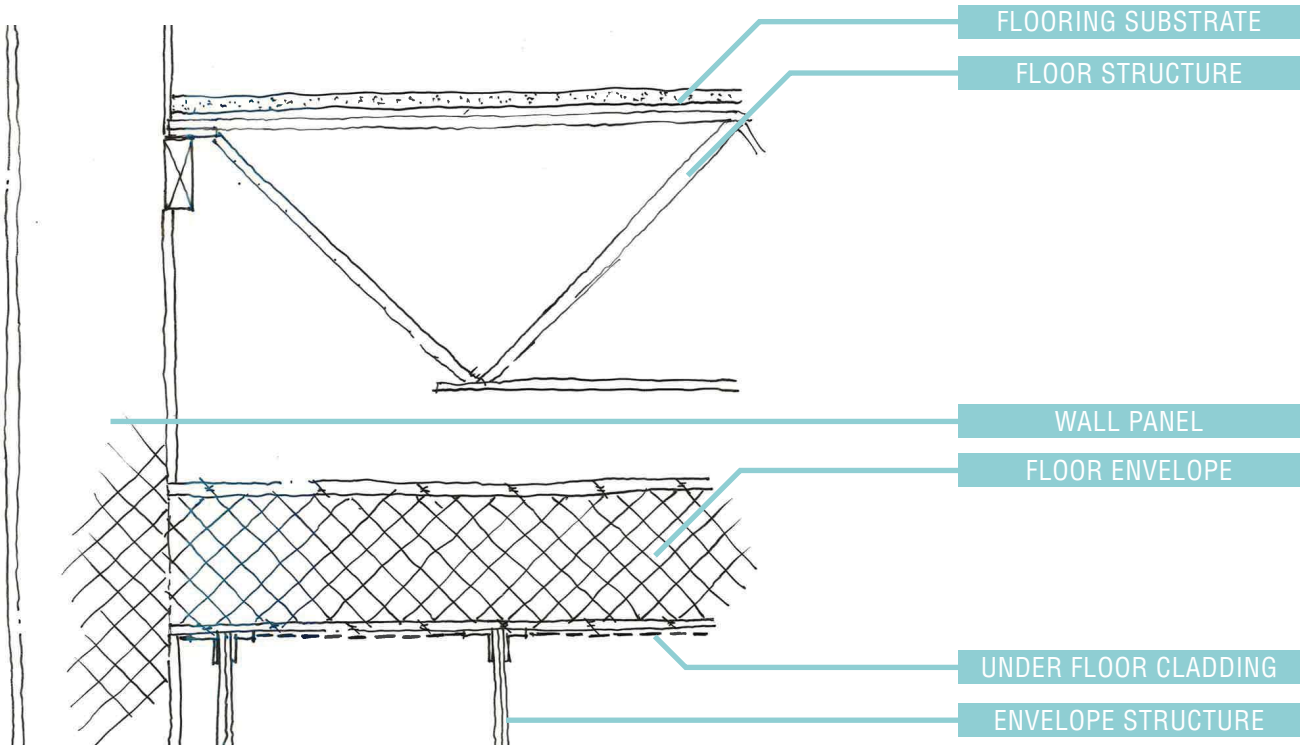
1. CBD-48: Requirements for Exterior Walls by Hutcheon, N.B. Canadian Building Digest #48, December 1963.
2. "Building Envelope Design Guide - Wall Systems" in Whole Building Design Guide (http://www.wbdg.org/design/env_wall.php)
3. BSD-149: Unvented Roof Assemblies for All Climates, Christopher Schumacher, http://buildingscience.com/documents/digests/bsd-149-unvented-roof-assemblies-for-all-climates

Floors

ELEVATED FLOOR ASSEMBLY

Many structures on the Antarctica ice and permafrost use elevated foundations to avoid the possibility of melting the frozen ground and causing settlement issues. This is a common solution to building on frozen soil and is an appropriate solution for parts of this station.

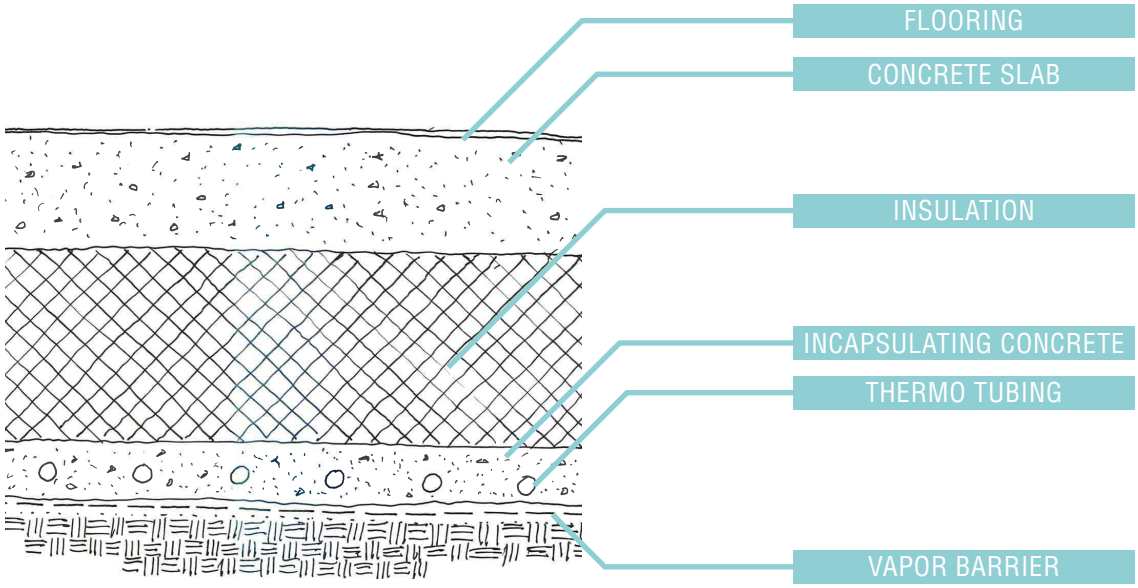
Due to the size of floor panels, using a raised foundation, McMurdo Station does not allow wind to totally scour snow build up under the building. To keep the snow out, the building perimeter wall will continue down to the ground allowing the cold air to ventilate the space. This perimeter wall below the floor line would be uninsulated.



Floors

COOLED SLAB ON GRADE

Where an elevated slab is in impractical due to its usage, the slab must meet the ground, the soil needs to be insulated from the warm concrete above through several inches of rigid insulation. However, this is not enough as the heat would eventually reach the permafrost and cause thawing. While the insulation is effective in slowing down the heat migration, it does not completely remove the heat. To totally remove the remaining heat, tubes of cold air or fluid would flow through an additional layer of concrete or gravel and remove the heat away from the ground and into the atmosphere.



Doors

Two basic types of doors were investigated. Passage Doors for the passage of people and Loading Dock Doors for the passage of large materials and equipment from interior to exterior. Basis of selection include thermal performance of the door panel and frame along with the ability to prevent snow & ice accumulation in the gap between door and frame.

Doors can be either "standard" manufactured steel or fiberglass products, standard freezer style doors or custom designed and manufactured glass reinforced plastic can be used. In selecting doors it is important to consider the expected number of operations and the seal type, to ensure the best possible weather barrier. If the door does become iced up, it is highly likely that crew will use ice axes to remove the ice. The door needs to be robust enough to accommodate this aggressive treatment. Hardware needs to ensure a firm closure of the door and the type of handles used on freezer doors is probably the best solution.

All of the door types investigated have been used at multiple Antarctic stations.

PASSAGE DOORS & FRAMES

Insulated Metal Swing
System insulating values up to R=4.0 are standard. Door panels with insulating values up to R=10.0 are available in polyurethane cores. These are time proven technology currently in use at McMurdo Station. To reduce the energy transfer through the steel frame, there are thermally broken frame options available and recommended.

Insulated Fiberglass Swing
Similar insulating values to steel doors. Lower level of thermal transmission as the door has fiberglass faces instead of steel faces. Fiberglass frames are also available for increased thermal performance.

Cold Storage Swing Type
This door type is commonly referred to as a walk-in freezer door. This type of product is used at the main entrance to the Crary Science and Engineering Center at McMurdo Station. Thickness of the door directly relates to the thermal performance. Standard doors are 4" thick metal clad with foamed-in-place polyurethane insulation achieving values up to R=24.

Glass Reinforced Plastic Swing
This type of door and frame is a custom construction and in use at the Halley VI Station. Insulation values up to R=40 are achievable. Halley VI has a stepped edge to the door and frame with stainless steel elements building into the door and frame to provide attachment points for hinges.

Doors

LOADING DOCK DOORS

Insulated Overhead Coiling
Coiling doors are a proven technology. Available with electric operators or with manual operators. Insulating values up to R=10.9 available.

Insulated Overhead Sectional
Coiling doors are a proven technology. Available with electric operators or with manual operators. Insulating values up to R=26.0 for the door is available with a 3" thick section. System installed values of R=7.0.

Cold Store Overhead Sectional
Available in standard sizes up to 12' x 12'. Insulating performance similar to solid doors of R=24. Available with heat cables imbedded within the sections to ensure consistent smooth operation. Power operation or manual operation.

Cold Store Vertical Lift
Single panel door available standard up to 12' x 12'. Insulating performance similar to solid doors of R=24. Available with heat cables imbedded within the perimeter to ensure consistent smooth operation. Power operation or manual operation.

Oversized Insulated Metal Swing
Energy performance similar to standard insulated steel doors. An option to sectional, coiling or vertical lift doors. Standard limitation on available size of opening at 8' x 8'.

Fenestration

Windows

Windows and roof lights can be glazed into the building panels and should be designed to allow replacement from within if they should be broken. Rounded corners will reduce joints in gaskets, minimizing heat loss. Window glazing insulating values should be maximized. Insulated glazing units are available with values reaching close to R=14.0. If manufactured window assemblies are used, products that incorporate insulation into the frames should be used.

To prevent glare due to the low sun angles, the visible light transmittance will need to be controlled. A visible light transmittance factor of 35% - 50% is anticipated. Glazing over science cameras and lidars needs to be specified to suit the needs of the science. Window design should utilize warm edge technology so that spacers between panes of glass are non conductive. It may be appropriate to include operable windows. Frames need to incorporate thermal breaks and ideally should be manufactured from non-thermal conductive materials such as fiberglass or GRP. Gasket selection will be crucial to prevent heat loss and risk of ice build up.

In some areas it may be beneficial to maximize natural light while controlling heat loss. In locations where clear glazing is not imperative, translucent insulated panels can be used. Current technology incorporates aerogel insulation materials into the assemblies with the ability to reach R=20.

Roof lights are valuable to bring natural light into the heart of buildings. These however need to be fully sealed against the impacts of melt water flowing over the roof in summer.

The main key performance aspect for windows is total system thermal resistance measured as R value. The higher the R value, the better the thermal performance. Other performance factors are the thermal resistance of the frame material, durability of the frame material, and aesthetic contribution.

Fenestration

Windows

EXTRUDED VINYL WINDOWS

Typical application is in residential construction. Existing industry has the ability to achieve total window system R values up to R=6.66 (U=0.15) for non-impact resistant locations. Coastal units are available that provide a higher degree of impact resistance through the use of laminated glazing and modification to the frame construction. Coastal window system R values of up to R=3.70 (U=0.27) are available. Manufacturers have the ability to provide units with an integral nailing fin which provides additional protection against air and water infiltration. The frame thermal performance is good as vinyl has a low thermal conductance. Concerns are the impact performance of vinyl at the -40 F to -50 F winter temperatures. Aesthetic contribution is low due to limited color options and overall look.

ALUMINUM CLAD WOOD WINDOWS

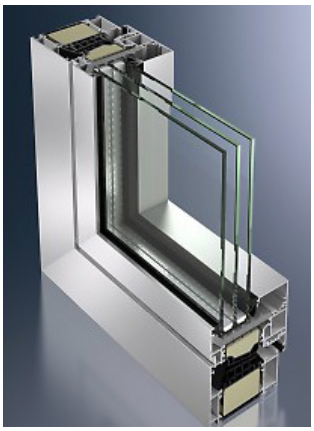
Typical application is in residential construction. Existing industry has the ability to achieve total window system R values up to R=6.25 (U=0.16) for non-impact resistant locations. Units are available that provide a higher degree of impact resistance through the use of laminated glazing. Manufacturers have the ability to provide units with an integral nailing fin which provides additional protection against air and water infiltration. The frame thermal performance is good as wood has a low thermal conductance. Aesthetic contribution is good with availability of multiple paint and anodized aluminum finishes for the exterior and the real wood exposure on the interior.

ALUMINUM COMMERCIAL STOREFRONT WINDOWS

Typical commercial window product. Available in thermally broken arrangement where the interior and exterior frame sections are separated with a non-metallic connector. This is to reduce the thermal transmittance from exterior to interior. Units are available in fixed window and multiple operable configurations. System thermal R values vary based on the frame to glazing ratio and the glazing R value. Lower end performance is R=3.70 (U=0.27) and upper end performance is R=6.25 for a 90% glazing / frame ratio.

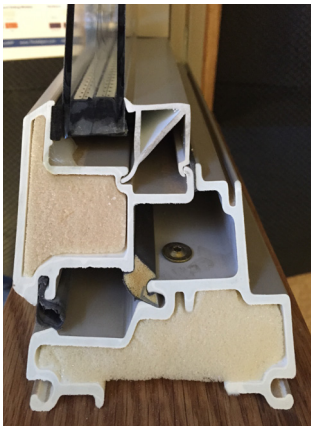
Fenestration

Windows



HIGH-PERFORMANCE ALUMINUM WINDOWS

Primary example for this type is Schueco. They have been used at the South Korean Jang Bogo Antarctic Research Station. They are thermally broken in much the same way as commercial storefront windows but are thermally enhanced with extruded rigid foam insulation inserted inside the aluminum extrusions when the windows are built. Standard thermally broken aluminum windows have a frame R value of R=1.72. Shueco AWS90.SI+ aluminum frames have a R value of R=7.14.



FIBERGLASS WINDOWS

Primary example for this type is Alpen Windows. They have been specified for the US Arctic Program's Atmospheric Watch Observatory at Summit Station, Greenland. Units are available in fixed window and multiple operable configurations. The fiberglass frame is not thermally broken in the manner of aluminum storefront windows since fiberglass has a low thermal transmittance value. The thermal performance is enhanced with extruded rigid foam insulation inserted inside the fiberglass frame when the windows are built. Existing industry has the ability to achieve total window system R values up to R=9.10 (U=0.11). There is research underway to bring total system R values to above R=10.0 in the "very near future".

Glazing

Glazing is a significant contributor to the performance of the building skin as it is typically the area with the lowest insulating value. The ability to increase the performance of the glazing can have dramatic impact on the overall building energy performance. Glazing options include traditional double pane insulated glazing units, triple pane with a suspended film or third layer of glass between the outer panes of glass, quad pane where 2 separate suspended films are inserted between the outer panes of glass, vacuum insulated glazing panels and electrochromic shading glass. For maximum insulating performance, all glazing will have a minimum of 2 low-E coatings incorporated into the assembly.

DOUBLE PANE INSULATED GLAZING UNITS

This is a proven technology with industry performing continuous enhancements to the edge sealing methods. Has limitations regarding insulating values due to only a single air-space between the two layers of glass. Double pane insulated glazing has the ability to achieve insulating values up to R=5.00 (U=0.20) when the cavity is filled with Argon gas.

TRIPLE PANE INSULATED GLAZING UNITS

This is also a proven technology in the glazing industry. Standard methods are for 3 panes of glass providing 2 separate air chambers or with a suspend film as the third pane. Insulating values for 3 panes of glass with Argon filled cavities can reach R=7.69 (U=0.13) and with a suspended film with Argon gas can reach R=9.1 (U=0.11).

QUAD PANE INSULATED GLAZING UNITS

Quad pane windows use a double suspended film between 2 panes of glass. The technology is proven and has been specified for the US Arctic Program's Atmospheric Watch Observatory at Summit Station, Greenland. When combined with Argon gas in the chambers, insulating values of up to R=13.7 (U=0.07) are possible. Industry leader Alpen Windows are working on achieving R=15.0 with their next generation of product and feel that R=20.0 is possible in the near future.

VACUUM INSULATED GLAZING UNITS

This is a proven technology that has been around for 20+ years but unproven in Antarctic environments. Pilkington Spacia is a leading product in the marketplace. It is manufactured by placing a grid of 0.5 mm micro pillars between two panes of glass. The edges are glass welded and a vacuum pulled through a port placed in the inner pane of glass. The total thickness of the unit is a fraction over ¼" thickness. Insulating values are similar to traditional 1" double pane insulating units at R=5.0 (U=0.20). It is not appropriate for use where there is large temperature differences between interior and exterior as the stress on the glass weld has a potential to fail. Industry research is underway on combining the vacuum insulated panel into a traditional insulated glazing unit to provide a thermal break from interior to exterior. This would require a proof of concept testing to determine if it is viable for Antarctic environments.

Glazing

IMPACT RESISTANT GLAZING

Impact resistant glazing is created by laminating a pvc interlayer between 2 panes of float glass. The interlayer provides the strength to resist impacts from flying objects. With ultimate wind speeds at McMurdo of 150 mph and higher, this may be necessary depending upon USAP code requirements. Laminated glazing can be integrated into insulated glazing units and allow for insulation values consistent with double, triple and quad glazed units.

ELECTROCHROMIC SHADING GLASS

Electrochromic glass also has the name 'smart glass'. The shading coefficient of the glass can be varied from 58% visible light transmittance to 1% transmittance through preset intervals. This allows for solar and glare control to vary throughout the day. Another benefit is the ability to eliminate mechanical shading methods such as curtains or mechanical blinds. The smart glass is integrated into an insulated glazing unit as one of the panes of glass. Insulating performance levels similar to those noted in previous sections are able to be achieved.

SELF-CLEANING GLASS

Self-cleaning glass has a coating that allows for natural cleaning of glass under specific environmental conditions. The glass has a coating applied that provides a photocatalytic reaction with daylight that breaks down organic dirt. The second step of the cleaning process is where rainwater hitting the glass reacts in a hydrophilic fashion and evenly spreads across the glass surface and removing the loosened organic dirt. Given the information that McMurdo Station does not experience much if any rainfall events, this does not appear to be a viable technology to implement.

Skylights

INSULATED SKYLIGHTS

The benefits of insulated skylights is in providing diffuse light, rather than direct light. This allows for a reduction of artificial lighting when natural lighting is available. Ideal for any location where artificial lighting is required. Can be used in both vertical and horizontal applications. System insulation values reach up to R=20.0 (U=0.05) for both types of systems.

KALWALL FRP PANEL WITH AEROGEL

The glazing panel is 2 layers of fiberglass reinforced polymer with Lumira aerogel insulation sandwiched between. Visible light transmittance is 20%.

OCALUX GLASS PANEL WITH OKAGEL

This is a proven system having been installed at the Halley VI Antarctic Station. The glazing panel is 2 layers of glass with Okagel aerogel insulation sandwiched between. Visible light transmittance is 45%.

SECTION 3
FINDINGS & RECOMMENDATIONS

RANKING THE COMPONENTS AND ASSEMBLIES

Section 1 establishes the design criteria for both the selection of individual building components and full envelope assemblies. *Section 2* identifies and determines the performance characteristics of a wide spectrum of potential building envelope, as well as possible combinations of components to form full assemblies.

This final section evaluates those components and assemblies against the design criteria. Each Component and Assembly was ranked from high to low relative to other Components and Assemblies per each Evaluation Criteria. In addition, each of the Evaluation Criteria was weighted in terms of value to the project. Two identical matrices are depicted. One matrix symbolically shows the grading enabling a quick overall comprehension of the ranking. A second matrix adds numerical values by multiplied the individual component or assembly evaluation to the evaluation criteria weighting giving a better basis to understand the overall comparison. The result is two system alternatives and multiple fenustration alternatives with associated costs. The building design may be based on any of these technical recommendations, as appropriate to meet the project design objectives.

McMurdo Station Modernization - Building Shell and Fenestration Study - Matrix of Design Options

		Design																									Construction Cost			Construction												Bldg. Life			
Evaluation Criteria		Proven Technology	Thermal Performance	Complexity/Reliability	Structural Suitability	Ice Build Up	Fire Resistance	Aesthetics/Image (Exterior)	Product Life Span	Adaptability	Temperature Sensitivity (in-situ)	Compliance: Made in American	Indoor Air Quality	Air/Vapor Infiltration	Aesthetics - Interior	Stability / Thermal Expansion	Impact Resistance	Reliance on Sub-structure	Ability to Allow Curves	Abrasion Resistance	Corrosion Resistance	Reflectivity	Ultraviolet Light (UV) Resistance	Acoustical Resistance	Embodied Energy	Allowance for Complex 3D Shapes	Relative Cost/SF	Minimum ($/SF)	Maximum ($/SF)	Off Site Constructability	Constructability	Quality Control	Ability for Non-Standard Fabrication	On-site Workability	Labor Intensive Construction	Shipping Efficiency	Construction Duration	Construction Equipment Req'd	Enviro. Impact During Construction	Marketplace Availability	On-Site Construction Waste	Reparability	Create Future Penetrations	Supplier Track Record	Maintenance/Req'd Expertise
Evaluation Criteria Weight		5	5	5	5	4	4	4	4	4	4	4	4	4	3	3	3	3	1	2	2	2	2	2	2	1	5				5	5	4	4	3	3	2	2	2	1	1	4	4	3	3
Building Systems and Components	**Design Systems / Options**																																												
1.0 Components																																													
A. Cladding																																													
	Steel (mill finish)	△	▽	▷			▲	△	▲	▲	~	△	~	▲	~	△	▲	~	△	▲	▽	▷	▲	▼	▽	△		$6.00	$8.00		△	▷	△	△	▷	~	▲	△	~	△	~	△	△	△	▲
	Steel (painted finish)	▲	▽	▷			▲	▷	▲	▲	~	△	~	▲	~	△	△	~	△	△	△	△	△	▼	▽	△		$5.00	$8.00		▲	△	△	▲	▷	~	▲	△	~	△	~	△	△	△	▲
	Stainless Steel	▲	▷	▷			▲	▲	▲	▲	~	△	~	▲	~	▲	▲	~	△	▲	▲	▽	▲	▼	▽	△		$9.00	$22.00		△	▲	△	▷	▷	~	▲	△	~	△	~	△	△	△	△
	Steel (weathered)	△	▽	▷			▲	△	▲	▲	~	△	~	▲	~	△	▲	~	△	▲	▷	▲	▲	▼	▽	△		$7.00	$13.00		△	△	△	△	▷	~	▲	△	~	△	~	△	△	△	▲
	Aluminum (mill finish)	△	▽	▷			△	△	▲	▲	~	△	~	▲	~	△	△	~	△	△	△	▽	▲	▽	▼	△		$5.00	$12.00		▲	▷	△	△	▷	~	▲	△	~	△	~	△	△	△	▲
	Aluminum (anodized)	▲	▽	▷			△	△	▲	▲	~	△	~	▲	~	△	△	~	△	▲	▲	△	△	▽	▼	△		$6.00	$15.00		▲	△	△	▲	▷	~	▲	△	~	△	~	△	△	△	▲
	Aluminum (painted)	▲	▽	▷			△	△	▲	▲	~	△	~	▲	~	△	▷	~	△	△	△	▷	△	▽	▼	△		$4.75	$11.00		△	△	△	△	▷	~	▲	△	~	△	~	△	△	△	▲
	Copper	△	▼	▷			△	▲	▲	△	~	△	~	▲	~	△	▷	~	△	△	△	▷	▲	▽	▽	△		$33.00	$45.00		△	△	△	▲	▷	~	△	△	~	△	~	△	△	△	△
	Zinc	▽	▽	▷			△	▲	▲	△	~	△	~	▲	~	△	▽	~	△	△	△	▷	▲	▽	▼	△		$30.00	$40.00		△	△	△	▼	▷	~	△	△	~	△	~	△	△	△	△
	Cement Fiber Board	▽	△	▽			△	△	▷	▲	~	△	~	▲	~	▲	△	~	▼	△	△	△	▽	△	▲	▽		$4.00	$6.00		▽	▷	△	▽	▽	~	▲	△	~	△	~	▽	▷	△	▷
	Glass Reinforced Plastics Panel	△	▲	▲			▽	▲	▽	▲	~	△	~	▲	~	▲	▲	~	▲	△	▲	△	▽	△	▼	▲		$4.50	$7.00		▽	▲	▽	▼	△	~	▲	▲	~	△	~	▽	▽	▷	▼
	Concrete	▽	▷	△			▲	▷	▲	△	~	△	~	▲	~	▽	▲	~	▷	▲	▷	▲	▲	▲	△	▷		$18.00	$27.00		▷	▷	△	▽	△	~	△	▲	~	△	~	▽	▽	▽	▲
	EPDM	▽	△	△			▷	▽	▷	▲	~	△	~	▲	~	▷	▷	~	▲	▽	▲	▲	▽	▷	▽	▲		$3.00	$4.25		▲	▷	△	△	▽	~	▽	△	~	△	~	▲	△	△	△
	TPO	▽	△	△			▷	▷	▷	▲	~	△	~	▲	~	▷	▷	~	▲	▽	▲	▲	▽	▷	▽	▲		$3.50	$5.00		▲	▷	△	△	▽	~	▽	△	~	△	~	▲	△	△	△
	Wood (kiln dried)	▲	△	▲			▼	△	△	▲	~	△	~	▽	~	▷	▷	~	▷	▼	▲	▲	▽	△	▲	▷		$6.50	$9.00		△	▷	△	▲	▷	~	△	△	~	△	~	▲	▲	△	▲
B. Vapor Barrier																																													
Measured in Perms	Class I - Aluminum Foil	▲	~	▷	▽	~	~	~	△	~	▷	▲	~	▲	~	▽	▼	~	~	~	~	~	~	~	~	~		$0.13	$0.13	~	▷	▽	▽	▽	▷	~	△	~	~	~	~	▼	▼	~	~
ASTM E-96 Method A and Method B	Class I - Polyethylene Sheet (0.0006 thk)	▲	~	▲	△	~	~	~	▽	~	△	▲	~	▲	~	▷	▽	~	~	~	~	~	~	~	~	~		$0.05	$0.20	~	▲	▽	△	△	▲	~	△	~	~	~	~	▽	▽	~	~
	Class I - Polyethylene Sheet (0.002 thk)	▲	~	▲	△	~	~	~	▽	~	△	▲	~	△	~	▷	▽	~	~	~	~	~	~	~	~	~		$0.25	$1.50	~	▲	▽	△	△	▲	~	△	~	~	~	~	▽	▽	~	~
	Class I - Fluid Applied Membrane	▽	~	▲	▷	~	~	~	▽	~	▼	▲	~	▲	~	△	△	~	~	~	~	~	~	~	~	~				~	▷	△	▲	▽	▲	~	△	~	~	~	~	▲	△	~	~
	Class II - Vapor Retarder Latex Paint	▽	~	▲	▲	~	~	~	▼	~	▼	▲	~	▽	~	▽	▷	~	~	~	~	~	~	~	~	~		$0.30	$0.30	~	▷	▽	△	▽	▲	~	△	~	~	~	~	△	△	~	~
	Class II - Insulation Facing, Foil	△	~	▷	△	~	~	~	△	~	△	▲	~	▽	~	▽	▼	~	~	~	~	~	~	~	~	~		in other systems		~	▷	▷	▷	▽	▷	~	△	~	~	~	~	▼	▼	~	~
	Class II - Plywood (Doug Fir, Exterior Glue)	△	~	▽	▷	~	~	~	▲	~	△	▲	~	▽	~	▷	▲	~	~	~	~	~	~	~	~	~		in other systems		~	△	▼	△	▽	△	~	▽	~	~	~	~	▽	▽	~	~
	Class II - Insulation Facing, Kraft	△	~	▷	△	~	~	~	▷	~	△	▲	~	▽	~	▽	▼	~	~	~	~	~	~	~	~	~		in other systems		~	▷	▷	▷	▽	▷	~	△	~	~	~	~	▼	▼	~	~
	Class III - Gypsum Board	▽	~	▽	▷	~	~	~	▲	~	△	▲	~	▼	~	▷	▲	~	~	~	~	~	~	~	~	~		in other systems		~	△	▼	△	▽	△	~	▽	~	~	~	~	▽	▽	~	~
	Class III - Typ Latex Paint	▽	~	▲	▲	~	~	~	▼	~	▼	▲	~	▼	~	▽	▷	~	~	~	~	~	~	~	~	~		$0.07	$0.14	~	▷	▽	△	▽	▲	~	△	~	~	~	~	△	△	~	~
C. Air Barrier																																													
Measured in L/s*m2	Self Adhered Sheets (< 0.004)	△	~	△	△	~	~	~	▷	~	▷	△	~	▲	~	▷	▽	~	~	~	~	~	~	~	u	~		$0.53	$0.86		▷	▷	△	△	▷	~	▷	▷	~	~	~	▽	▽	▷	~
ASTM E2178	Fluid Applied (< 0.003)	△	~	△	▷	~	~	~	▷	~	▽	△	~	▲	~	▷	▽	~	~	~	~	~	~	~	u	~		$0.72			▷	△	△	▽	▷	~	▷	▷	~	~	~	▷	▷	▷	~
ASTM M E96	Sprayed Polyurethane Foam (Med Density) (< 0.004)	△	~	△	▽	~	~	~	▷	~	▼	△	~	▲	~	▽	▽	~	~	~	~	~	~	~	u	~		in other systems			▷	▷	▼	▼	△	~	▷	▷	~	~	~	▽	▽	▷	~
	Mechanically Fastened Building Wrap (< 0.05)	△	~	▽	▽	~	~	~	▷	~	△	△	~	▼	~	▽	▽	~	~	~	~	~	~	~	u	~		$0.15	$0.20		▷	▽	△	▲	▷	~	▷	▷	~	~	~	▽	▽	▷	~
	Board Stock (Rigid Insulation) (< 0.05)	△	~	▽	▽	~	~	~	▷	~	△	△	~	▼	~	▽	▷	~	~	~	~	~	~	~	u	~		in other systems			▷	▽	△	▲	▽	~	▽	▷	~	~	~	▽	▽	▷	~
	Adhesive Backed Building Wrap (< 0.01)	△	~	▷	△	~	~	~	▷	~	▷	△	~	▷	~	▷	▽	~	~	~	~	~	~	~	u	~		$0.22			▷	▽	△	△	▷	~	▷	▷	~	~	~	▽	▽	▷	~
D. Insulation																																													
Thermal measured in U-Value (at -15dC)	Rigid Foam - EPS	▲	▷	~	△	~	▽	~	▲	~	~	▲	▽	△	~	~	~	~	△	~	~	~	~	~		▽		$1.08		▲	▲	▲	▷	▲	~	~	~	~	~	▲	~	▷	▲	▲	~
BTU/hr*ft2 (* = measured at 75d F)	Rigid Foam - GPS	△	▷	~	△	~	▷	~	▲	~	~	▲	▽	△	~	~	~	~	△	~	~	~	~			▽				▲	▲	▲	▷	▲	~	~	~	~	~	△	~	▷	▲	▷	~
Surface Burning	Rigid Foam - XPS	▲	▷	~	△	~	▽	~	▲	~	~	▲	▽	△	~	~	~	~	△	~	~	~	~	~		▽		$1.57		▲	▲	▲	▷	▲	~	~	~	~	~	▲	~	▷	▲	▲	~
ASTM E84	Rigid Foam - Polyisocyanurate	▲	▽	~	△	~	△	~	▲	~	~	▲	▲	▲	~	~	~	~	△	~	~	~	~	~		▽		$2.02		▲	▲	▲	▷	▲	~	~	~	~	~	▲	~	▷	▲	▲	~
Environmental Impact	Rigid Foam - Phenolic	▽	△	~	△	~	▲	~	▲	~	~	▲	▲	▽	~	~	~	~	△	~	~	~	~	~		▽		$1.70		▲	▲	▲	▷	▲	~	~	~	~	~	▲	~	▷	▲	▲	~
Global Warming Impact	Rigid Board - Polyurethane	▲	▲	~	△	~	△	~	▲	~	~	▲	▲	▲	~	~	~	~	△	~	~	~	~	~		▽		$1.75		▲	▲	▲	▷	▲	~	~	~	~	~	▲	~	▷	▲	▲	~
	Spray-In Foam - Icynene (water-blown)	▽	△	~	▽	~	▷	~	▲	~	~	▲	▲	▽	~	~	~	~	▲	~	~	~	~	~		▲		$1.10		▲	▽	▽	▲	▽	~	~	~	▽	~	▲	~	▽	△	▽	~
	Batts - Fiberglass	▷	▽	~	▽	~	▲	~	▽	~	~	▲	▲	▽	~	~	~	~	▲	~	~	~	~	~		▲		$0.60		▲	▲	▷	△	▲	~	~	~	~	~	▲	~	▲	△	▲	~
	Batts - Rockwool	▷	▽	~	▽	~	▲	~	▽	~	~	▲	▲	▽	~	~	~	~	▲	~	~	~	~			▲		$0.60		▲	▲	▷	△	▲	~	~	~	~	~	▲	~	▲	△	▲	~
	Batts - Cotton Batts	▼	▽	~	▽	~	△	~	▽	~	~	▲	▲	▽	~	~	~	~	▲	~	~	~	~	#		▲		$0.90		▲	▲	▷	△	▲	~	~	~	~	~	▲	~	▲	△	▲	~
	Loose Fill	▼	▽	~	▽	~	△	~	▽	~	~	▲	▲	▽	~	~	~	~	▽	~	~	~	~			▽		$0.31		▽	▽	▽	▽	▲	~	~	▽	~	~	▲	~	▲	△	▲	~
	Flexible Non-Organic Polyurethane	▼	△	~	▽	~	▲	~	▲	~	~	▽	▽	▽	~	~	~	~	△	~	~	~	~			▽				▲	▲	△	△	▲	~	~	~	~	~	▼	~	▲	△	▷	~
	Aerogel Insulation	▼	▲	~	▽	~	▲	~	▲	~	~	▲	▲	▲	~	~	~	~	▲	~	~	~	~	~		▲		$3.20	$15.00	▲	▲	▲	△	▲	~	~	~	~	~	▼	~	▼	▽	▽	~
	Vacuum Insulated Panel	▼	▲	~	▽	~	▽	~	▲	~	~	▲	▲	△	~	~	~	~	▼	~	~	~	~	~		▼		$10.00	$12.00	▲	▽	▲	▼	▼	~	~	~	~	~	▽	~	▼	▼	▷	~
E. Substrait for Interior Finishes																																													
F. Shading and Light Control																																													

Key
Evaluation Criteria

▲	Excellent
△	Positive
▷	Neutral
▽	Negative
▼	Poor
(yellow)	Major Driver
×	Disqualifyer
5	Highest Priority
1	Lowest Priority

Cost/R-Value	
.06	Rigid Foam - EPS
.04	Rigid Foam - GPS
.10	Rigid Foam - XPS
.08	Rigid Foam - Polyisocyanurate
	Rigid Foam - Phenolic
.09	Rigid Board - Polyurethane
.16	Spray-In Foam - Icynene (water-blown)
.02	Batts - Fiberglass
.06	Batts - Rockwool
.05	Batts - Cotton Batts
.02	Loose Fill
1.4	Flexible Non-Organic Polyurethane
	Aerogel Insulation
	Vacuum Insulated Panel

McMurdo Station Modernization - Building Shell and Fenestration Study - Matrix of Design Options

Evaluation Criteria		Design																								Construction Cost			Construction										Bldg. Life				
		Proven Technology	Thermal Performance	Complexity/Reliability	Structural Suitability	Ice Build Up	Fire Resistance	Aesthetics/Image (Exterior)	Product Life Span	Adaptability	Temperature Sensitivity (in-situ)	Compliance: Made in American	Indoor Air Quality	Air/Vapor Infiltration	Aesthetics - Interior	Stability / Thermal Expansion	Impact Resistance	Reliance on Sub-structure	Ability to Allow Curves	Abrasion Resistance	Corrosion Resistance	Reflectivity	Ultraviolet Light (UV) Resistance	Acoustical Resistance	Embodied Energy	Allowance for Complex 3D Shapes	Relative Cost/SF	Minimum ($/SF)	Maximum ($/SF)	Off Site Constructability	Constructability	Quality Control	Ability for Non-Standard Fabrication	On-site Workability	Labor Intensive Construction	Shipping Efficiency	Construction Duration	Construction Equipment Req'd	Enviro. Impact During Construction	Marketplace Availability	On-Site Construction Waste	Reparability	Create Future Penetrations	Supplier Track Record	Maintenance/Req'd Expertise	Key
Evaluation Criteria Weight		5	5	5	5	4	4	4	4	4	4	4	4	4	3	3	3	3	1	2	2	2	2	2	2	1	5			5	5	4	4	3	3	2	2	2	1	1	4	4	3	3	Evaluation Criteria
Building Systems and Components	**Design Systems / Options**																																										
2.0 Openings																																											
A. Doors																																											
Man Doors	Insulated Metal	▲	▷	▲	~	~	▲	▲	▲	~	△	▲	▲	△	▲	△	△	△	▼	△	▲	▷	△	△	▽	▽	△	$30.00	$33.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	△	~	▲	▲	
	Insulated Fiberglass	▲	△	▲	~	~	▲	▲	▲	~	▲	▲	▲	△	▲	△	△	△	▼	△	▲	▷	△	△	▽	▽	△	$32.00	$35.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	△	~	▲	▲	
	Walk-in Freeezer Type (CSEC)	▲	▲	△	~	~	△	▲	▲	~	▲	▲	▲	▲	▲	▲	△	△	▼	▲	▲	▷	▲	▲	▽	▽	▽	$85.00	$110.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	△	~	▲	▲	
	GRP Custom made (Halley VI)	▷	▲	▷	~	~	△	▲	▲	~	▲	▲	▲	▲	▲	▲	△	△	△	△	▲	▷	△	▲	▽	△	▼	$110.00	$125.00	▲	△	▲	▼	▼	▲	▲	▷	▲	▷	▲	△	~	▷	△	
Loading Dock	Insulated Overhead Coiling - standard commercial	▲	▼	▲	~	~	▲	▲	▲	~	△	▲	▲	△	▲	△	△	△	▼	▲	▲	▷	△	△	▽	▽	△	$35.00	$40.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	△	~	▲	▲	
	Insulated Overhead Sectional - standard commercial	▲	▽	▲	~	~	▲	▲	▲	~	△	▲	▲	△	▲	△	△	△	▼	▲	▲	▷	△	△	▽	▽	△	$27.00	$33.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	△	~	▲	▲	
	Insulated Overhead Sectional - walk-in freezer type	▲	▲	▲	~	~	△	▲	▲	~	▲	▲	▲	△	▲	△	△	△	▼	▲	▲	▷	▲	▲	▽	▽	▽	$88.00	$96.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	△	~	▲	▲	
	Insulated Vertical Lift - walk-in freezer type	▲	▲	▲	~	~	△	▲	▲	~	▲	▲	▲	△	▲	△	△	△	▼	▲	▲	▷	▲	▲	▽	▽	▽	$88.00	$96.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	△	~	▲	▲	
	Oversized Swing Doors	▲	▷	▲	~	~	▲	▲	▲	~	△	▲	▲	△	▲	△	△	△	▼	△	▲	▷	△	△	▽	▽	△	$33.00	$38.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	△	~	▲	▲	
B. Windows																																											
	Integrated Window (Halley VI)	▲	▲	▲	~	~	▲	▲	▲	~	▲	▲	▲	△	▲	▲	△	△	▼	▲	▲	▷	▲	△	▽	▽	▽	$55.00	$68.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	▽	~	▲	▲	
	Aluminum Storefront - thermal & hurricane	▲	▷	▲	~	~	▲	▲	▲	~	▷	▲	▲	△	▲	△	▲	△	▼	▲	▲	▷	▲	△	▽	▽	▽	$60.00	$75.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	▽	~	▲	▲	
	Aluminum Storefront - hurricane	▲	▷	▲	~	~	▲	▲	▲	~	▷	▲	▲	△	▲	△	▲	△	▼	▲	▲	▷	▲	△	▽	▽	▽	$55.00	$68.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	▽	~	▲	▲	
	Aluminum Storefront - high performance thermal	▲	▲	▲	~	~	▲	▲	▲	~	▷	▲	▲	△	▲	△	▽	△	▼	▲	▲	▷	▲	▷	▽	▽	▽	$55.00	$68.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	▽	~	▲	▲	
	Aluminum Storefront - standard thermal	▲	▷	▲	~	~	▲	▲	▲	~	▷	▲	▲	△	▲	△	▽	△	▼	▲	▲	▷	▲	▷	▽	▽	▷	$50.00	$62.00	▲	△	▲	▼	▷	▲	▲	▷	▲	▲	▲	▽	~	▲	▲	

Evaluation Criteria	Design																												Construction				Construction													Building Life					TOTAL
	Proven Technology	Thermal Performance	Complexity/Reliability	Structural Suitability	Ice Build Up	Fire Resistance	Aesthetics/Image (Exterior)	Product Life Span	Adaptability	Durability	Temperature Sensitivity (in-situ)	Compliance: Made in American	Indoor Air Quality	Air/Vapor Infiltration	Aesthetics - Interior	Stability / Thermal Expansion	Impact Resistance	Reliance on Sub-structure	Abrasion Resistance	Corrosion Resistance	Reflectivity	Ultraviolet Light (UV) Resistance	Acoustical Resistance	Embodied Energy	Ability to Allow Curves	Allowance for Complex 3D Shapes	SUBTOTAL	Relative Cost/SF	Minimum ($/SF)	Maximum ($/SF)	SUBTOTAL	Off Site Constructability	Constructability	Quality Control	Ability for Non-Standard Fabrication	On-site Workability	Labor Saving Construction	Shipping Efficiency	Construction Duration	Construction Equipment Req'd	Enviro. Impact During Construction	Marketplace Availability	On-Site Construction Waste	Reparability	Create Future Penetrations	Product Track Record	Maintenance/Req'd Expertise	SUBTOTAL	
Value	5	5	5	5	4	4	4	4	4	4	4	4	4	4	3	3	3	3	2	2	2	2	2	2	1	1	344	20				5	10	10	4	4	7	4	10	2	2	2	1	4	4	3	3	300	644
PANELS																																																
* SIPS	3	3	4			3		3	4		3	4		2	1	3	3	3	4	2	3	3	1	2	1	1	188					4	3	3	2	4	3	4	4	3		4	3	3	3	3	4	243	431
SIPS with Frame	4	3	4	4		3		3	4		4	4		2	1	3	3	2	4	2	3	3	1	2	1	1	214					4	3	3	2	4	2	3	3	3		4	3	3	3	3	4	222	436
Glass Reinforced Plastics w/Steel Frame	4	4	4	4		3	4	4	1		4	3		4	1	4	3	3	3	4	2	2	3	1	4	4	243					4	4	4	4	2	4	3	3	3		1	4	2	3	2	2	238	481
* Glass Reinforced Plastics as Structural	4	4	4			3	4	4	1		4	3		4	1	4	3	3	3	4	2	2	3	1	4	4	223					4	4	4	4	2	3	4	4	3		1	4	2	3	2	2	245	468
Mass Timber as Structural	1	3	3	4		4		3	3		3	3		3	3	3	3	3	4	2	3	3	3	3	1	1	205					4	3	3	2	2	3	4	4	3		2	3	2	2	3	3	220	425
Insulated Metal Panels with Frame	4	2	2	4		4	2	1	1		1	4		1	1	1	1	1	2	1	3	3	0	2	3	1	154					2	2	3	3	1	3	3	3	3		4	3	1	3	2	2	184	338
Engineered Timber Panels with Frame	3	2	2	4		1		3	3		2	3		2	1	3	3	2	4	2	3	3	1	2	1	1	170					4	4	3	2	2	3	3	3	3		2	3	3	3	2	3	221	391
Engineered Timber Panels as Strucutral	3	2	1			1		3	3		2	3		2	1	3	3	3	4	2	3	3	1	2	1	1	148					4	4	3	2	2	3	4	4	3		2	3	3	3	2	3	235	383
Precast Concrete Construction as Structural	3	2	1	4		4	1	1	4		2	4		1	1	2	4	4	4	4	4	4	4	3	2	3	202					2	1	1	3	0	1	1	2	1		4	3	2	1	1	3	110	312
Standard Stick Frame	4	2	0	4		1		1	4		3	4		1	1	3	1	1	4	2	3	3	1	1	3	1	156					0	1	0	2	4	0	0	0	2		4	0	4	4	4	4	102	258
Rainscreen	1	~	0	~	0	~	~	~	~		~	3	~	~	~	~	~	~	4	2	3	3	~	~	~	~						~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	~	

***** It is highly unlikely that any panel of the size needed can have enough internal support to be built without a frame

ASSIGNING RANKING TO EVALUATION CRITERIA

Within each Evaluation Criteria are descriptions (as depicted in the following tables) of how the Components and Assemblies are relatively ranked from high to low. The grading primarily considered the core area but should also define other future structures. This is especially true of the Structural Suitability where the size of the core facilities eliminate some assemblies that might otherwise be appropriate for smaller buildings. The grading is complete for all Components & Assemblies assuming that they could be used for smaller buildings.

MCMURDO EVALUATION CRITERIA EXPLANATION OF RANKING		
CATEGORY	**HIGH**	**LOW**
DESIGN		
PROVEN TECHNOLOGY	Multiple years in marketplace, multiple projects & suppliers	New to marketplace, few projects & installers
THERMAL PERFORMANCE	R value above 60 without degradation over 50 years in reasonable thickness	R value degrades over 50 year lifespan, unreasonable thickness to achieve R 60
COMPLEXITY RELIABILITY	Uses proven manufacturing and assembly methods for quality product	Requires complex manufacturing & assembly; quality control is demanding
STRUCTURAL SUITABILITY	Allows for long spans & high winds to build concept design	Cannot meet concept design requirements for span & winds without major alterations to existing standards
ICE BUILD UP	No areas for snow accumulation	Snow accumulation possible
FIRE RESISTANCE	Are fire retardant or resistant	Products are combustible
AESTHETICS/IMAGE (EXTERIOR)	Level of quality and craftsmanship inherent in the materials	Cannot be easily configured into a quality design
PRODUCT LIFE SPAN	Withstand elements for 50 years	Frequent preventative maintenance required
ADAPTABILITY	Can be modified for different uses	Hard to reconfigure
TEMPERATURE SENSITIVITY (IN-SITU)		
COMPLIANCE: MADE IN AMERICAN	All components are Domestic	All components are Foreign
INDOOR AIR QUALITY	Does not contribute to poor air quality	Contributes to poor air quality
AIR/VAPOR INFILTRATION	Air & vapor barriers are integral to design	Air & vapor barriers require additional products, time, and limited weather conditions
AESTHETICS - INTERIOR	Interior surface can be exposed and is attractive	Interior surface requires covering
STABILITY / THERMAL EXPANSION	Thermal expansion does not require large or special jointing	Thermal expansion requires large or special jointing
IMPACT RESISTANCE	Resists snow accumulation, wind driven objects, and small equipment impact	Damaged by snow accumulation, wind driven objects, and small impacts
RELIANCE ON SUB-STRUCTURE	Is self-supporting	Relies on separate structural frame
ABRASION RESISTANCE	Surpasses requirements	Underperforms requirements
CORROSION RESISTANCE	Surpasses requirements	Underperforms requirements
REFLECTIVITY	Allows for a wide range of reflectivity	Limited range of Reflectivity
ULTRAVIOLET LIGHT (UV) RESISTANCE	Surpasses requirements	Underperforms requirements
ACOUSTICAL RESISTANCE	Provide interior & exterior acoustical separation	Provide little interior fr exterior acoustical separation
EMBODIED ENERGY	Contain low embodied energy	Contain high embodied energy
ABILITY TO ALLOW CURVES	Can be curved	Only flat panels possible
ALLOWANCE FOR COMPLEX 3D SHAPES	Can take on multiple shapes & forms	Product limited to rectangular forms

MCMURDO EVALUATION CRITERIA EXPLANATION OF RANKING		
CATEGORY	**HIGH**	**LOW**
CONSTRUCTION		
OFF-SITE CONSTRUCTIBILITY	Skills and techniques suited to standard factory means and methods	New techniques & tools required
FIELD CONSTRUCTIBILITY	Use of simple labor and equipment	Highly skilled labor & special equipment
QUALITY CONTROL	Tight tolerances and consistency readily achievable	Materials prevent consistency tight tolerances and
ABILITY FOR NON-STANDARD CONSTRUCTION	Pre-assembly of components into large building blocks	Components require Labor intensive assembly
FIELD WORKABILITY	Ability to make in the field corrections	Corrections require time and special personnel
LABOR SAVING CONSTRUCTION	Small teams erect large sections	Large teams erect small sections
SHIPPING EFFICIENCY	Multiple assemblies fit within shipping containers	Bulky heavy units that don't stack or fit in shipping containers
CONSTRUCTION DURATION	Weeks	Seasons
CONSTRUCTION EQUIPMENT REQ'D	Readily available equipment used in off-loading ships used in construction	Special large equipment imported for work
ENVIRO. IMPACT DURING CONSTRUCTION	None	Requires controlled environment to build and or special breathing apparatus
MARKETPLACE AVAILABILITY	Several sources for product	Proprietary
FIELD CONSTRUCTION WASTE	None	All products are cut in the field
BUILDING LIFE		
REPEATABILITY	Basic skills & material available to staff	Requires special skills & staff
CREATE FUTURE PENETRATIONS	Cutting & sealing by staff	Requires special tools & materials
SUPPLIER TRACK RECORD	Products stocked and warranted	Custom fabrications by small, young companies
MAINTENANCE/REQ'D EXPERTISE	Simple procedures & products	Complex procedures with specialized products

Recommended Assemblies

This study recommends two alternatives that fulfill all performance requirements, while offering a range of options to achieve the logistical, aesthetic goals and budget goals that will be further refined during the design process.

Alternative 1: METAL-CLAD SIPS

STEEL-CLAD SIPS

This envelope assembly consists of:

1. Exterior Cladding of metal
2. Dimpled drainboard with geotextile fabric
3. Air Barrier of self-adhered 40mil membrane with air permanence of 0.0001 cfm/ft^2 75Pa
4. Thermal Barrier of SIPs panel, comprised of 9" of Polyurethane (PUR) rigid insulation sandwiched by two layers of 3/4" Plywood
5. Vapor Barrier of self-adhered Class 1 membrane
6. Interior wall assembly of wood studs and a range of possible interior facing materials

This assembly achieves an overall thermal resistance of approximately R-72, which represents an optimal performance level based on energy-use modeling and preliminary cost modeling.

Primary benefits of this assembly include its ability to be pre-manufactured off site, structural integrity, ease and speed of erection, ready availability, and long-proven performance

Another key benefit of this assembly lies in its versatility accommodating a wide range of both exterior and interior finish materials. Exterior materials may vary according to desired aesthetics and cost, while interior materials may vary according to particular use, aesthetics and cost.

DESIGN

Exterior Cladding

The outer layer of this recommended SIPs panel is steel or aluminum cladding. This type of cladding is recommended over all other considered materials (including copper, zinc, phenolic, GRP, wood, concrete and rubber membranes) for their strength, durability, dimensional stability, life cycle cost-effectiveness, and importantly, its wide range of achievable aesthetics.

These two materials do perform differently on their own. Aluminum performs better when considering panel size, but steel performs better when evaluating finish selection and thermal expansion. However, both materials can be applied to a phenolic core. When they are applied to a core, the differences between the two products become negligible considering their technical characteristics, freeing the designer to select the color and finish as desired.

Steel and aluminum finishes are considered equal in our recommendation. These two materials have the ability to be applied as plates, coils, sheet metals, and composites panels. All applications have been reviewed. Plates are not recommended due to their weight and inconsistent finish quality. Bent coil steel panels are not recommended due to their required folds creating unwanted air gaps behind each joint and panel. Sheet metals have limitations due to oil canning. Each cladding piece would have a limited size capacity, adding cladding joints. To limit cladding joints, reduce weight, and control air flow behind each panel, composite panels are recommended. Composite panels would constitute of a thermoset phenolic core sandwiched between two layer of metal.

The variety of finishes for this steel cladding ranges from raw mill-finish, weathering (i.e. "Corten"), stainless, painted or galvanized finishes. Aluminum finishes range from raw mill finish to anodizing finishes.

Alternative 1: METAL-CLAD SIPS

Air Barrier
Under this cladding is positioned a dimpled drainboard to move air behind the cladding, where condensation could occur. Due to the concern of snow entering into this air space, geotextile fabric, will be partnered with the drainboard to block the intrusion of snow or other airborne particulates.
The air barrier blocks the penetration of cold air and wind from entering into the insulation space, while allowing for the outward transmission of vapor. It is recommended that this air barrier be self-adhered, as opposed to mechanically-fastened. Additionally, fluid-applied barriers have unproven reliability in conditions of extreme cold that are present at Ross Island.

Thermal Barrier
This air barrier is applied to the outer Plywood layer of the two layers constituting the SIPs panel. Plywood is a highly-sustainable and cost-effective component because it is primarily comprised of reconstituted wood waste material.

The recommended insulation between these two layers of Plywood is Polyurathane (PUR), the most thermally-resistive closed cell rigid insulation available. Furthermore, because PUR is inherently fire-resistive, there is no need for the assembly to contain fire-retardants, which are often environmentally-harmful due to off-gassing. The recommended thickness of this PUR is 9". The recommendation of the thickness is directly related to common limitations and maximum thicknesses available at the manufacturer level. This thickness results in an R-value of 63 for this component.

It is also recommended to insulate structural foundation members from creating a thermal bridge to the interior of the building. Any steel should be wrapped with insulation encased in a metal shield and thermal isolators should be used between foundation and building structure.

Vapor Barrier
Attached to the inner layer of the SIPs panel Plywood is a recommended Class1 perm-rated vapor barrier. As opposed to the sheet membrane form of the outer Air Barrier, this inner vapor barrier is recommended to be fluid-applied because of its capacity for self-healing, and its ability to be installed without fasteners.

Alternative 1: METAL-CLAD SIPS

Interior Wall Assembly
A critical final component to this recommended envelope assembly is an interior wall, whose primary function is to protect the integrity of the vapor barrier. Without such an inner wall, the installation of a simple mounting bracket could severely compromise the integrity of the wall, with the fastener acting as a thermal bridge on which ice would readily form.

This interior wall is comprised of thermally-efficient 3 ½"-deep wood studs, whose cavities are filled with a R-10 mineral wool insulation for additional thermal and fire-resistance. Finally, a wide range of interior finishes or substrates to which mounting brackets can be freely attached without compromising the vapor barrier.

FABRICATION AND ASSEMBLY

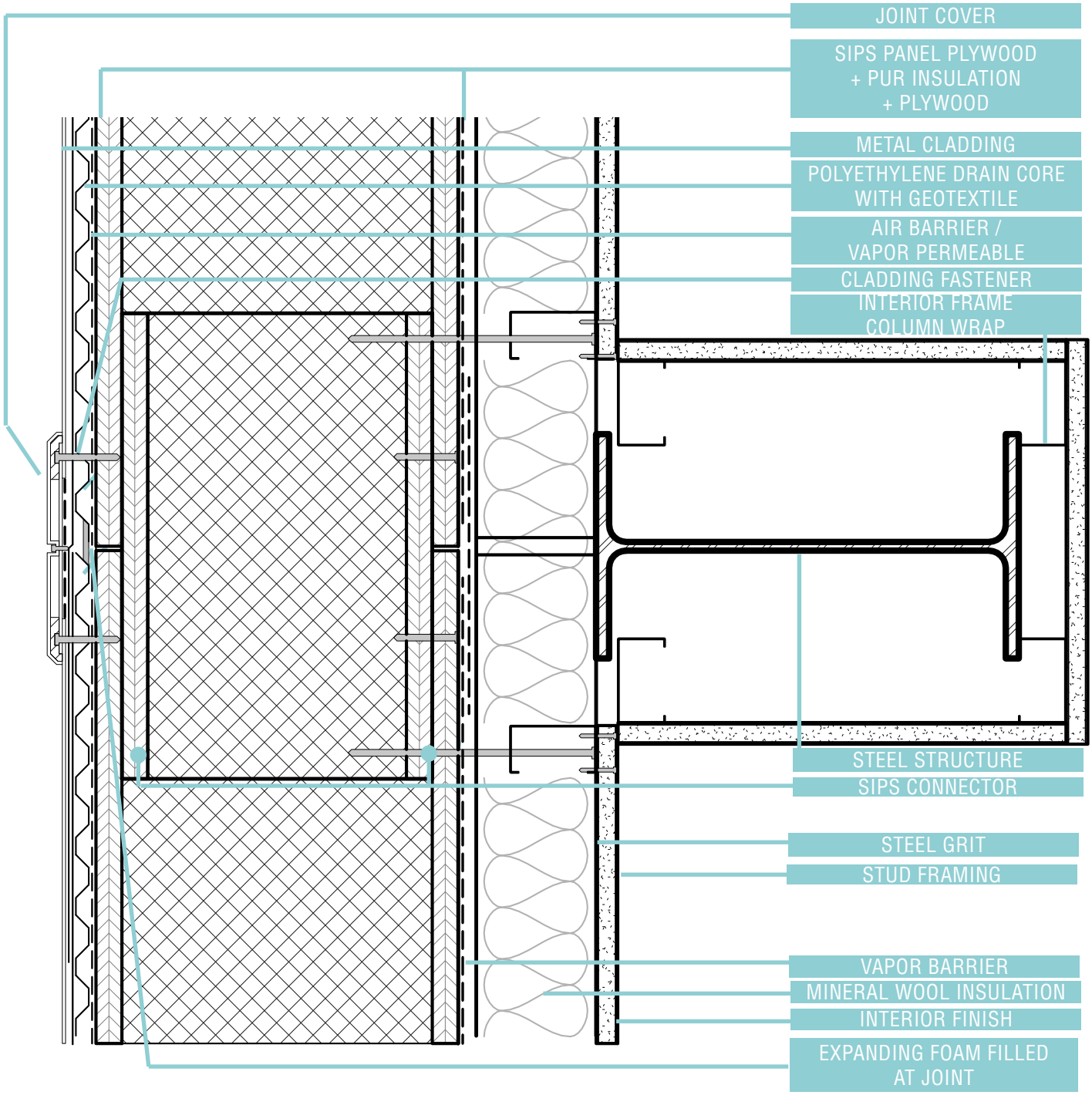
SIPs panels are produced off-site, and can transported to McMurdo Station via truck and ship. Their maximum size is relatively large, at 8' x 24', as limited by current and projected manufacturing facilities.
Once on site, only the joining and mounting of these panels is required. Here, it is recommended that Polytetrafluoroethylene (PTFE, or "Teflon") be applied to the exposed PUR insulation at the joint, in order to assure a continuous, tight fit and maximum thermal performance.

Upon joining of the panels, the air barrier will be spliced together with a strip barrier. Finally, a joint cover will protect the fasteners, cladding edges, and the air barrier. On the inside, the insulation would be held back to allow access to the vapor barrier. A compatible self-adhered strip barrier will bind the two adjoining vapor barriers.

Finally, these panels are mounted to a steel frame work. The attachment involves slotted clips to both facilitate ease of mounting and to allow for differential movement over time.

Recommended Assemblies

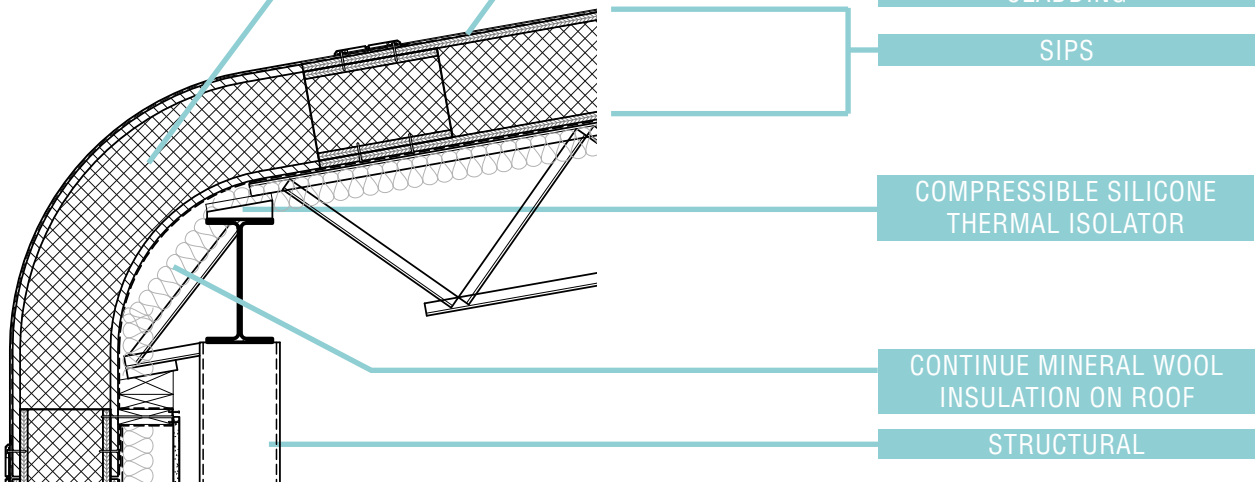
Alternative 1: METAL-CLAD SIPS



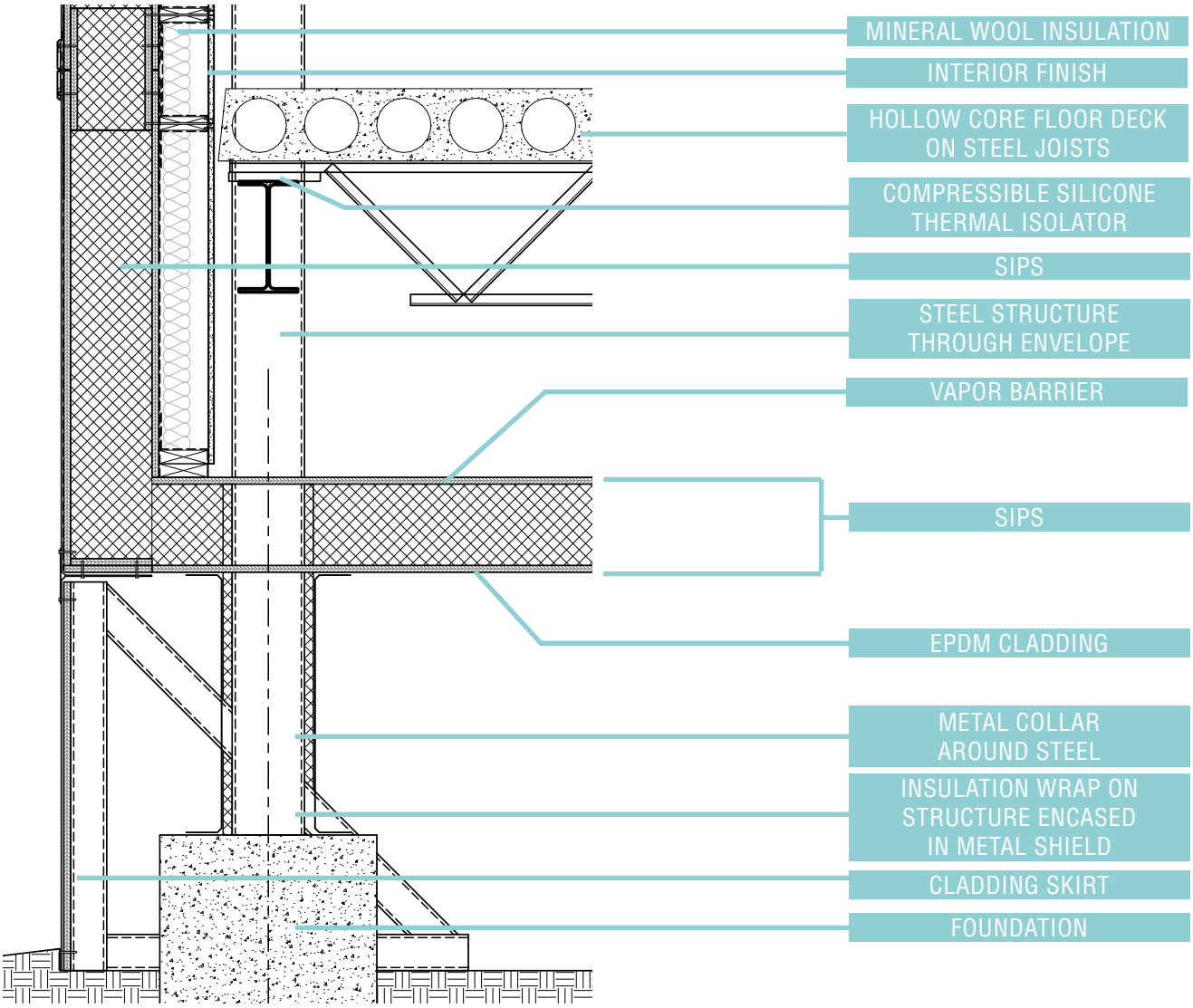
STEEL-CLAD SIPS PANEL

Alternative 1: METAL-CLAD SIPS

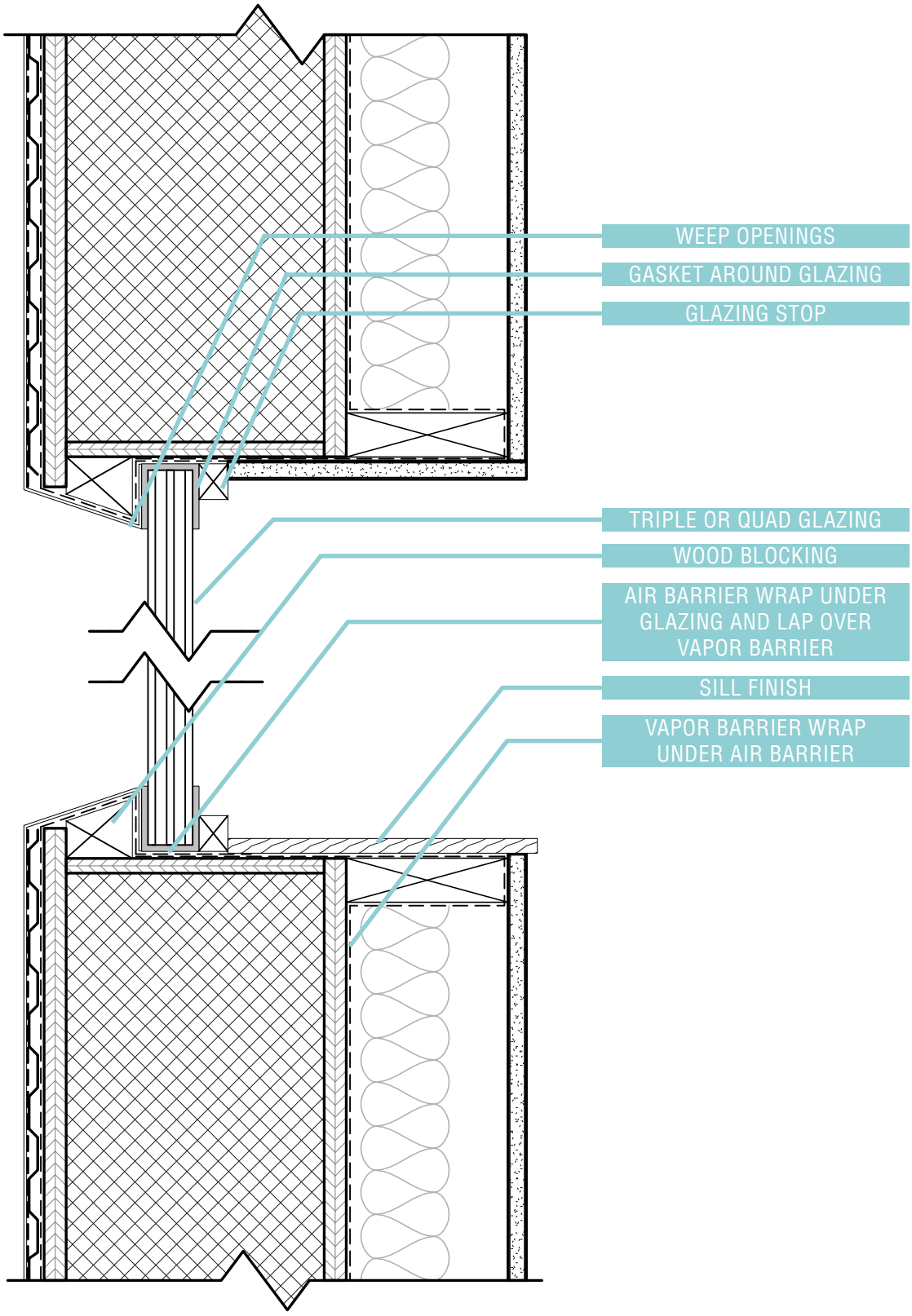
ROOF TO WALL



FLOOR TO WALL



Alternative 1: METAL-CLAD SIPS



WINDOW DETAIL

Alternative 1: METAL-CLAD SIPS COST ANALYSIS

Component costs are installed costs in Denver, Colorado. Shipping to McMurdo Station and premium labor rates are not included. Component costs are shown as a range to reflect the variables of the construction market. These variables include fluctuation of material costs due to market forces, impacts of labor force availability, economies of scale and bidding methodologies amongst other influences.

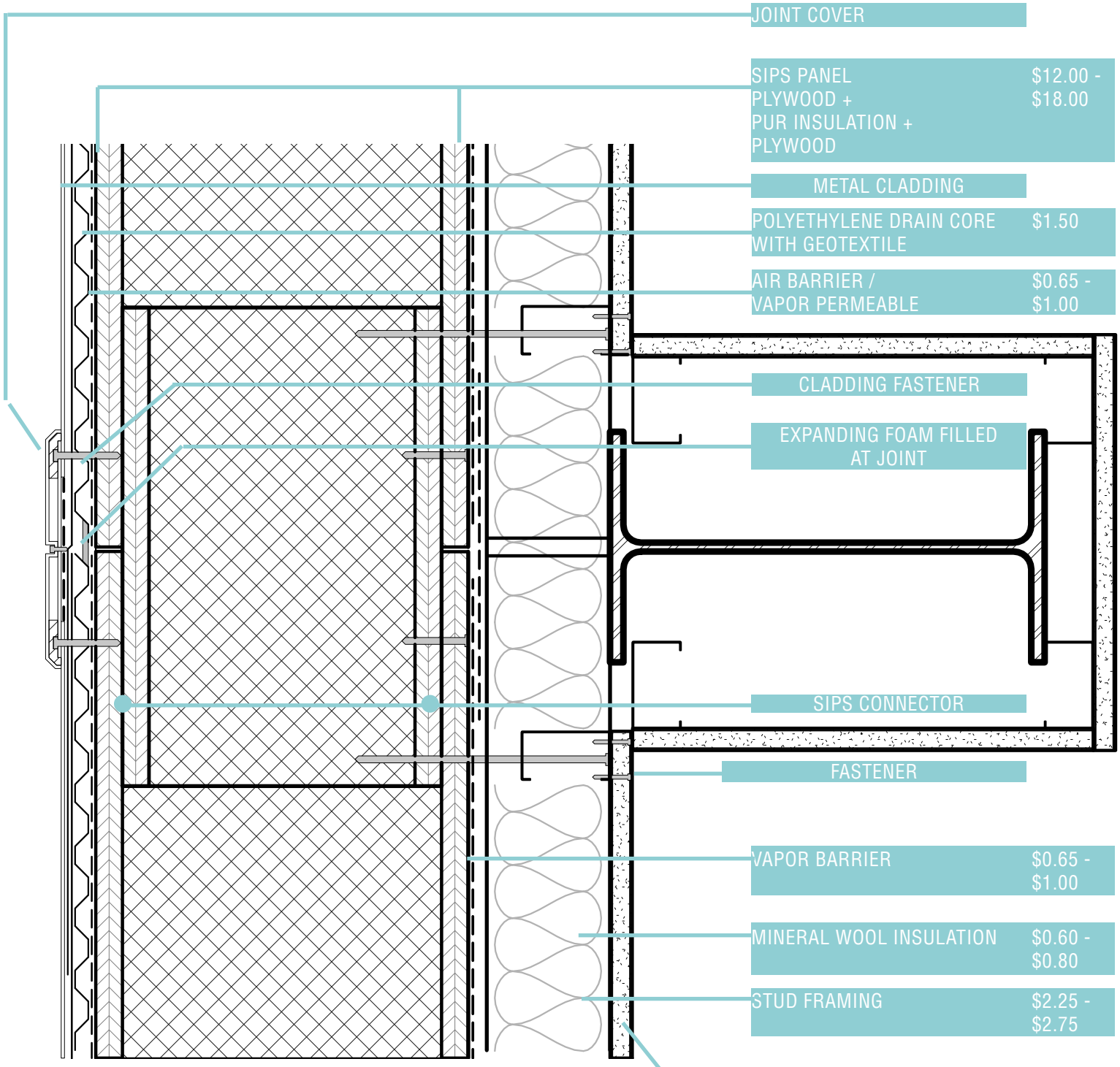
This alternate offers good potential for factory fabrication of full wall panel system. Pre-fabrication can allow for faster 'dry-in' and allow for reduced on-site construction. System allows for pre-installation of secondary systems such as electrical, communications and blocking. Higher on-site construction requirement than CLT.

Will require secondary structure of structural columns and girts, which is included in component cost.

For panels of the same size, SIPS will be a lighter panel than CLT which may have an influence construction equipment selection, therefore affecting costs.

Recommended Assemblies

Alternative 1: METAL-CLAD SIPS COST ANALYSIS



LOW	HIGH
$19.15	$29.05

Alternative 2: MASS TIMBER (CLT)

This envelope assembly consists of:

1. Exterior cladding of metal
2. Dimpled drainboard with geotextile fabric
3. Air Barrier of self-adheared 40mil membrane with air permanence of 0.0002 cfm/ft^2 75Pa
4. Thermal Barrier of 9" PUR insulation with nailable substrate
5. Vapor Barrier of self-adhered Class 1 membrane
6. 5-Ply Cross-Laminated Timber structural and interior finish panel

This assembly achieves an overall thermal resistance of approximately R-72, which represents an optimal performance level based on energy-use modeling and preliminary cost modeling.

A goal for air tightness shall be 0.60 ACH50.

Primary benefits of this assembly include its ability to be pre-manufactured off site, structural integrity, ease and speed of erection, sustainable attributes, and proven, accepted fire resistance.

Furthermore, because the CLT is exposed to the interior, a warm, inviting aesthetic is possible. At the same time, if internal function dictates, the CLT wood surface can be easily covered by any number of interior finish materials.

DESIGN

This system is comprised of many of the components that make up the Alternative 1 SIPs assembly above. The cladding, drainboard, air barrier, exterior Plywood, and insulation all would be selected and applied in the same manner as the SIPs panel. Please refer to the previous assembly for a detailed description of these various components.

The main difference of this Mass Timber system is that instead of an integral structural insulation panel secured to steel frame support and covered by an interior wall assembly, the CLT Mass Timber panel acts as both structural component and interior finish.

FABRICATION AND ASSEMBLY

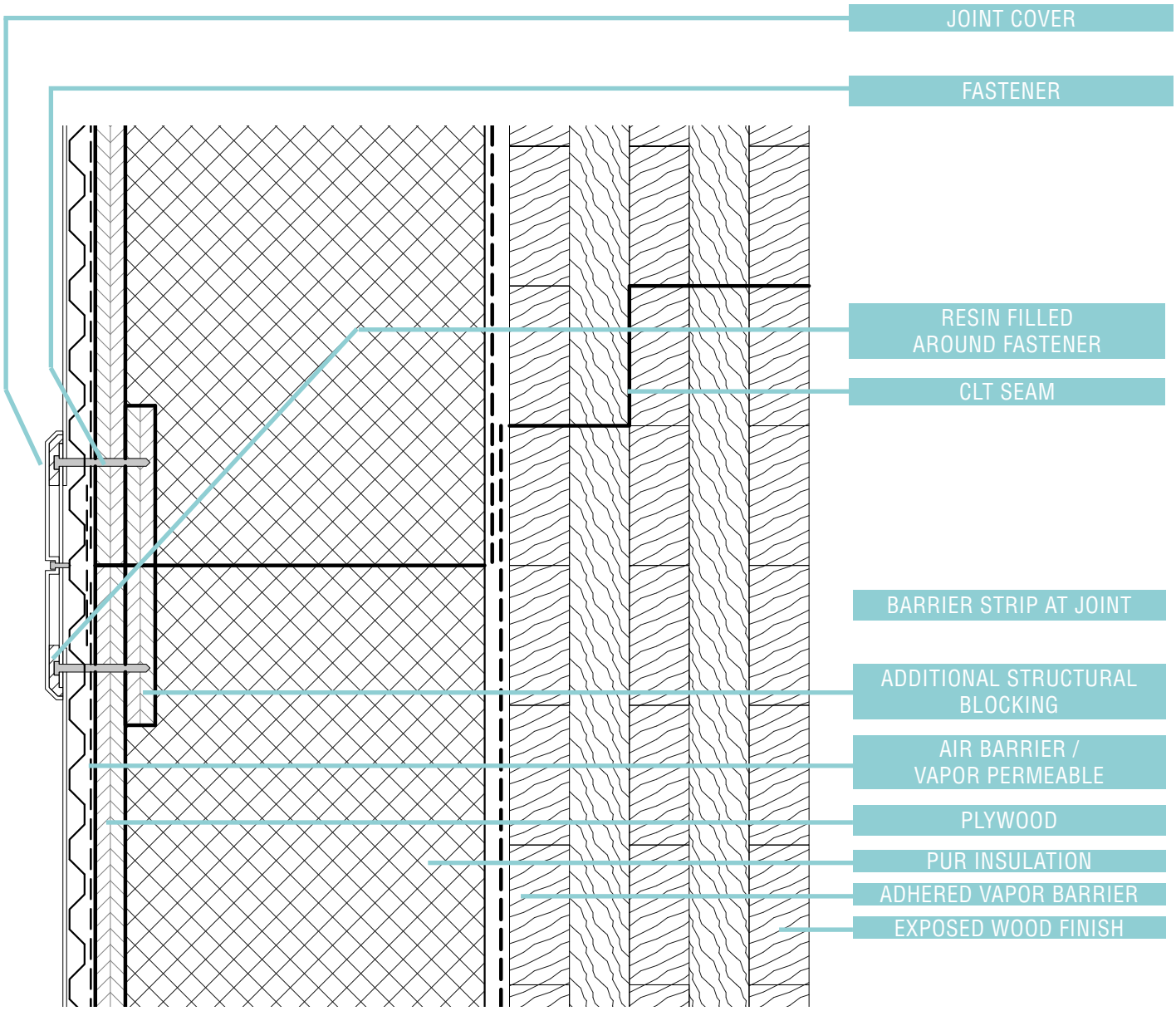
Like SIPs, the Mass Timber envelope will be assembled off site in panels. The advantage is these panels are assembled with the structure included, and simply fitted together on site. This significantly reduces construction time. Ryan Smith of the University of Utah stated, "[in the cases studied in his report] reduced their construction time by an average of 20% compared with traditional construction...The reduction of time in the production of buildings that use solid timber construction is one of, if not, the greatest incentive that this method of construction has to offer."

The panel sizes can be significantly larger than SIPs panels. At 8' x 60', the limiting factor is highway transportation. This larger panel results in reduced on site construction time and far fewer joints between panels, minimizing the opportunities for breaks in the thermal resistance.

Like the SIPs system, both the exterior cladding, air and vapor barriers are required to be joined at the intersection of each panel. Unlike the SIPs alternative, the Mass Timber envelope assembly does not necessarily rely upon a structural backing support, as the CLT panels are capable of spanning from floor to floor. Finally, unlike the SIPs alternative, the Mass Timber assembly does not require a separate inner wall to protect the integrity of the vapor barrier, since the 5-ply CLT panel is fully capable of supporting any number of interior mounting penetrations.

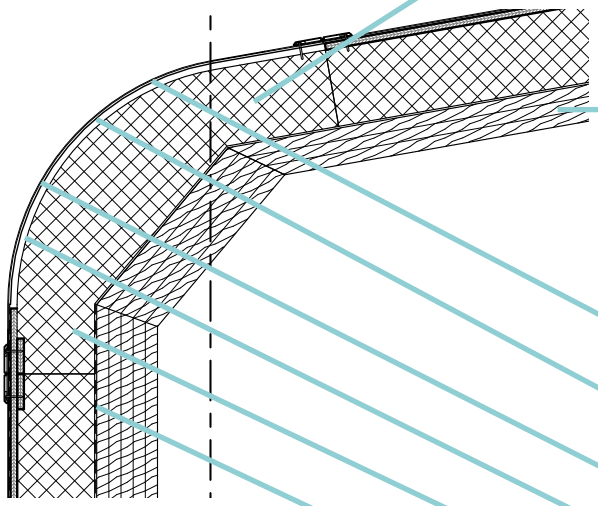
Alternative 2: MASS TIMBER (CLT)

WALL JOINT



Alternative 2: MASS TIMBER (CLT) DETAIL

ROOF TO WALL



PREFORMED INSULATION WITH ROUNDED EDGE

CLT

CLADDING

DIMPLED DRAIN BOARD WITH GEOTEXTILE FABRIC

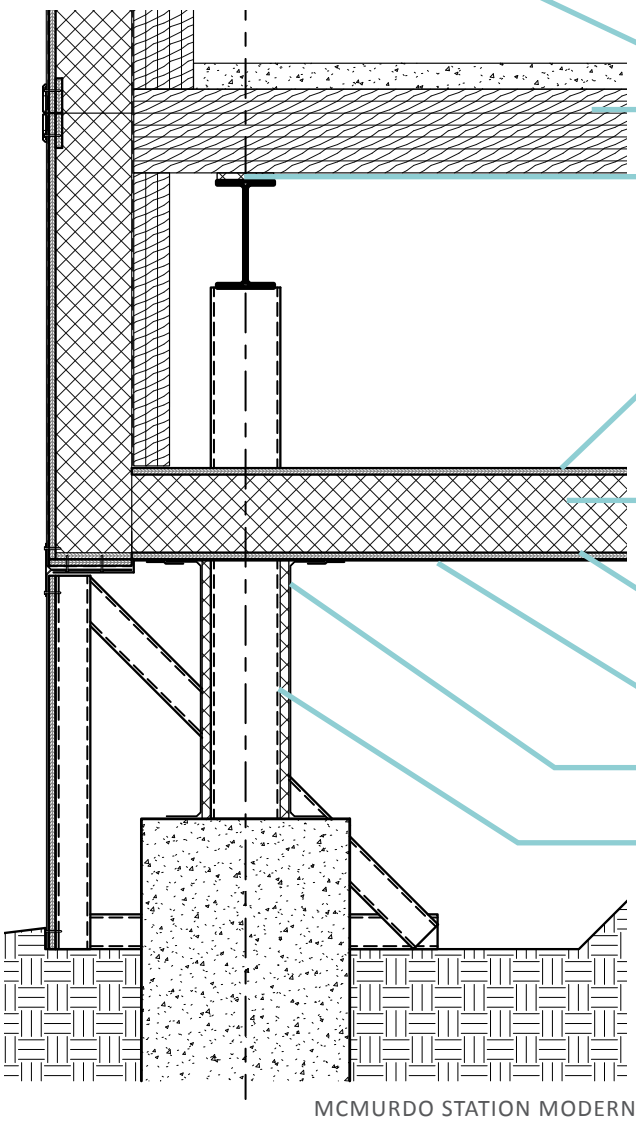
AIR BARRIER

PLYWOOD

PUR INSULATION

VAPOR BARRIER

FLOOR TO WALL



CLT

COMPRESSIBLE SILICONE THERMAL ISOLATOR

VAPOR BARRIER

PUR INSULATION

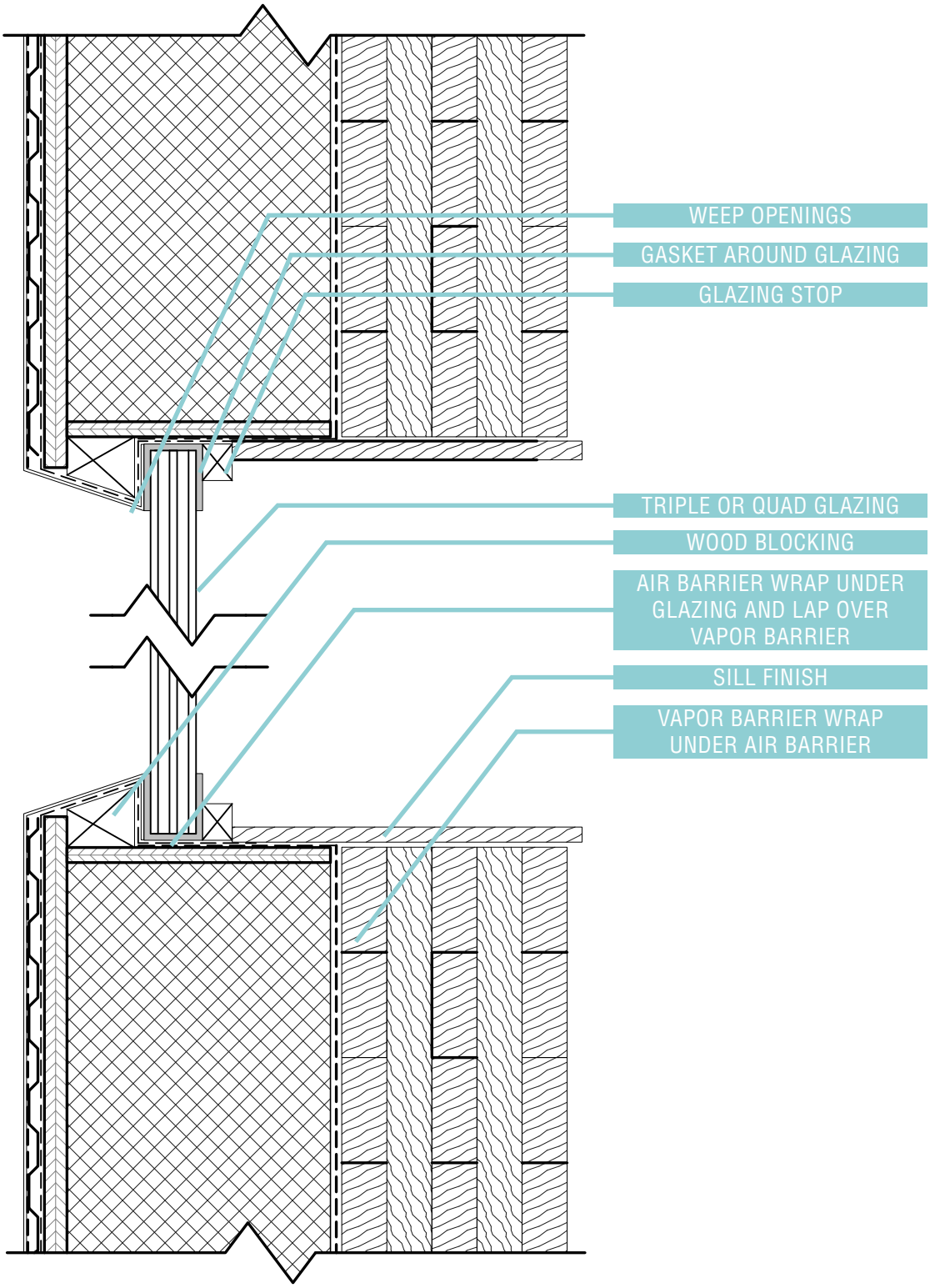
PLYWOOD

EPDM CLADDING

METAL COLLAR AROUND STEEL

INSULATION WRAP ON STRUCTURE ENCASED IN METAL SHIELD

Alternative 2: MASS TIMBER (CLT)



WINDOW DETAIL

Alternative 2: MASS TIMBER (CLT) COST ANALYSIS

Component costs are installed costs in Denver, Colorado. Shipping to McMurdo Station and premium labor rates are not included. Component costs are shown as a range to reflect the variables of the construction market. These variables include fluctuation of material costs due to market forces, impacts of labor force availability, economies of scale and bidding methodologies amongst other influences.

This alternative offers good potential for factory fabrication of full wall panel system. Pre-fabrication can allow for faster 'dry-in' and allow for reduced on-site construction. With CLT as exposed interior surface, less on-site construction than SIPS option.

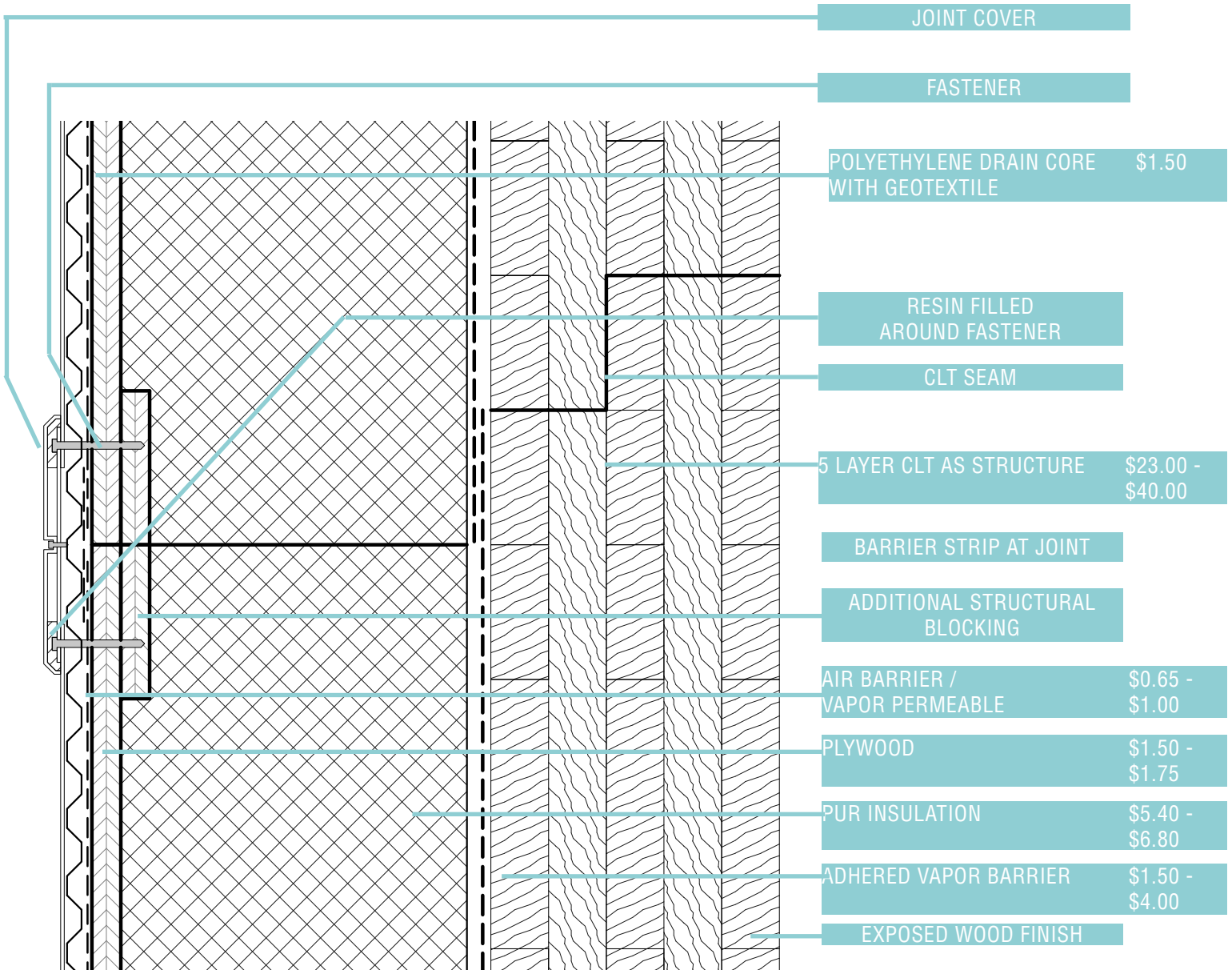
Has the ability to be part of the load bearing structural system, reducing the need for secondary structural elements which is reflected in the component cost.

Exposed CLT offers a higher aesthetic level as it expresses the natural wood.

For panels of the same size, CLT will be a heavier panel than SIPS which may have an influence construction equipment selection, therefore affecting costs.

Recommended Assemblies

Alternative 2: MASS TIMBER (CLT) COST ANALYSIS

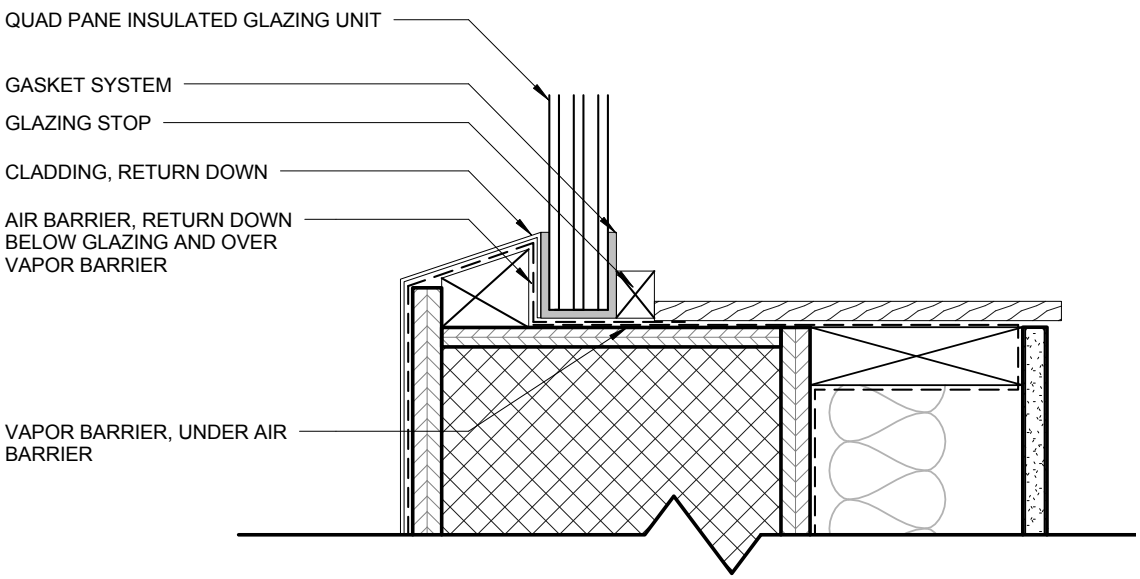


LOW	HIGH
$33.55	$55.05

Fenestration: Windows - Direct Set Glazing

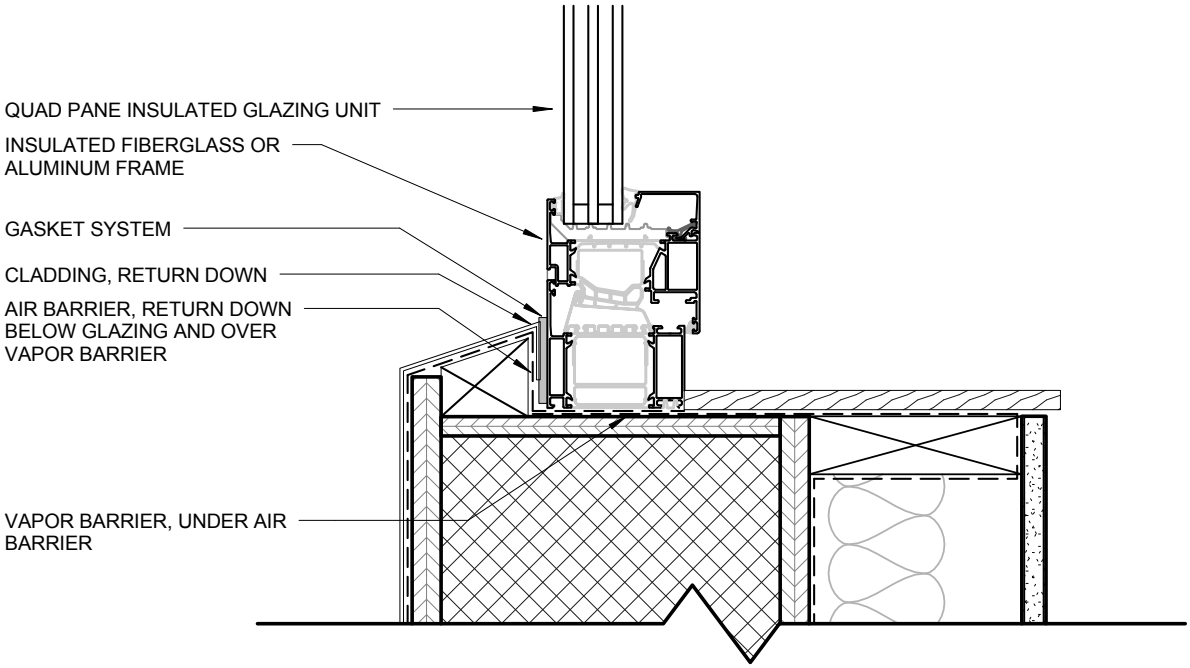
The thermally weakest part of a window assembly is the frame. Insulated glazing units currently achieve up to R=13.7 (U=0.07) while an insulated aluminum frame only achieves a value up to R=7.14 (U=0.14) or just 52% that of the insulated glazing unit.

The recommendation for glazing is to direct set the insulated glazing unit into the wall assembly. The glazing unit should be set with a flexible & compressible gasket for maximum water & air infiltration resistance. The glazing stop is on the interior to allow for easy re-glazing when necessary.



Fenestration: Windows - Integrated Insulated Frame Unit

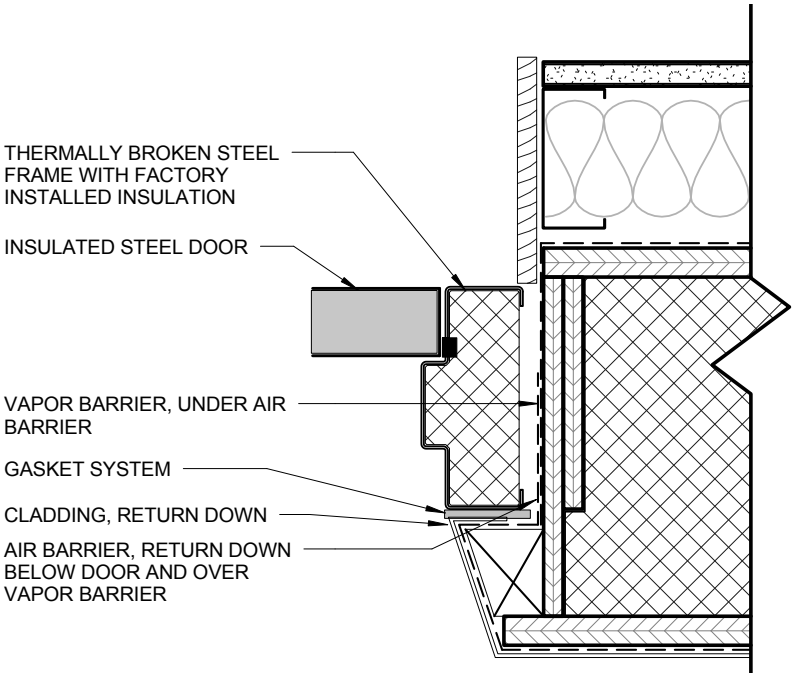
If a manufactured window unit is the desired product, the recommendation is to integrate it into the wall assembly. The window unit should be set with a flexible and compressible gasket for maximum water and air infiltration resistance. The window unit will be an interior glazed product to allow for easy re-glazing when necessary.



Fenestration: Doors - Personnel / Passage Doors Insulated Steel Door with Thermally Broken and Insulated Steel Frame

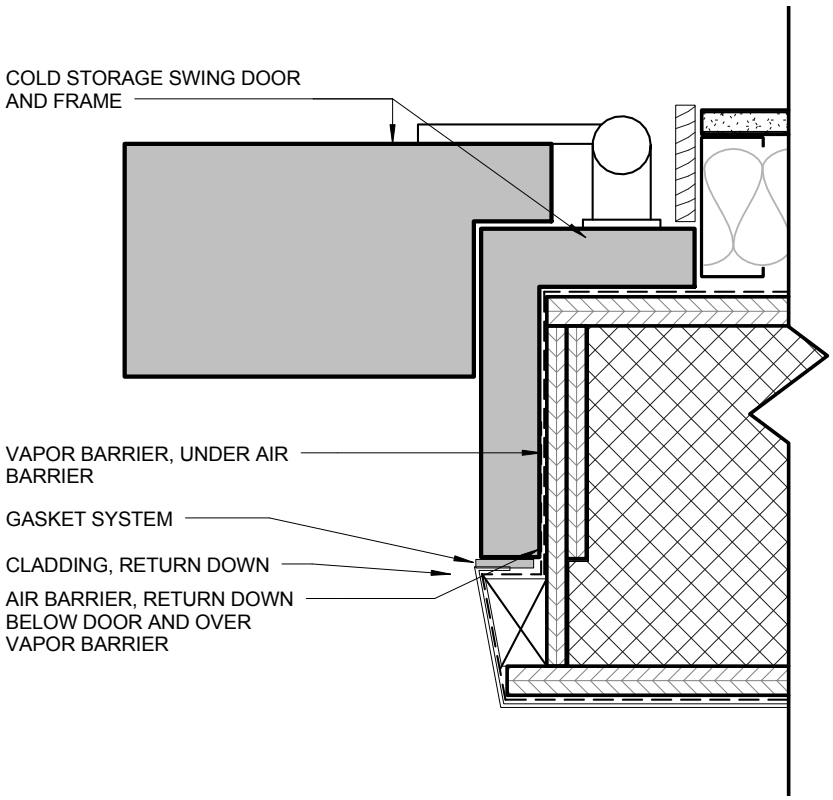
The recommendation for all exterior Personnel / Passage doors is to implement a full air-lock vestibule. The full perimeter of the vestibule should be insulated to the same level at the exterior wall.

At high use locations the recommendation is for insulated steel doors with thermally broken and insulated steel frames. Steel doors withstand wear and tear better than other available products and are available from many different suppliers.



Fenestration: Doors - Low Use Locations
Cold Storage Swing Type

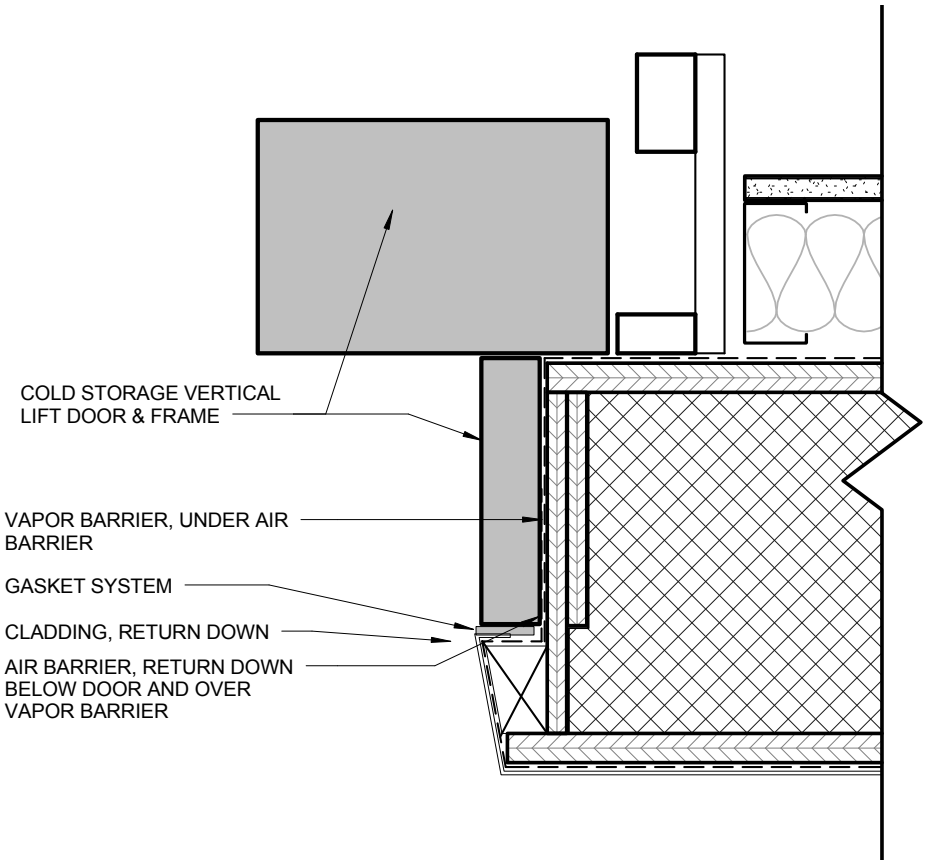
At low use locations it is recommended to use Cold Storage Swing Type Doors due to achieving maximum thermal performance levels. As these doors are more cumbersome to operate, they are appropriate at low use locations. With the increased thermal performance of the door and the infrequent use, a vestibule may be omitted.



Fenestration: Doors - Equipment Passage
Cold Storage Sectional Overhead or Vertical Lift

The recommendation for all exterior Equipment Passage doors is to implement a full air-lock vestibule. The full perimeter of the vestibule should be insulated to the same level at the exterior wall.

At equipment passage locations it is recommended to use Cold Storage Sectional Overhead or Vertical Lift Doors due to achieving maximum thermal performance levels. These doors have the ability to be power operated and typically have heating cables around the perimeter and between sections to ensure smooth operation.



Life Cycle Maintenance Requirements

Of the recommended wall assemblies, only the skin component and roofing material will require replacement and this is dependent on the specific material.

Metals with a natural finish such as aluminum, stainless steel or weathering steel, maintenance is not expected over the 50 year lifespan requirement.

If the finish on the skin material is a standard exterior paint, it is anticipated that this would need to be repainted at 8 – 10 year intervals at a cost of $0.50 / square foot at today's costs. Using the approximate 600,000 square feet of exterior skin as a basis of calculation, the 6 re-paintings add $3.00 / square foot to the lifetime cost of the skin material.

If the finish on the skin material is a factory applied Kynar finish, it is anticipated that it would need to be re-painted twice in the 50 year lifespan. This type of material has aged well at McMurdo Station with the finish on the Crary Science and Engineering Center having performed well for 25 years. Assuming the factory finished metal will be re-painted twice, once at the 33 year mark and again at the 42 year mark, this will add $1.00 / square foot to the lifetime cost of the skin material.

It is anticipated that the components of the wall assembly behind the skin will not have any life cycle cost impacts. Research on these materials indicate that when protected from direct exposure, they will perform for the full 50 year lifespan requirement.

The roofing material will have life cycle maintenance requirements. It is anticipated that both membrane roofing and metal roofing will need to be replaced once in the 50 year life span.

Typical routine maintenance requirements such as sealant joint replacement, damage repair, cleaning, etc., are in addition to the above costs and are required for all systems chosen.

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