Identifying Appropriate High-Performance Building Environmental Control Technologies for Commercial Code Enhancement in Montana
Part 2

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EXECUTIVE SUMMARY

The objective of this report is to identify and evaluate advanced design and construction practices that have been adopted in High Performance Buildings across Montana with the intent of evaluating the feasibility and affordability of such practices as well as to identify potential code measures appropriate to Montana. A general list has been compiled for High performance systems and equipment that were commonly found in the buildings that were surveyed. Several High Performance buildings were identified as case-studies. High performance technologies implemented in these buildings was documented and the buildings were evaluated in terms of energy performance. In addition, several emerging High performance technologies were identified from a literature review. The High performance environmental control technologies were then evaluated individually in terms of: advantages, applications, challenges of operating in a cold climate, incorporating system specifications in energy codes, and challenges associated with the O&M of the system.

ABBREVIATIONS

ASHRAE:	American Society of Heating Refrigeration & Air-conditioning Engineers
BAS:	Building automation system
BEQ:	Building Energy Quotient
CBECS:	Commercial Building Energy Consumption Survey
CW:	Chilled water
DDC:	Direct digital controls
DOAS:	Dedicated outdoor air system
EA:	Exhaust air
GSHP:	Ground source heat pump
HEX:	Heat exchanger
HPB:	High performance building
HVAC/R:	Heating, ventilation, and air-conditioning / refrigeration
HW:	Hot water
LEED:	Leadership in Energy and Environmental Design
OA:	Outdoor air
O&M:	Operation & maintenance
RA:	Return air
UFAD:	Underfloor air distribution system
VFD:	Variable frequency drive
VRF:	Variable refrigerant flow

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APPENDIX A: SURVEY OF HIGH PERFORMANCE COMMERCIAL BUILDINGS IN MONTANA

Table A-1: High Performance Commercial Buildings in Montana

PROJECT	CONSTRUCTED	LOCATION		TYPE	CERTIFICATION
Addition & Renovation - 40 Bed Wing		Montana Veterans' Home	Columbia Falls, MT	Hospital	
Anderson Hall- School of Journalism		University of Montana	Missoula, MT	Education	LEED Gold
Applied Technology Center (Diesel Tech)		MSU Northern	Havre, MT	Education	Green Globes
Barrett Hospital and HealthCare	2012		Dillon MT	Hospital	LEED Gold
Ben Steele Middle School	2017		Billings, MT	Education	
Big Sky Health and Fitness Center			Big Sky, MT		LEED Gold
Billings Federal Courthouse	2012		Billings, MT	Civic	LEED Gold
Billings Public Library	2015		Billings, MT	Civic	LEED Platinum
Blue Cross Blue Shield			Helena, MT	Office	LEED Silver
Bozeman City Hall Renovation	2006/2007		Bozeman, MT	Office	LEED Silver
Bozeman Public Library	2006		Bozeman, MT	Civic	LEED Silver
Central Land Office		DNRC	Helena, MT	Office	LEED Gold
Chemistry Bio-research Facility	2007	Montana State University	Bozeman, MT	Laboratory	
Cooley Labs Renovation	2012	Montana State University	Bozeman, MT	Laboratory	LEED Gold
CTA Architects Engineers	2004		Billings, MT	Office	LEED Gold
Cycle Center			Billings, MT	Retail	
Department of Natural Resources			Helena, MT	Office	LEED Gold
Department of Veteran Affairs			Helena, MT	Office	LEED Certified
Dillon Middle School Remodel			Dillon MT	Education	USGCB Award
Early Learning and Job Training Center		Helena Housing Authority	Helena, MT	Education	LEED Platinum
Education Center		Montana Law Enforcement Academy	Helena, MT	Education	
element	2015		Bozeman, MT	Hotel	LEED Certified
Expand Great Falls College of Technology		Great Falls College of Technology	Great Falls, MT	Education	
ExplorationWorks!	2008		Helena, MT	Civic/Education	LEED Certified
First Interstate Bank Operations Center	2009		Billings, MT	Office	LEED Silver
First Interstate Bank	2009		Missoula, MT	Office	LEED Gold
Gaines Hall Renovation	2011	Montana State University	Bozeman, MT	Education	LEED Silver
Gardiner Public Schools			Gardiner, MT	Education	LEED v4
Garlington Lohn Robinson			Missoula, MT	Office	LEED Gold
GE Operations Buildiing			Billings, MT	Office	LEED Certified
Good Earth Market	2006		Billings, MT	Retail	Energy Star
GYC Bozeman Headquarters	2012		Bozeman, MT	Office	LEED Gold
Helena Aviation Readiness Center		Montana National Guard	Helena, MT	Office	LEED Gold
Home on the Range	2007		Billings, MT	Office	LEED Platinum Energy Star
Interdisciplinary Science Building		University of Montana	Missoula, MT	Education	
Interfaith Chapel		Montana State Hospital - Warm Springs	Warm Springs, MT	-	
Jabs Hall	2015	Montana State University	Bozeman, MT	Education	LEED Gold
Kalispell DNRC-DEQ Office		DNRC Kalispell	Kallispell, MT	Office	LEED Certified
KLOS Building			Billings, MT	Office	LEED Platinum
Kohls Bozeman	2011		Bozeman, MT	Retail	LEED Silver
Last Chance Block			Helena, MT	Office	LEED Goal: Certified
Main Hall Renovation		University of Montana Western	Dillon MT	Dormitory	
Math/Science Building		Blackfeet Community College	Browning, MT	Education	LEED Platinum
McMullen Hall Renovation	2011	Montana State University - Billings	Billings, MT	Office	
Medicine Crow Middle School	2016		Billings, MT	Education	
Miles City Readiness Center		National Guard	Miles City, MT	Civic	
Miller Dining Hall	2015	Montana State University	Bozeman, MT	Dormitory	LEED Silver
Missoula County Courthouse			Missoula, MT	Civic	LEED NC v2009
Missoula Federal Credit Union Russell Branch			Missoula, MT		LEED Platinum
Missouri River Courthouse		US District 9 Federal Courthouse	Great Falls, MT	Civic	LEED Silver
Montana State Fund Office Building			Helena, MT	Office	LEED Gold
Montana Wild		Montana Fish, Wildlife & Parks	Helena, MT	Civic	
Morrison Maierle, Inc	2007		Bozeman, MT	Office	LEED Gold
Morrison Maierle, Inc	2018		Missoula, MT	Office	
MSU Gallatin Hall	2015	Montana State University	Bozeman, MT	Dormitory	LEED Gold
Museum of the Rockies Curatorial Center of Humanities	2017		Bozeman, MT	Civic	LEED Gold
Natural Resources Building		Montana Tech of the University of Montana	Butte MT	Office	
NIH/NIAID Rocky Mountain Lab Bldg. 7			Hamilton, MT	Office	LEED Gold
Norm Asbjornson Hall	2018/2019	Montana State University	Bozeman, MT	Education	
NorthWestern Energy Headquarters	2015		Butte MT	Office	LEED Gold
"Orange Crush" CTA Office	2015		Great Falls, MT	Office	LEED Gold
Payne Native American Center	2010	University of Montana	Missoula, MT	Office	LEED Platinum
Pioneer Block Office building			Helena, MT	Office	LEED Silver
RPA Corporate Headquarters	2017		Helena, MT	Office	LEED Silver
Safeway 2999	2011		Bozeman, MT	Retail	LEED Silver
Stockman Bank	2014		Billings, MT	Civic?	LEED Gold
Stockman Bank	2018?		Missoula, MT	Civic?	LEED Platinum v4?
Sussex School	2011		Missoula, MT	Education	LEED Gold
The Boys & Girls Club	2012	Carbon County	Red Lodge, MT	Civic	LEED Platinum
Underriner Motors	2014		Billings, MT	Retail	LEED Certified
Yellowstone Hall	2016	Montana State University	Bozeman, MT	Dormitory	LEED Gold

Table A-1 Continued: High Performance Commercial Buildings in Montana

PROJECT	POINT OF CONTACT	ARCHITECT	LANDSCAPE ARCHITECT	GENERAL CONTRACTOR	MECHANICAL CONTRACTOR	LEED CONSULTANT
Addition & Renovation - 40 Bed Wing		DSA Architects		Hammerquist Casalegno, LLC		
Anderson Hall- School of Journalism		StudiFORMA Architects		Jackson Contractor Group, Inc.		
Applied Technology Center (Diesel Tech)	Jason Egeline/Bucky Kempa	CWG Architects Gordon Whirry Architecture		Clausen & Sons Construction		
Barrett Hospital and HealthCare		MMW Architects		Swank Enterprises	Associated Construction Engineering	Kath Williams + Associates
Ben Steele Middle School	Todd Mehlinig	A&E Architects			Associated Construction Engineering	
Big Sky Health and Fitness Center		Reid Smith Architects	Valley of the Flowers Landscaping	Greene Construction	Redleaf Consulting, PLLC	Kath Williams + Associates
Billings Federal Courthouse	Raelynn Meisnner	NBBJ		Mortenson Construction	NBBJ, CTA Architects Engineers	Kath Williams + Associates
Billings Public Library		will bruder+PARTNERS	Foley Group, L.L.C.	Jackson Contractor Group	Associated Construction Engineering	Design Balance
Blue Cross Blue Shield		Schlenker McKittrick Architects	TD & H Engineering	Dick Anderson Construction	MKK Engineering	Kath Williams + Associates
Bozeman City Hall Renovation		Comma-Q Architecture		Dick Anderson Construction	Three River Engineering	Kath Williams + Associates
Bozeman Public Library		Overland Partners StudioFORMA	CTA Architects Engineers	Martel Construction	Associated Construction Engineering	Jess Glowacki Kath Williams + Associates
Central Land Office		Gordon Whirry Architecture		Dick Anderson Construction		
Chemistry Bio-research Facility		L'Heureux Page Werner, PC		Dick Anderson Construction		
Cooley Labs Renovation		Architects Design Group PC		Dick Anderson Construction	GPD, Inc., Great Falls, MT	Lesly Mroczkowski Kath Williams
CTA Architects Engineers		CTA Architects Engineers			CTA Architects Engineers	
Cycle Center		A&E Architects				
Department of Natural Resources		Mosaic Architects		Dick Anderson Construction	CTA Architects Engineers	
Department of Veteran Affairs		CWG Architects		Diamond Construction		Robert B. Morton
Dillon Middle School Remodel	Jason Egeline/Bucky Kempa	CWG Architects		Swank Enterprises	Coffman Engineers, Morrison Maierle, GPD	
Early Learning and Job Training Center		Intrinsik Architecture	Design 5 Landscape	Wadsworth Builders Company	Morrison Maierle, Inc	Lesly Mroczkowski Kath Williams
Education Center		Think One Architects		Swank Enterprises	Morrison Maierle, Inc	
element		GH2 Architects Tulsa, OK	Design 5 Landscape	Martel Construction	PE Services	Lesly Mroczkowski Kath Williams + Associates
Expand Great Falls College of Technology		CTA Architects Engineers		Dick Anderson Construction		
ExplorationWorks!		Mosaic Architects		Yak & Abe Construction	CTA Architects Engineers	Lesly Mroczkowski Kath Williams + Associates
First Interstate Bank Operations Center		CTA Architects Engineers		Langlas & Associates		
First Interstate Bank		CTA Architects Engineers		Gordon Construction	CTA Architects Engineers	
Gaines Hall Renovation		Dowling, Sandholm Architects		BNBuilders, Inc.		
Gardiner Public Schools						Morgan Klaas Kath Williams
Garlington Lohn Robinson		OZ Architects		Jackson Contractor Group		
GE Operations Buildiing		A&E Architects		Langlas & Associates	Associated Construction Engineering	Jason McGimpsey Kath Williams
Good Earth Market		High Plains Architects				
GYC Bozeman Headquarters		CTA Architects Engineers		R & R Taylor	CTA Architects Engineers	Lesly Mroczkowski Kath Williams + Associates
Helena Aviation Readiness Center		SMA Architects		Swank Enterprises	Design 3 Engineering	Lesly Mroczkowski Kath Williams + Associates
Home on the Range		High Plains Architects		JD Broadbent, Hardy Construction	Art Fust, Energy A.D.	
Interdisciplinary Science Building		StudiFORMA Architects				
Interfaith Chapel		HGFA Architects		FHG Construction		
Jabs Hall	Erik Renna	Comma-Q Hennebery Eddy Architects	Design 5 Landscape	Dick Anderson Construction	Morrison Maierle, Inc	Kath Williams + Associates
Kalispell DNRC-DEQ Office		StudioFORMA Architects Gordon Whirry Architecture	Bruce Boody Landscape Architect	Hammerquist Casalegno, LLC	GPD Engineering	Mark Headley Kath Williams
KLOS Building		High Plains Architects				
Kohls Bozeman						
Last Chance Block		Mosaic Architects		Dick Anderson Construction		
Main Hall Renovation		Richard M. Shanahan Architects, Inc.		Swank Enterprises		
Math/Science Building		Gordon Whirring- Great Falls Mark Headley- StudioFORMA		Swank Enterprises	GPD, Inc	Lesly Mroczkowski
McMullen Hall Renovation		Collaborative Design Architects		General Contractors Construction Co		
Medicine Crow Middle School	Todd Mehlinig	A&E Architects			Associated Construction Engineering	
Miles City Readiness Center		A&E Architects		Jackson Contractors		
Miller Dining Hall		Nelson Architects		Swank Enterprises	Morrison Maierle, Inc	Nelson Architects Kath Williams
Missoula County Courthouse	John Melvin	A&E Architects		Jackson Construction	JM Engineering	Lesly Mrockzkowski Kath Williams
Missoula Federal Credit Union Russell Branch		MMW Architects				
Missouri River Courthouse		Nelson Architects Hoefer Wysocki Architects		BC Development Co		
Montana State Fund Office Building		Mosaic Architects		Dick Anderson Construction	CTA Architects Engineers	Jeff Downhour Kath Williams
Montana Wild	Jason Egeline/Curt Smit	CWG Architects		Wadsworth Builders Company	CDS Engineering	
Morrison Maierle, Inc		ThinkOne				
Morrison Maierle, Inc		A&E Architects				
MSU Gallatin Hall		Schlenker McKittrick Architects Mithun		Jackson Contractor Group	MKK Engineering	SMA Architects Kath Williams
Museum of the Rockies Curatorial Center of Humanities		Slate Architects		Jackson Contractor Group	Morrison-Mairle	
Natural Resources Building	Jason Egeline/Bucky Kempa	CWG Architects		Swank Enterprises	GPD Engineering	
NIH/NIAID Rocky Mountain Lab Bldg. 7		Architects Design Group PC		Jackson Construction	GPD Engineering	
Norm Asbjornson Hall	Bill DuBeau	ZGF Architects, A & E Architects		Martel Construction	Morrison Maierle, Inc Paul Erikson/David Conant Gilles AEI	Lesly Mrockzkowski Kath Williams
NorthWestern Energy Headquarters		Mosaic Architects		Dick Anderson Construction		
"Orange Crush" CTA Office	Gary Morris	CTA Architects Engineers		Guy Tobacco		
Payne Native American Center	Erikc Simonsen	A&E Architects Daniel J Glenn Architect	Rocking M Design	Jackson Contractor Group	Associated Construction Engineering	Kath Williams + Associates
Pioneer Block Office building	Jacob Mortensen	CTA Architects Engineers		Dick Anderson Construction		
RPA Corporate Headquarters		SMA Architects	RPA	Dick Anderson Construction	RPA	
Safeway 2999		MulvannyG2	The Land Group	Roche Constructors	Interface Engineering	MulvannyG2 Lesly Mroczkowski
Stockman Bank		CTA Architects Engineers		Hardy Construction		
Stockman Bank		CTA Architects Engineers				
Sussex School		OZ Architects	OZ Architects	Gaddy Construction & Ayers Construction	DC Engineering	Design Balance
The Boys & Girls Club		High Plains Architects				
Underriner Motors	Gerry Nichols-Pagel	CTA Architects Engineers		Hardy Construction	CTA Architects Engineers	
Yellowstone Hall		Schlenker McKittrick Architects		Langlas & Associates Inc.	Associated Construction Engineering	Lesly Mroczkowski Kath Williams

Table A-1 Continued: High Performance Commercial Buildings in Montana

PROJECT	HP BUILDING SYSTEMS	NOTABLE SYSTEMS- BRIEF SUMMARY
Addition & Renovation - 40 Bed Wing		
Anderson Hall- School of Journalism		
Applied Technology Center (Diesel Tech)		
Barrett Hospital and HealthCare		Energy efficient insulation and windows, regional materials, water-efficient plumbing fixtures, energy efficient elevators
Ben Steele Middle School		
Big Sky Health and Fitness Center		
Billings Federal Courthouse	PV Array High Performing Envelope Chilled Beams Radiant Floor Condensing Boilers Dedicated Outdoor System	PV Array, High Performing Envelope, Chilled Beams, Radiant Floor, Condensing Boilers, Dedicated Outdoor System
Billings Public Library	VFD pumps, high efficiency boilers	Rainwater collection (parking garden), stormwater management, local and reused materials, high efficiency fixtures
Blue Cross Blue Shield	Underfloor Air System	Underfloor Air System
Bozeman City Hall Renovation		
Bozeman Public Library	PV Array Wind Power Night Flushing	Low-flow plumbing fixtures, 34 kW PV Array, Connection to Two Dot Wind Farm, Night Flushing, Recycled Material
Central Land Office		
Chemistry Bio-research Facility		heat recovery coils on building exhaust
Cooley Labs Renovation	PV Array, Solar Wall, Enthalpy Wheel	Renovation, solar panels, sun shading on southern wall, energy recovery on building & lab exhaust, air handler
CTA Architects Engineers	PV Array	green roof
Cycle Center		
Department of Natural Resources		
Department of Veteran Affairs		
Dillon Middle School Remodel		Increase from 89k s.f. to 125 s.f. with same energy bill, reuse of existing structure
Early Learning and Job Training Center		
Education Center		
element		First LEED Certified hotel in the state, recycled materials, VOC paints, low flow fixtures, compact fluorescents, energy efficient appliances, visible recycling program,
Expand Great Falls College of Technology		
ExplorationWorks!	Hot water solar system PV Array Air to Air Heat Exchange Radiant Heat	Hot water solar system, 7.5 KW PV Array, Air to Air Heat Exchange, Radiant Heat, Straw Bale Wall Construction
First Interstate Bank Operations Center		98% construction waste diverted from landfill
First Interstate Bank	Building Automation System Open loop ground water system combined with a heat exchanger Refrigerants that minimize global warming High traction regenerative elevator equipment CO2 sensors to monitor and maintain fresh air levels	Low-flow plumbing, rainwater catchment, low-e insulated windows, use of nontoxic and recycled materials, light monitoring, open source groundwater cooling
Gaines Hall Renovation		
Gardiner Public Schools		As this is an existing building, the O+M was the main concern and focus
Garlington Lohn Robinson		
GE Operations Buildiing	HVAC low volume diffusers	Bioswales from parking and roofs, local materials, double-glazed low-e windows, Kalwall paneling, raised floor system for flexibility, HVAC low volume diffusers
Good Earth Market	Centralized refrigeration zone for heat waste reclamation to radiant floor and domestic hot water	Centralized refrigeration zone for heat waste reclamation to radiant floor and domestic hot water, dual flushing toilets
GYC Bozeman Headquarters		Renovation instead of building new, salvageable materials
Helena Aviation Readiness Center		
Home on the Range	PV Array Solar Hot Water Heating Radiant Heat Evaporative Cooling	10 KW PV System, Solar Hot Water Heating, Composting, Permeable Paving, Recycled materials, light shelves, radiant heat, evaporative cooling, drought -tolerant native landscaping
Interdisciplinary Science Building		
Interfaith Chapel		
Jabs Hall	Solar Wall, Enthalpy Wheel Geothermal Wells	Solar wall, geothermal wells, stormwater management, construction waste management, water reduction of 31%, recycled materials
Kalispell DNRC-DEQ Office		
KLOS Building	PV Array	Rainwater collection, natural ventilation, daylighting, 2 KW PV Array
Kohls Bozeman		
Last Chance Block		
Main Hall Renovation		
Math/Science Building	PV Array	PV System (excess goes to power company), operable windows, orientation strategies, shading, water saving fixtures
McMullen Hall Renovation		
Medicine Crow Middle School		
Miles City Readiness Center		
Miller Dining Hall	VRF	
Missoula County Courthouse		
Missoula Federal Credit Union Russell Branch		
Missouri River Courthouse		
Montana State Fund Office Building	Underfloor Air System Heat-exchange system from IT unit	Maximum site orientation, rainwater collection for landscaping, raised floor for access and air delivery, regional and low-maintenance materials, heat-exchange system from IT housing unit, green roof, emphasis on daylighting
Montana Wild		SIPS roof, operable windows metal clad, worked within SHPO
Morrison Maierle, Inc		
Morrison Maierle, Inc		
MSU Gallatin Hall	Solar Water Preheat	Pasive ventilation with fan assist
Museum of the Rockies Curatorial Center of Humanities		
Natural Resources Building		exceeds min code standards by 20%
NIH/NIAID Rocky Mountain Lab Bldg. 7		
Norm Asbjornson Hall	Geothermal, Heat Pumps	
NorthWestern Energy Headquarters	90% efficient gas boilers Demand-based ventilation systems Raised floor systems	90% efficient gas boilers Demand-based ventilation systems Raised floor systems
"Orange Crush" CTA Office	Radiant heat/cooling, geothermal	
Payne Native American Center	Passive solar heating VAV units and ground water cooling via "pump and dump" wells Demand control ventilation w/ CO2 monitoring Radiant floor heating in the hallways / campus steam heating Run-around heat recovery loop	
Pioneer Block Office building		
RPA Corporate Headquarters		Open space, efficient landscaping, recycling construction waste, regional materials
Safeway 2999		Site connection catering to pedestrains, bicycles, water saving fixtures, native landscaping, diverted 95% of construction debris, recycled/regional materials, tenant recycling policy
Stockman Bank		High efficiency boilers, double-pane windows, motion-detecting switches, efficient plumbing, recycled ceiling tiles
Stockman Bank		
Sussex School	Natural ventilation & cooling with operable windows High efficiency boiler (93% AFUE Radiant floor heatin Air-to-air heat exchangers for spaces requiring mechanical ventilation 5 kW solar electric array	Natural ventilation & cooling with operable windows High efficiency boiler (93% AFUE Radiant floor heatin Air-to-air heat exchangers for spaces requiring mechanical ventilation 5 kW solar electric array
The Boys & Girls Club		Reused/recycled materials, natural daylight and ventilation, 8.7 kW PV array, rainwater collection
Underriner Motors	Oversized ceiling fans EnergyStar rated air conditioners Renewable energy contract with utilities Radiant tube heaters	Skylights and Solar Tubes,
Yellowstone Hall	Solar Wall, Radiant Heating/Cooling	Educating on sustainable buildings, high efficiency boileers, etc.

APPENDIX B: LEED CERTIFIED CONSTRUCTION IN MONTANA

The figure below presents the trends in LEED certified construction in Montana since 2004. Currently there are 92 projects that are LEED certified. There are currently 59 building in the process of being certified in the state of Montana.

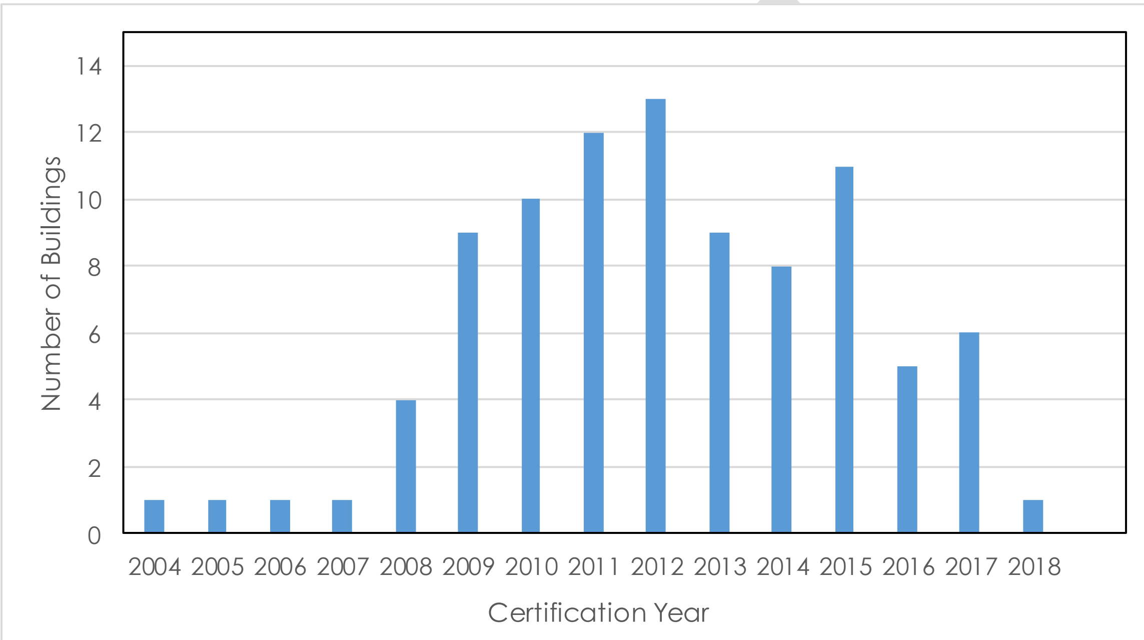

Figure B-1 Trends in LEED Certified Construction in Montana for time period of 2004 – 2018 (Source: USBGC)

APPENDIX C: CASE-STUDIES OF HIGH PERFORMANCE COMMERCIAL BUILDINGS ACROSS MONTANA

James F. Battin United States Courthouse

Location:	Billings, Montana
Building Type:	Public
Total Area:	128,742 ft^2
Architects:	NBBJ
Engineers:	CTA Group
Certification:	LEED Gold
High Performance Systems:	Chilled Beams, Dedicated Outdoor Air System (DOAS), Condensing Boiler

Figure C-1: View of the entrance court, James F. Battin United States Courthouse Billings Montana

Overview

The James F. Battin United States Courthouse was completed in 2012 in Billings Montana. The court houses the U.S. District Court, U.S. Magistrate Court, the U.S. Marshals Service and the U.S. Attorney's Office. The building was designed with the intent of making justice visible and support and enhance the function of the downtown area through regional place-making, landscaped public green space and sustainable, high-performance building systems. The building projects a 44% reduction in the overall energy use as compared to a typical courthouse project in the United States (NBBJ 2018).

Documenting and categorizing high performance HVAC systems

Hydronic distribution and control:

1. Radiant in-floor heat/cool system: Radiant in-floor system used for both heating and cooling located in the two-story entrance atrium of the courthouse

2. Active Chilled Beams: The perimeter space of the building (i.e., individual office spaces) uses the active chilled beam system as the primary heating and cooling source. The beams are connected to an induction outdoor air (OA) ventilation system. The beams are located at adequate distance from walls to ensure adequate circulation of conditioned OA in the space. For OA ventilation system, sensors detect dew points throughout the building many times throughout the day to make sure that the areas are being properly dehumidified. Active chilled beams require little maintenance, except for the panels to be vacuumed every three to five years. The only complaint with this system in the building is that it takes a while for the system to warm the space, although once warm the space is constant. The beams are now activated to turn on sooner and turn off later in the day for those working in the building. The beams' major downside is that they are costly for the fact that they don't always meet the building loads. (Supplier: VEMCO, TROX System).

Air distribution and control:

1. Variable air volume (VAV) system: All corridors and conference rooms do not include this system but instead rely on a VAV. This is most likely due to the high fluctuation of people within these spaces and the possible condensation issues that an induction system could not handle. VAV boxes with reheat are also used for the interior, conference rooms, open office areas and courtroom spaces. The building was served by five indoor air handling units whose outside air was all provided through a single Dedicated Outdoor Air System (DOAS) unit with a heat recovery wheel.

2. VAV Displacement ventilation system: VAV displacement system used in conjunction with the radiant system in the atrium of the building. The VAV displacement system provides fresh air to the atrium space. As the atrium is surrounded by glazing, this supplements the capacity of installed radiant system to mitigate the thermal loss of the space.

3. Dedicated Outdoor Air System: This system is hosted by one central unit, which temperate all at one point and increase the efficiency of heat recovery with

exhaust air. Heat recovery wheel is used for heat recovery. Additional preheating is required to preheat the incoming outdoor air. The system has additional humidification / dehumidification capabilities.

4. Demand Control Ventilation with CO2 monitoring: The building hosts approximately 200 employees a day, with fluxes in various spaces as the public and workers move throughout them. The project met ASHRAE 62.1-2007 and provided indoor airflow monitoring stations and CO2 alarms to meet the IEQ Credit 1 requirements for Outdoor Air Delivery Monitoring. These monitors work with ventilation to keep the thermal standards adequate. In terms of maintenance, this system does require a recalibration every five years. Because of this, the building has a second system that will take over monitoring during the recalibration.

Central equipment:

1. Condensing Boilers: This is a system that is highly effective in Montana. However, this system is viable only for new buildings that are designed to hold the system. A conventional boiler keeps a temperature of 180 ˚F. On the other hand, condensing boilers delivery temperatures are at 140 ˚F thus requiring larger heat exchangers to deliver the heating in the space. The maintenance is similar to regular boilers. (Supplier: AIRCO)

2. Chilled water system: The chilled water portion of the building was served by two water cooled chillers with cooling towers located on the roof and a water to water heat pump designed to serve the minimal load required during off hours and winter conditions.

3. Condenser: A Fluid cooler w/ glycol is implemented as a condenser in the building.

Motor control:

1. Pumps: Currently there are VFDs installed on all pumps in the building.

Renewable energy:

1. Solar PV Array: An X kW PV array was installed on the roof of the courthouse building. The system provides roughly 5% of the buildings total energy costs.

2. Service hot water heating: A solar thermal hot water heater to meet the hot water demand in the building

Performance monitoring:

1. Building Automation System (BAS): All of the mechanical equipment is tied to a network for monitoring energy usage. In addition to monitoring the performance of the mechanical systems, the BAS also provides trends for real-time energy usage, peak demand, and renewable energy usage. These trends are then projected to a monitor in the lobby for the public to see. This system also allows any manual changes to be made to improve efficiency and quality of the systems.

Assessment of building performance

Energy savings: The building achieved an energy cost reduction of 32% when compared to an ASHRAE 90.1-baseline. Targeting LEED Gold certification, the building is designed to be at least 30-per-cent more energy efficient than the industry standard and has already achieved an energy savings of 40.5% using the Energy Cost Method as outlined in the ASHRAE 90.1-2007 standard.

Orange Crush Office Building

Location:	Great Falls, Montana
Building Type:	Office / renovation of warehouse
Total Area:	25,000 ft^2
Architects:	CTA Group
Engineers:	CTA Group
Certification:	LEED Gold
High Performance Systems:	Geothermal heat pumps, Radiant heating & cooling, Solar preheated outdoor ventilation air (OA)

Figure C-2: View of the entrance, Orange Crush Building, Great Falls Montana

Overview

The Orange Crush Building was originally constructed in 1917 as a downtown grocery and warehouse. In 2006, due to disrepair and a lagging economy, the structure was vacated, its potential for reuse or renovation left to question. In 2008, a developer purchased the three-story, 25,000 ft^2. building and sought to develop it into a highly-sustainable multitenant building. The design team was charged with engineering the space and its systems to be exceptionally efficient.

Documenting and categorizing high performance HVAC systems

Hydronic distribution and control:

1. Radiant in-floor heat/cool system: The radiant in-floor system used for both heating and cooling. 'Warmboard' tubes used in the in-floor radiant system utilize highly conductive pipe runs that are paired with an aluminum sub-floor that distributes thermal energy more quickly and efficiently than similar systems with Gypcrete or concrete slabs.

   Not only does the radiant floor heat the structure, it is uniquely utilized for cooling. The CTA building was also able to use water from that aquifer for radiant cooling, which was made possible in part because of the dry Montana summer climate. The same manifold was used for providing water to radiant heating and cooling. On warmer days and in the few locations where solar gain contributes to increased load on the system, CTA has auxiliary cooling in place, as well as computerized monitoring to control condensation. Cooling is performed without compressors. This arrangement for cooling required further system engineering and technological control to monitor humidity and condensation levels. The fast response of a low mass system enhanced energy efficiency as well.

Air distribution and control:

1. Solar preheated ventilation air: The energy code requires ventilated air in the building so solar ductwork on the roof is utilized to capture the heat of the sun and preheat the fresh air intake. The solar air heating system preheats the ventilation air using solar radiation, wherein the bank of four solar ducts moves fresh air across dark metal surfaces warmed by the sun to preheat the air, thereby reducing loads on the heating systems. This results in a net gain of 20-25 degrees, and a large reduction in energy use.

   As outdoor air during summers is warmer than desired, fresh ventilation air automatically bypasses the solar ducts.

2. Demand Controlled Ventilation: Paired with passive solar preheated ventilation air and demand-based ventilation controls such as CO_2 sensors. VAV ventilation terminals measure and adjust the amount of ventilation air needed in space. CO_2 sensors allow air volume to be based on room CO_2 levels.

Figure C-3: Demand-based ventilation system with solar duct preheat, Orange Crush Building, Great Falls Montana

Central equipment:

1. Geothermal Heat Pump System: A 675-foot DEQ-approved water-source withdrawal well to capture energy from the earth's water. The primary heat source is the Madison Aquifer which maintains a constant 53 - 55 F ground water temperature. High-efficiency heat pumps extract energy from the near-constant 53-degree water and distribute it to the building's custom-designed conductive radiant floor system. Space cooling is performed without compressors by running the 53 F water obtained from the aquifer through the radiant floor panels installed throughout the building. The system relies on geothermal technology to heat and cool with the Warmboard radiant product only requiring a back-up boiler for emergency heat, which is rarely needed.

Performance monitoring:

1. Building Automation System (BAS): The BAS implemented in this building interconnects the solar ducts, radiant subfloor, the Madison Aquifer and standard mechanical system (should they be needed) in order to reduce the utility requirements of the building. BASE also incorporates programming to control the radiant floor system especially when in cooling mode, preventing humidity issues with the floor as it cools.

Assessment of building performance

Energy savings:

This building was tested repeatedly during the design phase with advanced energy modelling software and life-cycle costing equipment, the solution responds to and exceeds all the design criteria. For this region of North America, the design pushes the boundary of precedents for energy efficiency in adaptable reuse.

Costs – First, installation, operation & maintenance:

The firm spent $3 million to buy and renovate the building. Since its completion, the building's operation costs are $0.52 less per square foot than a typical building of equal size in a similar setting, equating to a 42% annual cost savings.

Compliance with energy green rating standards:
Based on actual real-time data acquired within the first year of occupancy, the building has achieved a U.S. Energy Star Performance Rating of 93 as compared to similar buildings in its class. In addition, the building has attained a LEED Gold status.

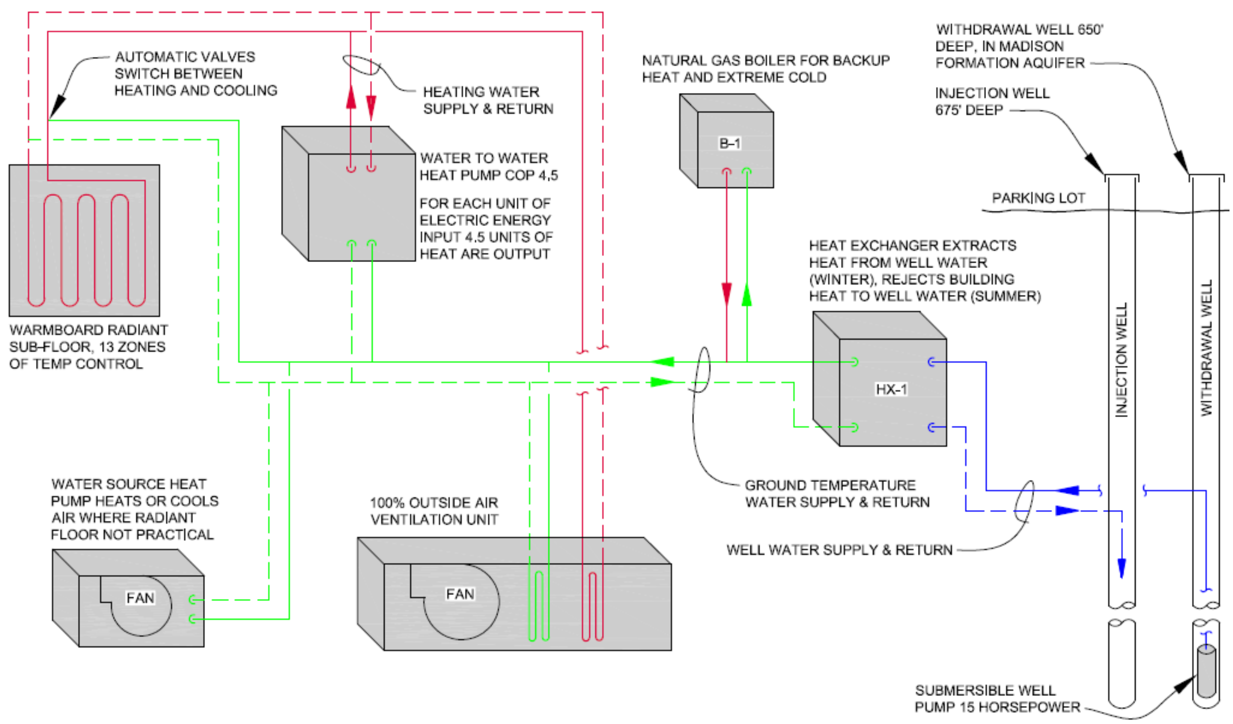

Figure C-4: Conceptual diagram of mechanical systems for the CTA office, Great Falls Montana

Bozeman High School

Location:	Bozeman, Montana
Building Type:	K-12 School
Total Area:	303,000 ft^2
Architects:	CTA Group
Engineers:	CTA Group
Certification:	CHPS
High Performance Systems:	VRF systems, Ground source water-to-water heat pumps, Dedicated Outdoor Air System (DOAS)

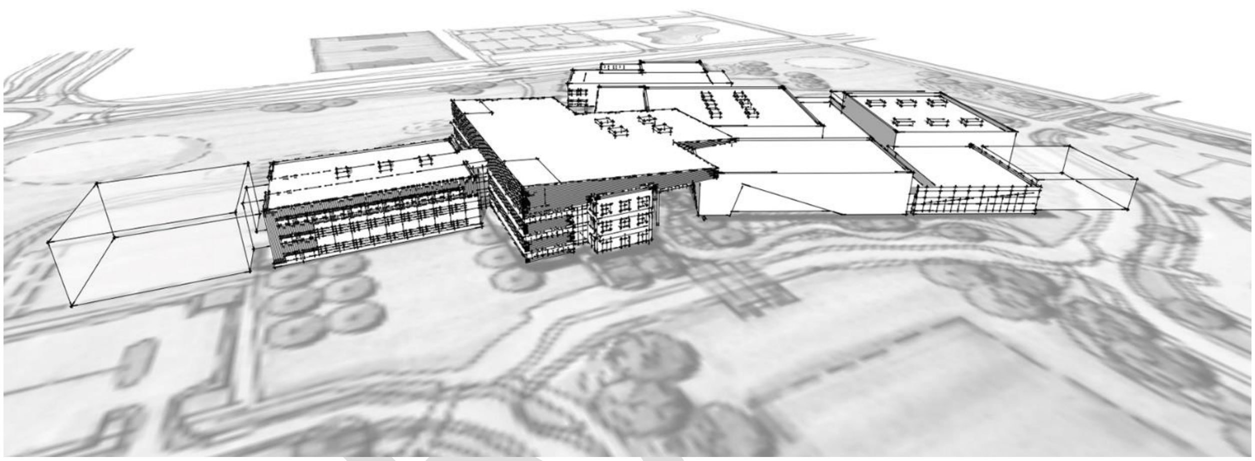

Figure C-5: Axonometric view of Bozeman High School, Bozeman Montana

The new Bozeman High School was designed to meet the expanding requirements of the current high school, which is expected to run out of space in three years because of the city's rapid growth. Several state-of-the-art environmental systems such as water-to-water heat pumps with geothermal wells and variable refrigerant flow systems were considered for this project. When considering the operation of water-to-water heat pumps instead of using traditional boilers for heating, the geothermal wells would draw water in from underground, use that energy to warm or cool the building, and then return the water to the aquifer.

Documenting and categorizing high performance HVAC systems

Hydronic distribution and control:

1. Variable Refrigerant Flow systems
   a. VRF units coupled with open loop ground water source heat pump
   b. Unit ventilators in conjunction with VRF system
   c. Air filters provided at room level
   d. Design team faced issue with mandatory requirements for air-side economizer as required by the code
   e. Water-side economizers instead of air-side economizers are used in this system

Air distribution and control:

1. Dedicated Outdoor System
   a. DOAS implemented along with VRF system to provide / meet fresh air requirements
   b. Coupling the operation of individual space VRF & DOAS system is key to optimal performance
   c. Require to preheat the incoming OA in the DOAs system
   d. Additional humidification / dehumidification capabilities also required

2. Transpired solar collector
   a. Solar wall to preheat OA coming into space

Central equipment:

1. Ground Water Sources Heat Pumps
   a. Open loop geothermal heat pump was used
   b. The heat pump takes advantage of the underground stream flowing under the site to preheat or precool the refrigerant used in the VRF system.

Motor control:

1. Pumps
   a. VFDs on all pumps

Renewable energy:

1. Solar PV Array:
   a. An X kW PV array was installed on the roof of the courthouse building. The system provides roughly Y% of the buildings total energy costs.

2. Service hot water heating:
   a. Solar thermal hot water heater

Performance monitoring:

2. Building Automation System (BAS)
    a. All of the mechanical equipment is tied to a network for monitoring energy usage.

Assessment of building performance

Energy savings:

- The building achieved an energy cost reduction of 32% when compared to an ASHRAE 90.1-baseline.
- Targeting LEED Gold certification, the building is designed to be at least 30% more energy efficient than the industry standard and has already achieved an energy savings of 40.5% using the Energy Cost Method as outlined in the ASHRAE 90.1-2007 standard.

Norm Asbjornson Hall, Montana State University Campus, Bozeman MT

Location:	Bozeman, Montana
Building Type:	Higher Education
Total Area:	110,000 ft^2
Architects:	ZGF Group
Engineers:	ACE Inc.
Certification:	Pursuing LEED Platinum
High Performance Systems:	Water-to-air heat pumps, transpired solar collectors, natural ventilation, dedicated outdoor air system (DOAS), economizers, natural ventilation

Figure C-7: View of the entrance court, Norm Asbjornson Hall, Bozeman Montana

Overview

The approximately 110,000 ft^2 building will house parts of the MSU College of Engineering and the MSU Honors College. It will feature nine classrooms, 17 laboratories and a presentation hall called "Inspiration Hall" that will seat approximately 300 people. The donor's desire was for an innovative HVAC design with opportunities for mechanical systems to be on display. Unique design aspects of the building include a transpired solar collector on the south side of the building as part of the wall system. Also implemented in the building is a comprehensive heat pump system that is designed and manufactured by AAON, a company founded by Asbjornson. The system reduces the use of duct runs and allows a more efficient method of conditioning the space as needed.

Documenting and categorizing high performance HVAC systems

Hydronic distribution and control:

1. Hot water loop for supplemental heating: A hot water loop provides supplemental heating via fin tube and also provided heat to entry vestibule cabinet unit heaters. The hot water is generated via MSUs central steam plant. The hot water loop also supplements the geothermal loop when it's needed.

Air distribution and control:

1. Dedicated Outdoor System (DOAS): Fresh air is provided by a DOAS system with a heat wheel and a geothermal heat pump to temper fresh air. The DOAS – ERV with hot water and GSHP for air tempering for fresh air will use VAV control for fresh air and exhaust based on air quality.

2. Transpired Solar Collector: The outside air (OA) coming into the ERV is heated by a transpired solar collector. This includes a bypass to prevent overheating or heating during summers.

3. Economizers: Air economizer are used to provide100% fresh through heat pumps. The economizers are combined with the DOAS units.

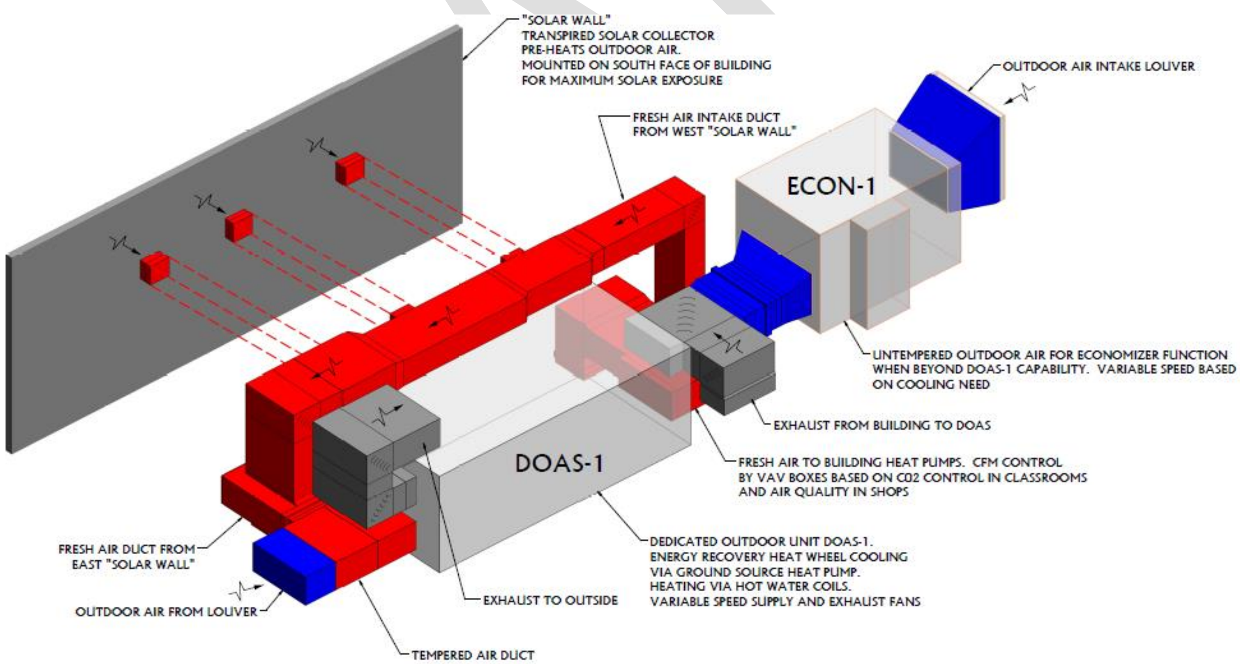

Figure C-8: Norm Asbjornson Innovation Hall fresh air system

4. Natural Ventilation: Natural ventilation is implemented for cooling of some spaces including the atrium and some offices as first stage of cooling. Atrium is provided with a smoke exhaust. Exhaust make up provided via operable windows and doors. This system is also used as a building pressure relief during economizer functions, and as a mechanical assist for the natural ventilation for first stage of cooling.

5. Indoor Air Quality: The Aircuity system monitors environmental parameters and adjusts air supply and exhaust delivery based upon indoor contaminant levels and thermal load. The automated system samples and analyzes packets of air which are routed to a centralized suite of sensors. The system provides input to the building ventilation systems to optimize indoor environmental quality and energy efficiency. In addition to CO2, total volatile organic compounds, particulates and CO are measured. The automated system samples and analyzes packets of air to determine air change rates required. The sensors need to be calibrated or replaced every six months.

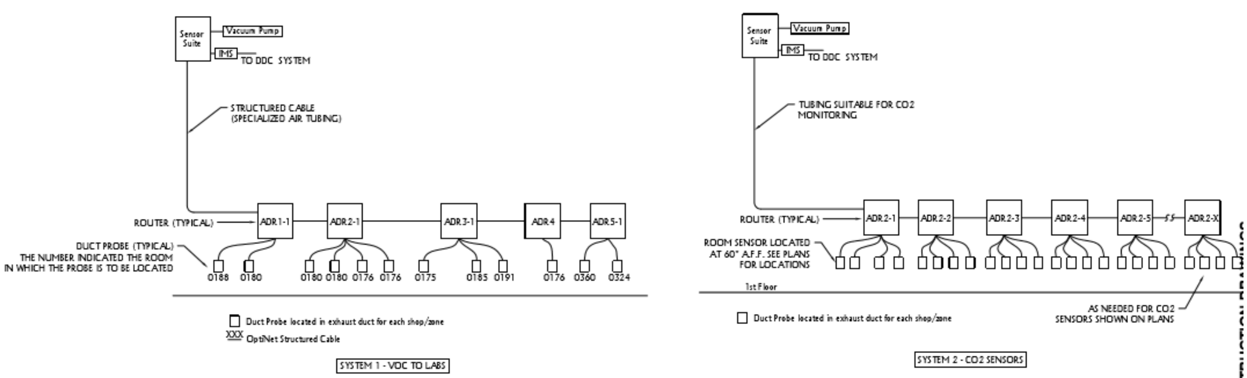

Figure C-9: Schematic layout of Aircuity sensors at the Norm Asbjornson Innovation Hall

Central equipment:

1. Ground Water Sources Heat Pumps: The HVAC system is a distributed water-to-air heat pump system utilizing a geothermal well field along with supplemental steam heating and evaporative cooling to temper the heat pump loop. The hybrid ground source heat pump system includes 104 geothermal wells as well as a connection to the central steam plant to provide heat to the geothermal loop during the coldest parts of winter. This hybrid system allows the steam system to handle the cold weather peaks and allow a reduced geothermal well quantity. The high efficiency heat pumps manufactured by AAON utilize the newest variable compressor technology.

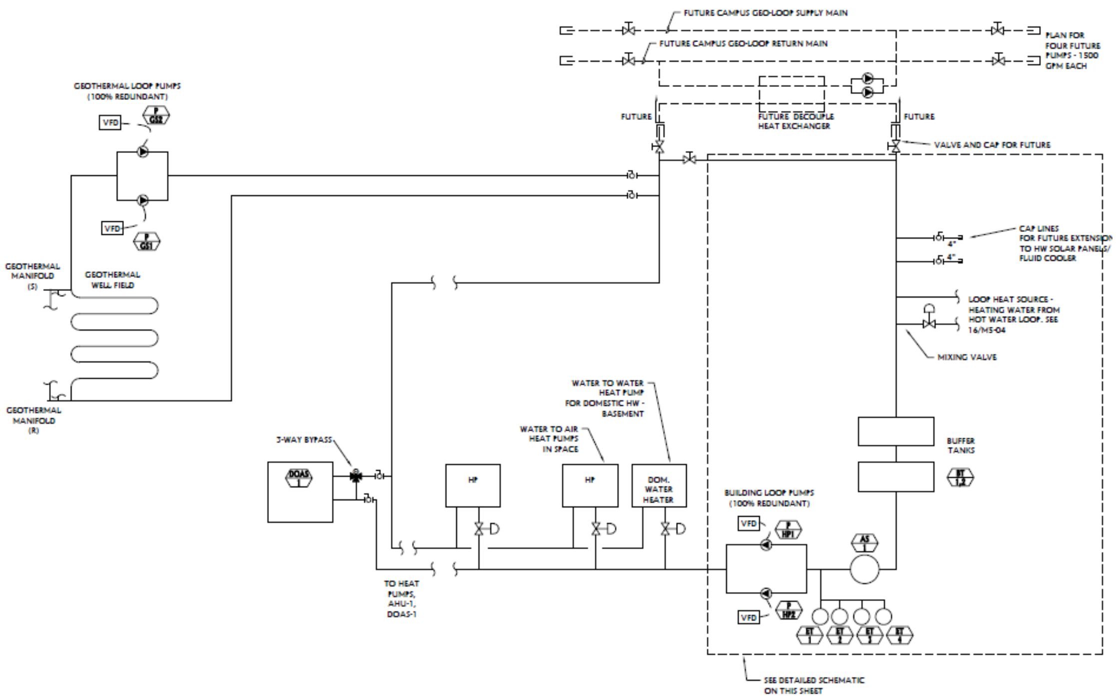

Figure C-10: Norm Asbjornson Innovation Hall heat pump loop schematic

Renewable energy:

1. Solar PV Array: A 250 kW PV array was installed on the roof of the courthouse building. The system provides roughly Y% of the buildings total energy costs.

2. Service hot water heating: Ground source heat pump is also used for domestic hot water heating.

Performance monitoring:

1. DDC controls
    a. The building will utilize DDC controls to control HVAC systems. There will be a web based DDC access wherever you have internet connection.
2. Metering
    b. Badger metering / Ion metering systems
3. Building Automation System (BAS)
    b. All of the mechanical equipment is tied to a network for monitoring energy usage.

Jabs Hall, Montana State University

Location:	Bozeman, Montana
Building Type:	Higher Education
Total Area:	50,830 ft^2
Architects:	Comma-Q, Henneberry Eddy Architects
Engineers:	Morrison - Maierle, Inc.
Certification:	LEED Gold
High Performance Systems:	Ground Source Heat Pumps, Transpired Solar Collector, Enthalpy Wheel, Radiant floor hydronic system, variable air volume systems (VAV)

Figure C-11: View of the entrance to Jabs Hall, Bozeman Montana

Overview

Jabs Hall was constructed in 2015 to house the growing School of Business at Montana State University (MSU). A $25 million gift to the university by notable alum Jake Jabs brought the project to fruition, as well as a name to the building. The HVAC systems were selected not only to be highly efficient, but also experimental. A thermocouple array spans the area of the transpired solar collector, and student researchers have analyzed their readings for several years to examine its efficiency, validate the technology, and determine the effect of wind stripping. Other notable systems include whole building hydronics, used in a radiant floor in the lobby and in the mechanical conditioning of air. This hydronic system is fed by closed loop ground source heat pumps, 52 geothermal bores, and campus steam.

Documenting and categorizing high performance HVAC systems

Hydronic Distribution and Control

1. The whole-building hydronic system is fed by ground source heat pumps and campus steam and serves a 2530 ft^2 radiant floor system in the main lobby of the building, several fin tube and cabinet style heaters dispersed throughout the building, and every variable air volume (VAV) terminal unit in the building. The radiant floor is simply PEX tubing embedded in a 6" concrete slab, and is capable of producing nearly 150 kBtu/hr.

Air Distribution and Control

1. Solar preheated ventilation air: A transpired solar collector allows for preheating of necessary ventilation air. An 8" plenum over a total collection area of 838 ft^2 utilizes the radiant energy of the sun to gain 20-25 °F. Depending on the temperature requirements of the building, ventilation is drawn either through the solar collector on the south face of the building, or when economizing, a louver on the opposite side, bypassing the preheated air.
2. Supply Air: Two air handlers, occupy a mechanical penthouse located on the top floor of Jabs Hall. One of the units is capable of performing energy recovery through an enthalpy wheel for the cold months and is directly connected to the transpired solar collector. These air handlers heat and cool air via a connection to the whole building hydronic system and provide the building with its primary form of conditioning: forced air through variable air volume (VAV) terminal units, which in turn are controlled by individual thermostats.

Figure C-12: View of the Transpired Solar Collector at Jabs Hall, Bozeman Montana

Central Equipment:

1. Geothermal Heat Pumps: Jabs Hall is served by several heat pumps located in the basement mechanical room. 52 geothermal bores provide thermal storage at a ground temperature of nearly 54 °F. These pumps move water through closed loops that reach 500 ft. in depth and through a plate and frame heat exchanger, which connects to the building hydronic system.

Assessment of Building Performance

1. Energy Savings: Jabs Hall has an energy use density (EUI) of 45.5 kBtu/ft^2/year, nearly half the intensity of comparable buildings around the country.
2. Costs: Jabs Hall was built using $18.5 million of Jake Jabs' $25 million gift to the university. Its yearly operational costs are heavily intertwined with other buildings on campus due to design flaws and are difficult to determine.
3. Compliance with Green Standards: Jabs Hall earned LEED Gold certification, with points awarded for numerous performance factors and design features including an innovative stormwater management system, energy performance optimization, 31% water use reduction, open space maximization, and recycled material selection.
4. Operational Challenges: As outdoor temperatures dip below 15 ˚F, it becomes imperative that the hydronic source water is at 140 ˚F, and this is not available from the centralized water-source heat pump system serving Jabs Hall. Steam is used to compensate, leaving the return hydronics at 120 ˚F, which is above the set point of the heat pumps. In other words the heat pump shuts down at 15 °F outside temperature. This is a design issue that was understood during the building design, and its not unusual for a heat-pump system generating heating water.

   The transpired solar collector supplies air to the south side of the building. The solar collector is heavily used, but under many circumstances generates such warm air that the air is mixed with unheated outside air to provide suitable air temperature for supplying to the building

   Additionally, a heat wheel is in the same loop. Because so much heat is generated by the solar wall, the heat wheel is not often used in the current arrangement.

APPENDIX D: CUTTING EDGE TECHNOLOGIES FOR ENVELOPE AND LIGHTING

High Performance Technologies for Lighting Systems

Dynamic Lighting

Dynamic lighting refers to a lighting system that is programmed to fluctuate in color temperature and illuminance while adjusting to the varying color temperatures of natural daylight throughout the day. The system automatically adjusts the intensity of light and its color temperature throughout the day to simulate a circadian rhythm, a rhythm that matches the natural daylight cycle. It balances a usage of warm and cool LED lighting to best optimize the occupant experience depending on the time of day and task at hand.

Dynamic lighting can be beneficial due to its ability to significantly reduce energy usage. Dynamic lighting systems implement LED lighting and daylighting sensing technologies both of which are established energy efficient technologies. It also helps improve the indoor environment quality in terms of lighting conditions. This is helpful when occupants need to spend long days inside due to the inclement weather during the winter. It creates an indoor lighting environment which is much more pleasing to be in instead of the potential spaces created during dark and overcast winter days. There is potential for dynamic lighting systems to reduce seasonal depression by improving the interior lighting qualities and simulating daylighting.

Dynamic lighting is used in a wide variety of situations including commercial (office), educational and industrial.

In office spaces, dynamic lighting is used to bring people together to improve their overall productivity. It is also used in situations such as in the AB Group office in Orzinouvi, Italy. In this case the dynamic lighting was used to help foster the connection between occupants of vastly different specialized fields within the realm of sustainability. They worked to foster these connections and improve the team work by tailoring the light qualities of the shared work spaces.

In education, dynamic lighting is being used to help improve the educational environment of children by changing the quality and type of lighting depending on the tasks at hand. If the kids need to be highly productive and working on classwork, the lighting can be increased in intensity, while as the intensity can be lowered for activity that more along the lines of recess. There is still debate as to whether or not warm lighting is better for classrooms versus cool lighting, but regardless, the fixtures can be calibrated to change for both scenarios.

In industrial settings, dynamic lighting allows for the occupants to maintain a connection to the outdoors, even when there are little to no windows in the facility. The ability for dynamic lighting to simulate circadian rhythms creates an established connection to the outside environment even if the occupants are physically disconnected from the outdoors.

Table D-1: Scorecards for high performance lighting technologies

Dynamic Lighting

SAVINGS	**Energy Savings Opportunity**		2			
	Cost Effectiveness			3		
	Measurability			3		
MARKET	**Defined and Available**				4	
	Market Ready	1				
	Market Friendly			3		
PROGRAMS	**Code Ready**			3		
	Industry support				4	
	Compatibility with Utility Programs	1				
	Currently Incentivized by Utility Programs	1				

High Performance Technologies for Envelope Systems

Building Integrated Photovoltaics

Building integrated photovoltaics (BIPV) is a system which integrates photovoltaics into the building's envelope. This allows the building envelope to also function as shading and energy generation. The use of BIPV can be divided into two main categories: wall systems and roofing systems. Wall systems are applications such as curtain walls, spandrel panels, and glazing, while roofing systems are more along the lines of shingles, tiles, standing seam products, and skylights. Depending on available land for development, BIPV systems can be the optimal method for installing renewable energy systems.

Utilizing the photovoltaics in the building skin reduces the overall costs of the system. The cost is reduced because there isn't a separate mounting system required, it's built into the building envelope.

The systems work the best on cold, clear days because the electricity generation is increased with lower ambient temperatures being significantly better for power production from PV systems. Higher ambient temperatures reduce the overall efficiency of the PV cells. Even though they can collect power on cloudy and overcast days, clear days have the most potential for power generation.

The photovoltaics can be used in a variety of ways within the building façade. They can replace traditional windows. There is less access to sunlight in these cases, however there is also more surface area available. They can also be added to old buildings in retrofit situations to hide parts of the façade that is either damaged or unattractive.

BIPV can also be used as a roofing material. In general, these take the form of shingles, tiles, standing seam products, and skylights. BIPV roof applications are also sometimes used as overhangs to help cover the ground below. This can be seen in cases such as the National Air and Space Museum in Washington, DC. The building has PV canopy that they use over a walkway as well as a PV curtain wall.

These systems can also be used in place of standard glazing. There are thin semi-transparent versions of the panels that can replace windows, allowing for both daylight to enter the space and power generation at the same time. These types of products can also be used as skylights and greenhouses. The ability for the panels to function as windows is a huge advantage in terms of a better integration between the building envelope and PV systems.

Table D-2: Scorecards for high performance envelope technologies - BIPV

Building Integrated Photovoltaics (BIPV)

SAVINGS	Energy Savings Opportunity					5
	Cost Effectiveness			3		
	Measurability				4	
MARKET	Defined and Available					5
	Market Ready		2			
	Market Friendly					5
PROGRAMS	Code Ready			3		
	Industry support				4	
	Compatibility with Utility Programs		2			
	Currently Incentivized by Utility Programs		2			

Advanced Window Technologies

Advanced window technologies generally have two main types, passively operated and electronically operated. Most varieties of both types function automatically without human intervention depending on the outdoor climatic conditions. The difference is whether or not the technology is powered by electricity. Most varieties of dynamic windows are available for commercial applications. Thermochromic windows function passively without added electricity. Liquid crystal device windows, suspended particle device windows, electrochromic windows, and gasochromic windows all require added electricity in order to function.

Thermochromic windows are a major dynamic window that is passively operated, without the use of electricity. Thermochromic windows function by using the infrared heat from the solar radiation incident on the surface of the window to tint the windows as needed. This technology is the simplest as well as the most advanced form of dynamic window technology. The resultant heat load from solar radiation entering the building through the window is minimized due to the constant fluctuation in window tint. In addition, the tinting capabilities of thermochromic windows helps to reduce glare. These windows might not be the best choice in cold climates due to the reduction in solar radiation admitted into the space that would normally provide free space heating, especially in the winter.

Liquid crystal device windows use the same type of liquid crystal display technology that is found in electronics such as TVs, phones, and wristwatches. They are one of the few dynamic window systems that are user operated instead of an automatic change based on the outside environment. The liquid crystals are placed between two electrical conductors. This system, called a polymer dispersed liquid crystal device (PDLC), is then put in between the panes of glass. Normally the crystals are unaligned, creating a translucent window that disperses the light that enters while allowing the full infrared heat from solar radiation to pass through. When the current is switched on, the window changes into a transparent glazing allowing for views. This window's design makes it great as a privacy window.

Suspended particle device (SPD) windows are very similar to liquid crystal device windows. The main difference is the particles themselves. The microscopic particles are suspended between the glass in a thin liquid-like layer. Without the current, the particles are unaligned giving the glazing a translucent quality. When the voltage is applied, the particles align making the glazing transparent. Depending on the voltage amount and the suspension, different colors are possible. The glazing can be colored by the particles to meet different operation requirements.

Electrochromic windows hold the most potential of all "switchable" window technology. The system sends concentrated ions back and forth in order to give the windows a blue-grey tint while preserving views. The switching speed is directly tied to the size and the temperature of the glazing. They appear similar in coloring to photochromic sunglasses. In general, these windows only use minimal amounts of electrical power, which is unlike most dynamic window technologies. The tint can be used to give added privacy. While tinted, the windows absorb solar radiation. Throughout the day, the window's tint changes based on the available light. This creates a wide variety of tints depending on the levels of solar radiation incident on the glass. Electrochromic windows might not be the best choice in cold climates. When it is cold outside, direct solar radiation incident on the surface of the window will cause the panes to warm up which in turn rapidly tints the glass. This can cause visual discomfort to the occupants in the space by creating a drastic change within too short a time span.

Gasochromic windows created a similar effect to the electrochromic windows, but instead diluted hydrogen is introduced into the cavity within an insulated unit. The mix between hydrogen and oxygen is used to control the amount of transparency the window has and maintains. U-values can be increased by introducing more panes or low-E coatings.

Table D-3: Scorecards for high performance envelope technologies – Dynamic windows

SAVINGS	**Energy Savings Opportunity**	1
	Cost Effectiveness	2
	Measurability	2
MARKET	**Defined and Available**	3
	Market Ready	2
	Market Friendly	3
PROGRAMS	**Code Ready**	4
	Industry support	3
	Compatibility with Utility Programs	1
	Currently Incentivized by Utility Programs	1

APPENDIX E: SURVEY QUESTIONAIRE – SAMPLE

COMMERCIAL CODE ENHANCEMENT SURVEY

INTEGRATED DESIGN LAB

Bozeman, Montana

NEEA is in the process of designing the Commercial Codes Enhancement (CCE) program, which adds dedicated strategic and operational resources to NEEA's current code efforts. The CCE program aims to bridge the gap between market practices, current codes, and state energy policies. This is accomplished by providing information about new technologies and practices available in the market, conducting demonstration projects to validate feasibility and affordability, and expanding code implementation training prior to adoption, which typically cannot be done with limited state training resources alone.

The following survey provides you an opportunity to assess the selected High Performing technologies in terms of MARKET READINESS, SAVING OPPORTUNITY, AND PROGRAM SUPPORT.

Please complete the survey to support the CCE program.
Thank you for your time.

DEDICATED OUTDOOR AIR SYSTEM

On a scale of 1 to 5, rate the **Dedicated Outdoor Air System** under the following categories:

Note: Use the description in each category to guide your number selection.

	CRITERIA	1	2	3	4	5
MARKET	Defined and Available	Currently in R&D with BPA Technology Readiness Level 1-9; Working prototype or pilot application in a building		Defined attributes or specs; Available by unique sourcing (custom or out of region) or limited regional capability		Turn-key local market availability from at least three sources
MARKET	Market Ready	Pre-commercialization - innovators 0-2.4% market penetration		Exceeds "early adopters" 13.5-33.9% market penetration Option Button 66		34% or greater market penetration
MARKET	Market Friendly	High cost, limited or no non-energy benefits, operational challenges		Moderate cost, some non-energy benefits. Meets multiple needs or multiple existing code requirements		Low-cost, significant non-energy benefits; Measurable, codifiable, meets TRC, UCT, SCT, CCT
SAVINGS	Energy Savings Opportunity	< 1aMW. Niche markets; No Unitized Energy Savings (UES) available.		Regional potential 10 - 25 aMW; Low UES		>25+ aMW regionally; Scalable; CE approved by RTF
SAVINGS	Measurability	Savings not-measureable; Enabling technology		Quantifiable, but with detailed measurement and evaluation and/or complex baseline		Readily quantifiable with simple measurement; discrete component
SAVINGS	Cost Effectiveness	High cost/savings ratio. Risk of diminishing savings over time. High maintenance costs.		Marginally cost-effective		Currently cost-effective (by chosen definition). Low cost/savings ratio. Persistent savings, minimal maintenance
PROGRAMS	Code Ready	Market available but complex elements for code		Stretch-code or voluntary (e.g. LEED) requirements		Currently in code/mandatory in some jurisdiction
PROGRAMS	Industry support	Industry hostile		Industry indifferent or split		Industry broadly supportive
PROGRAMS	Compatibility with Utility Programs	Currently not considered for programs, no pilot or early program development		Not yet cost effective and/or in pilot or demonstration projects		Cost effective savings /meshes with a particular utility program design
PROGRAMS	Currently Incentivized by Utility Programs	Not incentivized		Some pathways to incentive (whole building savings, case-by-case, etc.)		Currently incentivized by utilities in region (component basis, whole buildings or other)