# Identifying Appropriate High-Performance Building Environmental Control Technologies for Commercial Code Enhancement in Montana
# Part 1

12th December 2018
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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.



Disclaimer

The recommendations made in this report for the different HVAC systems are not intended to compare and make recommendations for different fuel types.

## 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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## INTRODUCTION

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. Figure 1 below shows how the CCE initiative fits as a complimentary initiative with the NEEA Codes program. The figure also provides an overview of how the CCE initiative relates to the other NEEA code programs.

While many advanced design and construction practices have been successfully demonstrated, they have yet to be adopted into mainstream practice in the commercial building industry (NEEA 2017). NEEA's Commercial Code Enhancement program bridges the gap between market practices and state policies by identifying, assessing, and validating the feasibility and affordability of the next-generation technologies and practices (NEEA 2017). By queuing up these technologies and practices, building market awareness and capability, and creating market support of new code measures the alliance is paving the way for the Northwest to adopt solution-oriented, market-supported technologies and practices (NEEA 2017).

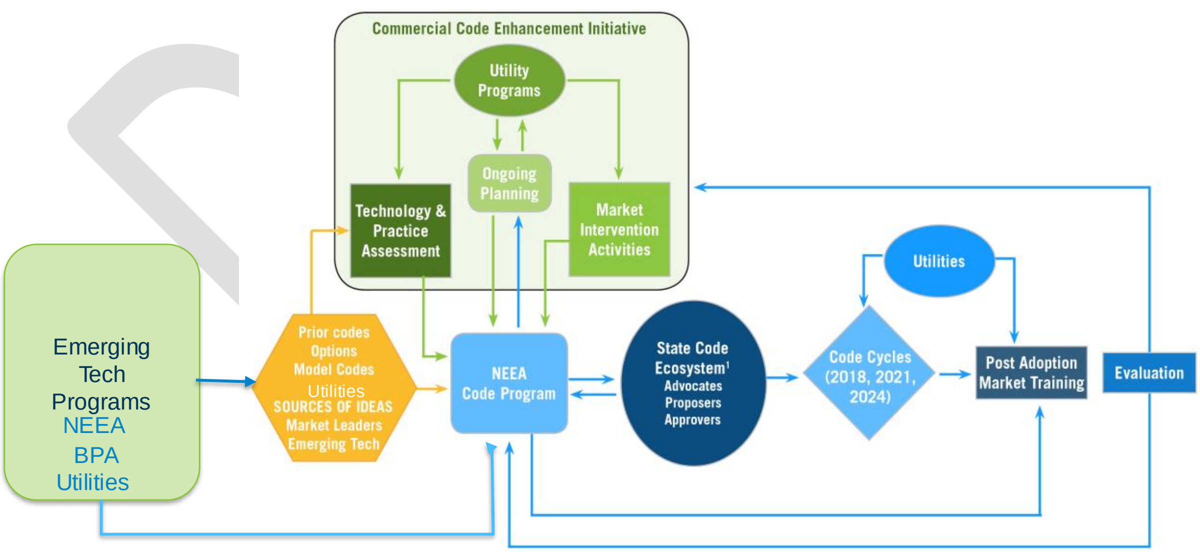


*Figure 1: Commercial Code Enhancement Initiative Relationship to NEEA Codes Program (Source: NEEA 2017)*

## PROCESS OF EVALUATING ADVANCED DESIGN & CONSTRUCTION PRACTICES

Northwestern Energy Efficiency Alliance (NEEA) has suggested a process for technology and practice assessment. (Ref Doc: CCE TP Assessment Process and Criterial 3302017)
Process

1. Estimate approximate goal for reduction in targeted code cycle
2. Scan 'Source Pools' for opportunities (See selection criteria below).
3. Over-select enough T/Ps to meet goal (N=3-5 depending on potential reduction from each)
4. Define specifications of each T/P
5. Review existing research or literature on each selected T/P
6. Prioritize T/Ps based on code readiness
7. For less ready T/Ps develop a research and development plan
8. Implement needed research on:
    a. Technical readiness
    b. Market readiness
    c. Barriers
    d. Market penetration
    e. Technical potential
9. For more ready ones determine level of awareness in market and need for demonstration, case study development, awareness building or training.
10. Identify relevant demonstrations completed or potential opportunities for new ones
11. Develop case studies, where appropriate
12. Implement demonstrations, where needed
13. Implement lab and/or field testing, where needed (then loop back to Step 8)
14. Refine T/P specifications and cost-effectiveness for code proposals
15. Work with appropriate team to develop code proposals

Technology/ Practices Screening and Selection Criteria:
Each T/P selected is screened using the criteria below in a sample scorecard:

1. More energy efficient than alternatives (energy savings potential)
2. Cost effectiveness
3. Measurability
4. Defined and commercially available
5. Market-ready
6. Market-friendly (offers solutions to known challenges)
7. Code-ready (definable in code language, enforceable)
8. Support of industry (AEC organizations)
9. Compatible with utilities' programs and plans

Table 1 tabulates the criteria for evaluation. Table 2 provides a sample scorecard for this process. The criteria definitions are tabulated below:

Criteria Definitions:

1. Energy saving opportunity: Does the technology save energy? What's the savings estimate and the technology cost? Does it offer an opportunity to displace other code requirements in a more cost efficient way?
2. Cost-effective: Quantifiable benefits exceed the cost to end users and to society.
3. Measurable: Can savings be attributed to the technology? Can market uptake be measured – is this a preferred technology – and can the impact on total code savings be measured?
4. Defined and Available: Definition of the measure, assembly, or system to assess industry use as a best practice and whether it is already covered by code. Is there some degree of market uptake?
5. Market ready: Is enough known about the technology to say it is ready for both the design and construction market? Where are the gaps?
6. Market friendly: Whether the technology/system/practice fills a gap in code through filling a need in building design.
7. Code ready: Will the technology fit into code logically? Can code language be developed logically? Can it be enforced? Is it broadly applicable or can it be targeted at specific occupancy types?
8. Industry support: Does the AEC community represented by their professional and trade organizations support inclusion of the T/P?
9. Compatibility with Utility programs: Meets utility cost-effectiveness and fits into existing utility programs, or utility programs can easily adapt to incorporate it with incentives or training etc., or fits within pilot program requirements. Utilities, NEEA and others can work collaboratively to move T&P forward.

## Table 1: Technology and Practices Assessment Criteria (Source: NEEA 2017)

| | | 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 Ready** | Pre-commercialization - innovators 0-2.4% market penetration | | Exceeds "early adopters" 13.5-33.9% market penetration | | 34% or greater market penetration. |
| | **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** | < 1MW. Niche markets; No Unitized Energy Savings (UES) available. | | Regional potential 10 - 25 MW; Low UES | | >25+ MW regionally; Scalable; CE approved by RTF |
| | **Measurability** | Savings not-measureable; Enabling technology | | Quantifiable, but with detailed measurement and evaluation and/or complex baseline | | Readily quantifiable with simple measurement; discrete component |
| | **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 |
| | **Industry support** | Industry hostile | | Industry indifferent or split | | Industry broadly supportive |
| | **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 |
| | **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) |

**Table 2: Sample Scorecard (Source: NEEA 2017)**

| | | | | | | |
|---|---|---|---|---|---|---|
| SAVINGS | **Energy Savings Opportunity** | | | | 4 | |
| | **Cost Effectiveness** | | | 3 | | |
| | **Measurability** | | | | 4 | |
| MARKET | **Defined and Available** | | | | | 5 |
| | **Market Ready** | | 2 | | | |
| | **Market Friendly** | | | | | 5 |
| PROGRAMS | **Code Ready** | | | | 4 | |
| | **Industry support** | 1 | | | | |
| | **Compatibility with Utility Programs** | | 2 | | | |

Outline for Technology Briefs

1. T/P Definition or description
2. Market-readiness - Commercial availability
3. Cost – equipment cost, installation cost
4. Energy efficiency and performance compared to alternatives
5. Relation to utility programs (to be completed by NEEA)
6. Market-friendly (solutions to other known challenges)
7. Code-readiness (definable in code language, enforceable)
8. Measurability – key indicators, data availability, and methods to collect data

## OBJECTIVE AND PROCEDURE ADOPTED BY THIS REPORT

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. In addition, the purpose of this report is also to identify potential code measures appropriate to Montana.

This report implements a process for evaluating HVAC technologies in High Performance commercial buildings in Montana. The report lists several High Performance commercial buildings in Montana and identifies various High-Performance HVAC systems that are implemented in these buildings. The report then selected 4 case-studies that are representative of the commercial building stock in Montana, which include an example of a high school, office, public and a higher education building. Several High Performance environmental control technologies were identified in these buildings. The identified technologies are then evaluated using the criteria identified by NEEA. Figure 2 provides a flowchart of the process followed in this report, which is a subset of the process identified by NEEA.

In addition to the technologies identified from the survey of High Performance commercial buildings in Montana, certain cutting-edge technologies are identified and briefly discussed. These cutting-edge technologies are yet to be implemented in the commercial buildings in Montana. However, literature review indicates that these technologies have proven to significantly contribute to energy savings in the commercial building.

The selected list of high performance technologies is evaluated using the criteria developed by NEEA presented in Table 1 and Table 2 of this report. A survey evaluating the performance of each of the selected high performance technologies was compiled and disseminated among the engineering community in Montana. The survey can be accessed from: http://ou.montana.edu/idl/cces.html . The results of the survey are yet to be collected and assessed. In addition, a number of experts active in the field of HVAC system design were consulted to assess the selected HVAC technologies. Their responses are recorded in section 'Step 4: Survey Results' of this report.

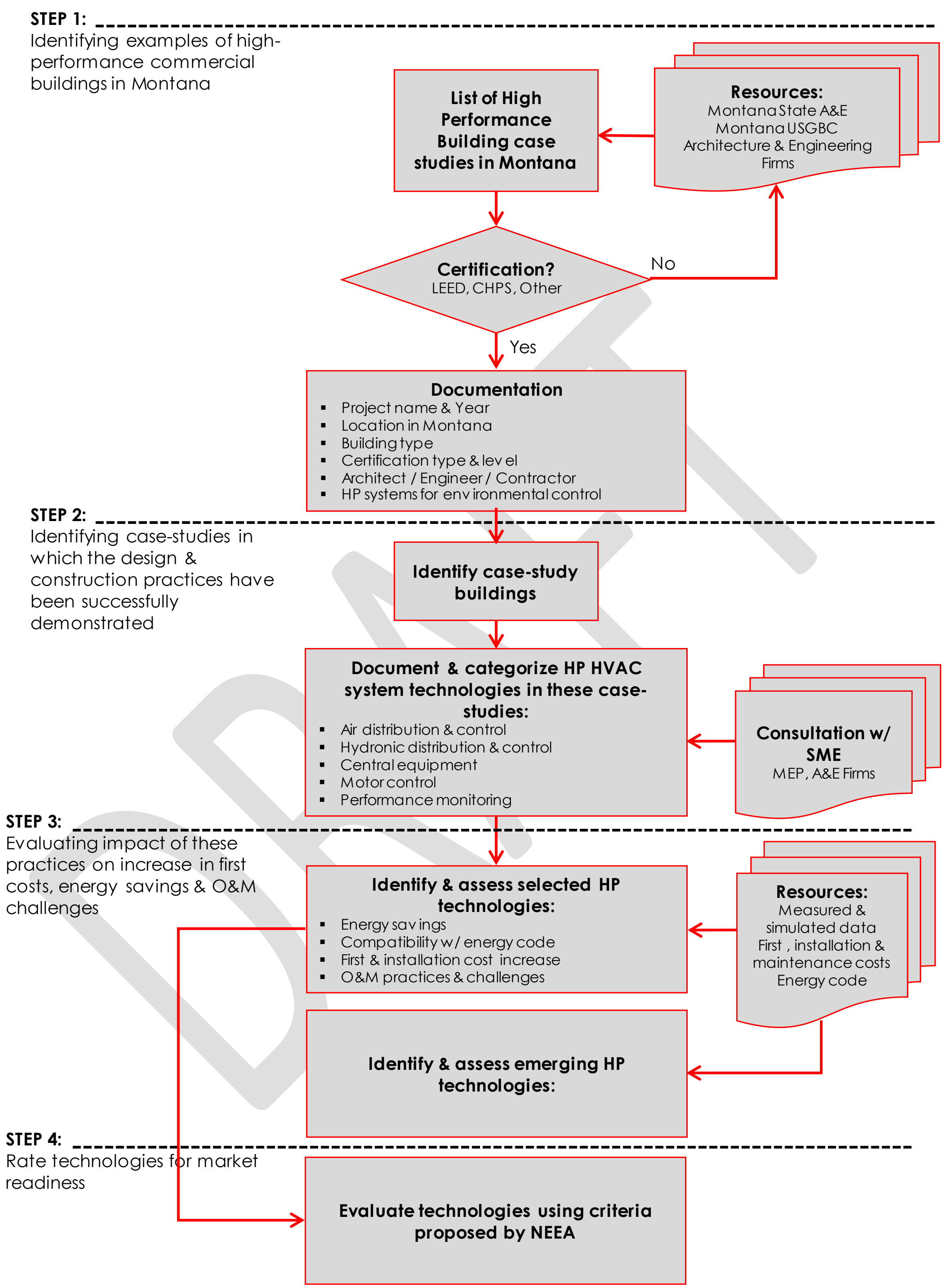


*Figure 2: Selecting and evaluating appropriate advanced HVAC technologies in commercial buildings in Montana*

# ANALYSIS

## *Step 1: Identifying examples of high performance commercial buildings in Montana*

In the 1st step of the analysis, various sources were consulted for information on High Performance commercial buildings. These include:

- Montana State A&E
- Montana USGBC
- Interviews with A&E firms

The identified high performance commercial buildings were then evaluated for appropriate certification awarded and level of certification. Certifications include:

- Leadership in Energy & Environmental Design (LEED)
- EnergyStar
- Green Globes
- Living Building Challenge
- Collaborative for High Performance Schools (CHPS)

The relevant information documented in a spreadsheet. Information included:

- Project name
- Location in Montana
- Building type
- Certification type and level
- Architecture, engineering and contractor firms responsible for design and construction
- A brief summary of the mechanical and renewable energy systems implemented in the

Buildings were located major town and cities across Montana, which included: Columbia Falls, Big Sky, Billings, Bozeman, Browning, Butte, Dillon, Gardiner, Great Falls, Hamilton, Helena, Miles City, Missoula, Red Lodge, and Warm Springs. Building types included in this analysis represented a large cross-section of commercial buildings, which included: hospitals, educational buildings, civic, hotels, laboratories, offices, and retail. A total of 72 high-performance buildings were identified. The complete list of buildings and their certifications are provided in Table 3. The complete tabulation is provided in Appendix A of this report. A trend in construction of LEED certified buildings is provided in Appendix B of this report.

## Table 3: List of High Performance Commercial Buildings in Montana

| PROJECT | YEAR | LOCATION | TYPE | CERTIFICATION |
|---|---|---|---|---|
| Addition & Renovation - 40 Bed Wing | | Columbia Falls, MT | Hospital | |
| Anderson Hall- School of Journalism | | Missoula, MT | Education | LEED Gold |
| Applied Technology Center (Diesel Tech) | | 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 | 2007 | Bozeman, MT | Office | LEED Silver |
| Bozeman Public Library | 2006 | Bozeman, MT | Civic | LEED Silver |
| Central Land Office | | Helena, MT | Office | LEED Gold |
| Chemistry Bio-research Facility | 2007 | Bozeman, MT | Laboratory | |
| Cooley Labs Renovation | 2012 | 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, MT | Education | LEED Platinum |
| Education Center | | Helena, MT | Education | |
| element | 2015 | Bozeman, MT | Hotel | LEED Certified |
| Expand 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 | 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 | | Helena, MT | Office | LEED Gold |
| Home on the Range | 2007 | Billings, MT | Office | LEED Platinum |

Note: Rows marked in RED represent buildings situated on Montana State University campus.

## Table 3: Continued

| PROJECT | YEAR | LOCATION | TYPE | CERTIFICATION |
|---|---|---|---|---|
| Interdisciplinary Science Building | | Missoula, MT | Education | |
| Interfaith Chapel | | Warm Springs, MT | - | |
| Jabs Hall | 2015 | Bozeman, MT | Education | LEED Gold |
| Kalispell DNRC-DEQ Office | | 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 Certified |
| Main Hall Renovation | | Dillon MT | Dormitory | |
| Math/Science Building | | Browning, MT | Education | LEED Platinum |
| McMullen Hall Renovation | 2011 | Billings, MT | Office | |
| Medicine Crow Middle School | 2016 | Billings, MT | Education | |
| Miles City Readiness Center | | Miles City, MT | Civic | |
| Miller Dining Hall | 2015 | 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 | | Great Falls, MT | Civic | LEED Silver |
| Montana State Fund Office Building | | Helena, MT | Office | LEED Gold |
| Montana Wild | | Helena, MT | Civic | |
| Morrison Maierle, Inc | 2007 | Bozeman, MT | Office | LEED Gold |
| Morrison Maierle, Inc | 2018 | Missoula, MT | Office | |
| MSU Gallatin Hall | 2015 | Bozeman, MT | Dormitory | LEED Gold |
| "Museum of the Rockies Curatorial | | Bozeman, MT | Civic | LEED Gold |
| Center of Humanities" | 2017 | Butte MT | Office | |
| Natural Resources Building | | Hamilton, MT | Office | LEED Gold |
| NIH/NIAID Rocky Mountain Lab Bldg. 7 | | Bozeman, MT | Education | |
| Norm Asbjornson Hall | 2019 | Butte MT | Office | LEED Gold |
| NorthWestern Energy Headquarters | 2015 | Great Falls, MT | Office | LEED Gold |
| "Orange Crush" CTA Office | 2015 | Missoula, MT | Office | LEED Platinum |
| Payne Native American Center | 2010 | Helena, MT | Office | LEED Silver |
| Pioneer Block Office building | | Helena, MT | Office | LEED Silver |
| RPA Corporate Headquarters | 2017 | Bozeman, MT | Retail | LEED Silver |
| Safeway 2999 | 2011 | Billings, MT | Civic? | LEED Gold |
| Stockman Bank | 2014 | Missoula, MT | Civic? | LEED Platinum v4? |
| Stockman Bank | 2018? | Missoula, MT | Education | LEED Gold |
| Sussex School | 2011 | Missoula, MT | Education | LEED Gold |
| The Boys & Girls Club | 2012 | Red Lodge, MT | Civic | LEED Platinum |
| Underriner Motors | 2014 | Billings, MT | Retail | LEED Certified |
| Yellowstone Hall | 2016 | Bozeman, MT | Dormitory | LEED Gold |

Note: Rows marked in RED represent buildings situated on Montana State University campus.

The buildings were also evaluated in terms of the implemented High Performance systems. This information was not readily accessible for all the buildings. A general list has been compiled for High Performance systems and equipment that were commonly found in these buildings. This list is presented in Table 4.

**Table 4: List of Identified High Performance Systems & Equipment for Commercial Buildings in Montana**

| List of High Performance / Energy Efficient Systems |
|---|
| **Hydronic distribution and control** |
| Chilled beams |
| Radiant floor system |
| **Air distribution and control** |
| Dedicated outdoor air system |
| Demand control ventilation system w/ CO2 monitoring |
| **Central systems** |
| Variable refrigerant flow system (VRF) |
| Evaporative cooling system |
| Underfloor air distribution system |
| Open loop ground source heat pump system |
| **List of High Performance / Energy Efficient Equipment** |
| Condensing boilers |
| Heat recovery |
| Run around heat recovery loop |
| Heat recovery ventilators |
| Enthalpy wheels |
| Heat-pump water heaters |
| Variable frequency drives on pumps and fans |
| **List of Renewable Systems** |
| Photovoltaic array |
| Solar transpired collectors |
| Solar hot water heating |

### *Step 2: Identifying examples of high performance HVAC technologies*

In the 2nd Step, a total of four buildings were identified as case-studies for further assessment. The buildings were selected to represent the commercial building stock in Montana. In addition, the selection was made with regard to availability of information. The selection of buildings include:

- Bozeman High School, Bozeman, MT
- Orange Crush office building, Great Falls, MT
- James F. Battin United States Courthouse, Billings, MT
- Norm Asbjornson Hall, Bozeman, MT
- Jabs Hall, Bozeman, MT

The information regarding the case-studies is presented in Appendix C of this report.

***Step 3a: Evaluating the impact of selected HVAC technologies***

From the case studies presented in Step 2 of this report key high-performance technologies for Montana were identified. The technologies were then evaluated in terms of the following:

- Advantages
- Applications
- Challenges of operating in a cold climate
- Incorporating system specifications in energy codes
- Challenges associated with O&M of the system

An overview of each technology was provided in terms of ideal application of the technology for different building types and sizes as well as the code readiness of the technology. Building characteristics were adapted from the prototype commercial building models developed by the Pacific Northwest National Lab for evaluating code compliance (US DOE. 2018). The building types were considered for assessing High Performance Technologies include: Offices, Retail, Schools, Healthcare, Hotels, Warehouses, Restaurants, and Apartments. The building sizes that were considered include: Small (<10,000 $ft^2$), Mid-size (10,000ft2< >100,000$ft^2$) and Large-size (>100,000$ft^2$).

A number of high performance technologies for lighting and envelope have been compiled in Appendix D of this report.

## Dedicated Outdoor Air System (DOAS):

| | |
|---|---|
| Building Type | Ideal for buildings with strict ventilation requirements<br>Schools, Offices, Hospitals, Hotels, Restaurants, Retail, Apartments |
| Building Size | Small-size, Mid-size, Large-size |
| Code Readiness | Near Term |

*Definition:*

A dedicated outdoor air system (DOAS) uses separate equipment to condition all of the outdoor air brought into a building for ventilation and delivers it to each occupied space, either directly or in conjunction with local or central HVAC units serving those same spaces. The local or central HVAC units are used to maintain space temperature.

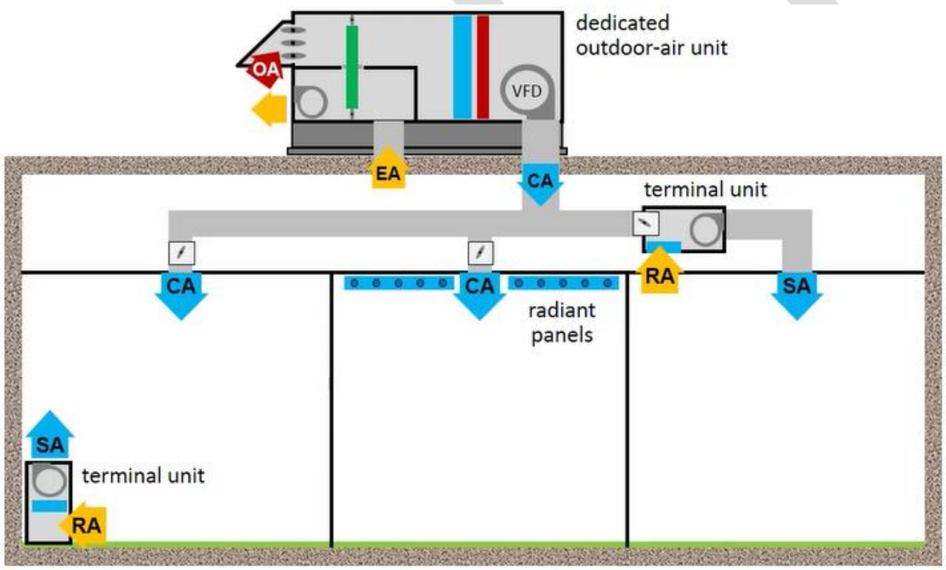


*Figure 3: Diagram of a typical DOAS system*

*Reasons for using DOAS:*

Some of the most common drivers for using DOAS are (Deng et al., 2014):

- Improving humidity control
- Reducing energy use
- Desire to simplify ventilation design and control
- Desire to use heating and cooling equipment that does not provide ventilation (i.e., radiant panels, chilled beams)
- Reducing installation costs

*Applications:*
DOAS can be implemented effectively in almost any type of commercial, institutional, industrial or multifamily building. While this system is beneficial to any building type, those building types with strict indoor air quality, ventilation, humidity, or energy efficiency requirements can benefit immensely. Also, as the ratio of outdoor air to recirculated air increases, DOAS benefits increase accordingly (Kosar et al 1998).

*Operating DOAS in cold climates:*
Cold climates such as Montana are heating dominated for a large portion of the year. In the coldest regions of this climate zone, its advisable to include a preheat coil in the DOAS unit. In slightly warmer areas it may be possible to produce warmer air temperatures with an air-to-air heat exchangers. In that case, if the DOAS unit discharges directly into the space, a reheat coil may be needed to avoid the perception of cold drafts.

An air-to-air enthalpy exchanger (eg. Enthalpy wheel, fixed membrane heat exchanger) help humidify the incoming outdoor air during cold weather, when outdoor air holds very little humidity. Frost prevention sequences are necessary to prevent the exhaust side of the exchanger from frosting. Heating coils are sized to account for full heating load of outdoors air, to incorporate the possibility that the air-to-air heat exchanger will frost up at cold outdoor conditions.

*Incorporating DOAS specifications in energy code:*
The two standards that are most relevant to commercial DOAS design are ASHRAE Standard 62.1 Ventilation for Acceptable Indoor Air Quality (ASHRAE 2016a) and ASHRAE Standard 90.1 Energy Standards for Buildings Except Low Rise Residential Buildings (ASHRAE 2016b).

ASHRAE Standard 90.1 includes a broad array of energy related items that might influence the selection of a DOAS unit. Some of these include the following:

- Minimum efficiencies
- Fan power limitation
- Use of economizer
- Requirements for simultaneous heating and cooling (as applicable to dehumidification)

Both ASHRAE Standard 62.1 and ASHRAE Standard 90.1 have users manuals that provide comprehensive guidance as well as calculation samples that can help engineers to meet the requirements of the standards (ASHRAE 2016c, ASHRAE 2014). For example, 90.1 2016 Users Manual example 6CCC details how to apply the fan power limits to a DOAS, and ASHRAE Standard 62.1-2016 Users Manual example 5-C shows the calculations required to show whether the relative humidity limit of 65% will be met for the 'dehumidifying challenge' condition (at peak outdoor dew-point and mean coincident dry-bulb design conditions, and at the design indoor latent and sensible loads, with solar loads at zero).

Until recently, an industry rating standard for DX DOAS did not exist. However, ASHRAE Standard 90.1-2016 added minimum efficiency requirements for DX DOAS units tested in accordance with ANSI/AHRI Standard 920 (AHRI 2016).

For most climate zones, ASHRAE Standard 90.1 requires each cooling system with a fan to include either an air or water economizer. However, there are a number of exceptions to this requirement. The most notable is Exception 1, which limits the requirement to fan cooling units of 4.5 tons or greater. With DOAS, local HVAC units are smaller than this threshold, rendering them exempt from this requirement. In addition, if the system uses condenser water heat recovery, it is also exempt from the need to have an economizer. This may be applicable in buildings such as hospitals, hotels, or dormitories, which commonly use DOAS (ASHRAE 2017).

When an economizer is required, the design team might consider one of the following potential solutions. First, the DOAS could be oversized to allow for the extra air flow to be delivered when economizing. For most applications, this is not desirable because it requires much larger ductwork and larger fans. Second, an additional air path could be created to deliver 100% supply airflow for economizing. This may work for zones that are near a perimeter wall, but it becomes challenging for interior zones. Finally, for water-based systems such as fan-coils, chilled beams, or radiant cooling, a water-side economizer at the chiller plant may present the easiest solution. If none of the approaches are viable for economizers, then the design team should use the energy cost budget method available for compliance (ASHRAE 2017).

*Challenges associated with O&M of DOAS:*
Providing building staff with system documentation will help ensure that the system is operated correctly. Documentation includes operation and maintenance manual, systems manual, as-built documentation and training plan for facilities personnel. In addition to predictive maintenance of DOAS equipment, regular monitoring of parameters such as ventilation rates, dehumidification and air-to-air energy recovery should be conducted. Finally, regular attention to air quality maintenance should be ensured by establishing relevant predictive maintenance practices such as filter removal and cleaning of cooling / heating coils and drain pans (ASHRAE 2017).

**Table 6.8.1-15 Electrically Operated *DX-DOAS Units*, Single-Package and Remote Condenser, without *Energy* Recovery—Minimum *Efficiency* Requirements**

| *Equipment* Type | Subcategory or Rating Condition | Minimum *Efficiency* | Test Procedure |
|---|---|---|---|
| Air cooled (dehumidification mode) | | 4.0 *ISMRE* | AHRI 920 |
| Air source heat pumps (dehumidification mode) | | 4.0 *ISMRE* | AHRI 920 |
| Water cooled (dehumidification mode) | Cooling tower condenser water | 4.9 *ISMRE* | AHRI 920 |
| | Chilled Water | 6.0 *ISMRE* | |
| Air source heat pump (heating mode) | | 2.7 *ISCOP* | AHRI 920 |
| Water source heat pump (dehumidification mode) | Ground source, closed loop | 4.8 *ISMRE* | AHRI 920 |
| | Ground-water source | 5.0 *ISMRE* | |
| | Water source | 4.0 *ISMRE* | |
| Water source heat pump (heating mode) | Ground source, closed loop | 2.0 *ISCOP* | AHRI 920 |
| | Ground-water source | 3.2 *ISCOP* | |
| | Water source | 3.5 *ISCOP* | |

**Table 6.8.1-16 Electrically Operated *DX-DOAS Units*, Single Package and Remote Condenser, with *Energy* Recovery—Minimum *Efficiency* Requirements**

| *Equipment* Type | Subcategory or Rating Condition | Minimum *Efficiency* | Test Procedure |
|---|---|---|---|
| Air cooled (dehumidification mode) | | 5.2 *ISMRE* | AHRI 920 |
| Air source heat pumps (dehumidification mode) | | 5.2 *ISMRE* | AHRI 920 |
| Water cooled (dehumidification mode) | Cooling tower condenser water | 5.3 *ISMRE* | AHRI 920 |
| | Chilled Water | 6.6 *ISMRE* | |
| Air source heat pump (heating mode) | | 3.3 *ISCOP* | AHRI 920 |
| Water source heat pump (dehumidification mode) | Ground source, closed loop | 5.2 *ISMRE* | AHRI 920 |
| | Ground-water source | 5.8 *ISMRE* | |
| | Water source | 4.8 *ISMRE* | |
| Water source heat pump (heating mode) | Ground source, closed loop | 3.8 *ISCOP* | AHRI 920 |
| | Ground-water source | 4.0 *ISCOP* | |
| | Water source | 4.8 *ISCOP* | |

Note:
*ISMRE: Integrated seasonal moisture removal efficiency*
ICOP: Integrated seasonal coefficient of performance

*Figure 4: Excerpts from ASHRAE Standard 90.1 2016 efficiency requirements for DX DOAS (Source: ASHRAE 2016b)*

Variable refrigerant flow (VRF) system:

| | |
|---|---|
| Building Type | Ideal for buildings with simultaneous requirements of space heating and cooling loads<br>Restaurants, Multifamily, Schools |
| Building Size | Small-size, Mid-size |
| Code Readiness | Near Term |

*Definition:*
Variable Refrigerant Flow (VRF) systems have developed into a promising emerging technology. While popular in some places in the world, these systems are quite new to the United States. The systems are an innovative version of a simple split system air conditioner that utilizes variable speed compressors, multiple zone refrigerant distribution, heat recovery, and low energy fan coils to cool and heat commercial buildings more efficiently than standard split systems and heat pumps.

The key components of a VRF system are the outdoor unit, indoor unit, refrigerant, and heat recovery unit. Refrigerant moves throughout the entire system, with both hot and cold refrigerant being produced by the outdoor unit. Both phases of refrigerant are sent to the heat recovery units where, in addition to heat recovery, the controls designate each indoor unit to receive hot or cold refrigerant based on whether they need heating or cooling.

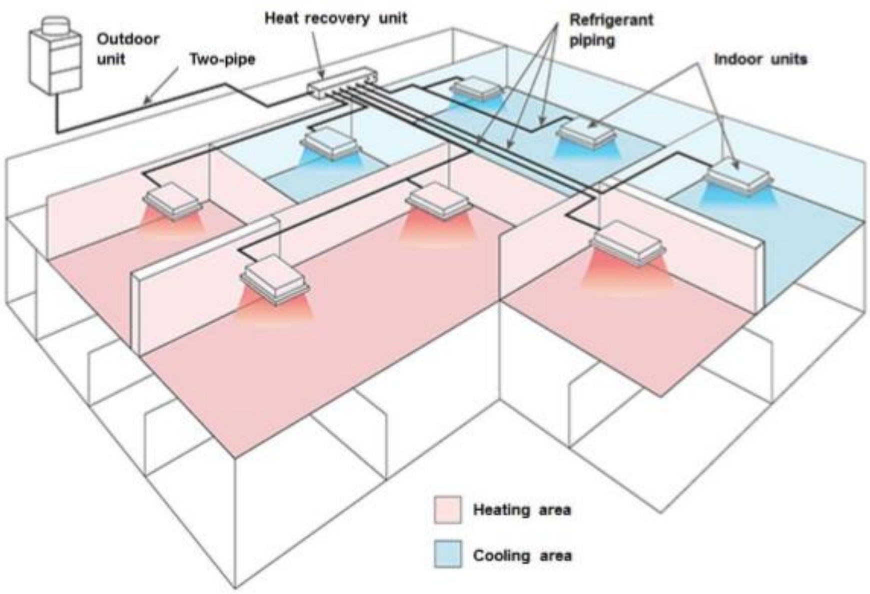


*Figure 5: Schematic diagram of a VRF system*

An additional, separate system for ventilation system is needed to serve the ventilation requirements of the spaces. Dedicated outdoor air system (DOAS) is one such ventilation system. Coupling VRF with DOAS systems typically seen in schools, which are a building type that require a large amount of ventilation air for classrooms. Coupling VRF with DOAS systems is key to optimal performance of the HVAC system, provided there is intelligent communication between the two systems (WAT_LinkedIn_2017).

*Reasons for using VRF:*
Benefits of using VRF technologies include: reduced energy consumption, quiet operation, precise temperature control, small footprint, and flexible installation (Schuetter and Hackel 2017).

The VRF system saves energy in four ways (Schuetter and Hackel 2017):

- Distribution of heating and cooling using refrigerant instead of air
- Variable speed compressors and fans
- Eliminating the reheating of air by providing only the needed heating and cooling
- Recovery of heat from cooling zones to heating zones in some systems

When considering energy savings, a study conducted on an office building in Madison, Wisconsin, the ground-source VRF system performed better than VAV (savings of $0.18/ft$^2$), WS VRF ($0.02/ft$^2$), and WSHP ($0.01/ft$^2$) (Hackel 2015).

Additional benefits include their small footprint particularly for retrofit applications with limited space for duct work. They require less area in new construction projects, feeing up leasable square footage (Schuetter and Hackel 2017). Their tight temperature control has a potential for increased occupant comfort (Schuetter and Hackel 2017).

*Applications:*
The simultaneous heating and cooling capabilities as well as the small footprint of VRF systems make these systems ideal candidates in building types such as educational facilities, office buildings, health care facilities and historic renovation projects.

*Operating VRFs in cold climates:*
Air source VRFs are typically not implemented in cold climates because they typically loose capacity and efficiency at low ambient temperatures. To overcome this disadvantage, VRF systems may be supplemented by an additional heat source or can be upgraded to water or ground source systems that are not subject to ambient temperatures.

When considering water source VRFs, coupling of the condensing units of the VRF with open loop ground water source heat pump avoids exposing the outdoor component (i.e., condenser) of the VRF equipment to cold outdoor air temperatures. Along with retaining efficiency of the VRF system, this approach addresses certain design challenges and maintenance issues associated with the implementation of VRF systems (Schuetter and Hackel 2017).

*Incorporating VRF specifications in energy codes:*
Prior to the release of ASHRAE Standard 90.1 2010, there were no efficiency requirements for VRF systems. The current version, ASHRAE Standard 90.1 2016 incorporates specifications of VRFs in various sections of the standard.

**Table 6.8.1-9 Electrically Operated Variable-Refrigerant-Flow Air Conditioners—Minimum *Efficiency* Requirements**

| *Equipment* Type | Size Category | Heating Section Type | Subcategory or Rating Condition | Minimum *Efficiency* | Test Procedure |
|---|---|---|---|---|---|
| *VRF* air conditioners, air cooled | <65,000 Btu/h | All | *VRF* multisplit *system* | 13.0 *SEER* | AHRI 1230 |
| | ≥65,000 Btu/h and <135,000 Btu/h | *Electric resistance* (or none) | *VRF* multisplit *system* | 11.2 *EER*<br>13.1 *IEER*<br>(before 1/1/2017)<br>15.5 *IEER*<br>(as of 1/1/2017) | |
| | ≥135,000 Btu/h and <240,000 Btu/h | *Electric resistance* (or none) | *VRF* multisplit *system* | 11.0 *EER*<br>12.9 *IEER*<br>(before 1/1/2017)<br>14.9 *IEER*<br>(as of 1/1/2017) | |
| | ≥240,000 Btu/h | *Electric resistance* (or none) | *VRF* multisplit *system* | 10.0 *EER*<br>11.6 *IEER*<br>(before 1/1/2017)<br>13.9 *IEER*<br>(as of 1/1/2017) | |

**Table 6.8.1-10 Electrically Operated Variable-Refrigerant-Flow and Applied Heat Pumps—Minimum *Efficiency* Requirements**

| *Equipment* Type | Size Category | Heating Section Type | Subcategory or Rating Condition | Minimum *Efficiency* | Test Procedure |
|---|---|---|---|---|---|
| *VRF* air cooled (cooling mode) | <65,000 Btu/h | All | *VRF* multisplit *system* | 13.0 *SEER* | AHRI 1230 |
| | ≥65,000 Btu/h and <135,000 Btu/h | *Electric resistance* (or none) | | 11.0 *EER*<br>12.9 *IEER*<br>(before 1/1/2017)<br>14.6 *IEER*<br>(as of 1/1/2017) | |
| | | | *VRF* multisplit *system* with heat recovery | 10.8 *EER*<br>12.7 *IEER*<br>(before 1/1/2017)<br>14.4 *IEER*<br>(as of 1/1/2017) | |
| | ≥135,000 Btu/h and <240,000 Btu/h | | *VRF* multisplit *system* | 10.6 *EER*<br>12.3 *IEER*<br>(before 1/1/2017)<br>13.9 *IEER*<br>(as of 1/1/2017) | |
| | | | *VRF* multisplit *system* with heat recovery | 10.4 *EER*<br>12.1 *IEER*<br>(before 1/1/2017)<br>13.7 *IEER*<br>(as of 1/1/2017) | |
| | ≥240,000 Btu/h | | *VRF* multisplit *system* | 9.5 *EER*<br>11.0 *IEER*<br>(before 1/1/2017)<br>12.7 *IEER*<br>(as of 1/1/2017) | |
| | | | *VRF* multisplit *system* with heat recovery | 9.3 *EER*<br>10.8 *IEER*<br>(before 1/1/2017)<br>12.5 *IEER*<br>(as of 1/1/2017) | |

*Figure 6: Excerpts from ASHRAE Standard 90.1 2016 efficiency requirements for VRF systems (Source: ASHRAE 2016b)*

Economizers are required by energy codes and standards, but VRF systems may be exempt in some codes and standards. Standards and codes typically have size thresholds, below which a unit does not need to meet the economizer requirements, and many VRF fan coils fall below those limits. Some jurisdictions treat the compressor unit capacity as the system capacity. In these cases, the system may qualify for an exception based on the compressor unit cooling efficiency exceeding the standard minimum efficiency requirement by a percentage or other measure. Washington state code allows a VRF exception for economizers when the VRF system has refrigerant heat recovery and includes a DOAS system with exhaust heat recovery. To meet local code in Seattle, Washington, energy modeling is required to prove the VRF system provides a net energy savings without an economizer.

*Challenges associated with O&M of VRF systems:*
VRF systems with their standardized configurations and sophisticated electronic controls are aiming toward near plug-and-play commissioning. Because they are DX systems, maintenance costs for a VRF should be lower than for water-cooled chillers, as water treatment issues are avoided. Normal maintenance for a VRF, similar to that of any DX system consists mainly of changing filters and cleaning coils. However, chillers which often operate for 20 to 30 years, normally would be anticipated to have a longer life expectancy than a DX system such as a VRF. The larger number of compressors in a VRF may create a higher probability of compressor failure, although the redundancy also leads, in many cases, to a greater ability to continue to occupy the space while the repairs are made (Goetzer, 2007).

During the installation process, the refrigerant piping skill of the contractor is critical because of the amount and complexity of the refrigerant piping involved. Although VRF does save energy, the first cost & installation costs of VRF systems typically generate longer payback periods. These higher costs are strongly related to the contractor's experience with system installation.

VRF may still be slightly more costly to maintain than a traditional rooftop VAV system due to the additional knowledge needed for some operational tasks (Hackel 2015)

Chilled beam system:

| | |
|---|---|
| Building Type | Ideal for buildings with high space sensible loads<br>Hospitals, Laboratories, Offices, Schools |
| Building Size | Small-size, Mid-size, Large-size |
| Code Readiness | Near Term |

*Definition:*

Active and passive beam systems are an energy efficient solution for spaces that require individual zone control and where the internal moisture loads are moderate. Active and passive beam systems provide good thermal comfort as well as energy and space saving advantages. The operation of the system is simple with low maintenance requirements. Although they are often referred to as 'Chilled Beams', in many cases active beams can be used for both heating and cooling the space.

Active and passive beams are room air recirculation devices that transfer sensible heat to and from the space using water. In addition, conditioned primary air is ducted to active beams. This primary air must satisfy the ventilation and latent requirements of the space and drive the induction of room air through the beams coil. In the case of passive beams, this primary air is delivered to the space through a decoupled ventilation system, Active and passive beams may be integrated with acoustic ceiling or independently mounted.

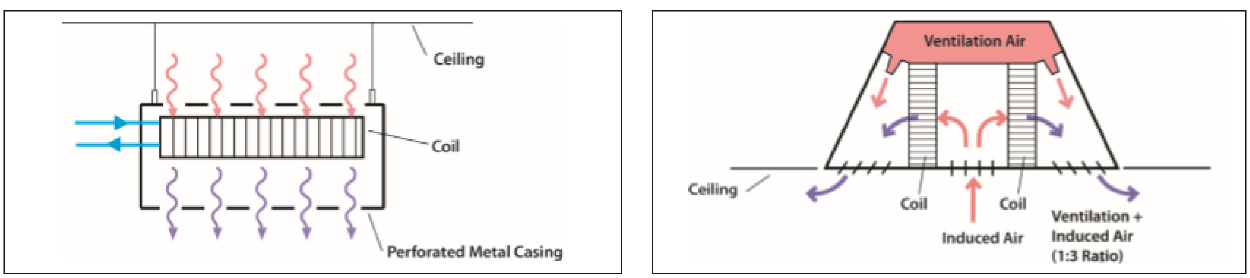


*Figure 7: Schematic diagram of passive chilled beams (left) and active chilled beams (right)*

*Reasons for using Chilled Beams:*

Benefits of using active and passive beam systems include: the use of higher chilled water temperatures, delivery of sensible cooling directly to space, reduction in ventilation energy, reduction in energy expended for reheating of cooled air (ROT_AJ_2007). In addition, the smaller infrastructure required for this reduced airflow allows for smaller plenum spaces and mechanical room footprints, translating into shorter floor-to-floor construction or higher ceilings and increased usable floor space. The reduced supply air volume and elimination of fans at or near the space offers a significant reduction in generated noise. The minimized air flow often translates to reheat requirements being reduced. (ASHRAE 2015)

*Applications:*
Active and passive beam systems have specific applications. As a result, each application must be reviewed for potential benefits as well as the suitability of these types of systems. One consideration that can assist in the use of hydronic systems as opposed to an all air system, is the air-side load fraction, or the percentage of the total air supply that must be delivered to the zone to satisfy the code and possible dehumidification requirements. The best applications for beam systems are those with the lowest air-side load fraction, because they are the ones that will benefit the most from the efficiencies of hydronic systems. Another factor that should be evaluated is the sensible heat ratio. To prevent latent removal by the hydronic system, the latent loads must be satisfied with an air system that will potentially offer some sensible cooling at the same time because of the temperature of dehumidified air. If the total sensible cooling load is significantly higher than the capacity of the air that would need to be supplied to satisfy the latent loads. A beam system is a good choice.

Ideal candidates for active and passive beam applications include commercial office buildings, schools, hospital patient rooms and laboratories. These building types are associated with sensible heat generated from equipment. Not recommended for buildings with high latent loads such as theatres, restaurants or health clubs (Roth 2007).

*Operating Chilled Beams in cold climates:*
To avoid condensation, both primary air and chilled water need to be at or above the space's dew point. In cold-dry climate such as Montana, these conditions can be easily met. In addition, as discussed in the previous section these systems can be highly effective in applications such as buildings with high sensible loads and more extreme climates where outdoor economizers are not effective (Stein and Taylor 2013). However, these systems have a tough competition from well-designed Variable Air Volume System with Reheat (VAVR) which have much lower energy costs and similar floor-to-floor heights. The added costs of piping and beams for Active Chilled Beam systems are simply too high and well-designed VAVRs are simply too efficient (Stein and Taylor 2013).

*Incorporating Chilled Beam specifications in energy codes:*
Patient rooms within health care facilities with few people and relatively large spaces represent another good application for chilled beams, because they have high prescriptive ventilation rates per code and low sensible loads. ANSI/AHSRAE/ASHE Standard 170-2013, Ventilation of Health Care Facilities, requires that a minimum of four total air changes per hour is supplied to the patient room (ASHRAE 2013). Two of those

air changes must be outside air. Recent revisions to the standard allow induced or recirculated air to count toward the non-outside-air changes, opening the door for chilled-beam technology and its ability to provide the necessary space cooling with just the two outdoor-air changes.

A VAV system in a patient room requires that at least four air changes be maintained, regardless of the cooling load. If the system throttles back in partial-load conditions and reaches the point where it is only bringing in four air changes, any additional drop in the cooling load means the HVAC system will continue to supply the same volume of air to the room. To prevent overcooling and the resulting patient discomfort, the air being supplied to the space for the four air changes must be reheated, expending additional energy to maintain the temperature in the space.

A chilled-beam system operating under the same conditions simply reduces water flow to the coil—or even shuts off the coil as the load decreases—and brings in only the two outdoor-air changes, using recirculated air for the other two required changes. Reheat is not necessary and fan energy is reduced. The result is a comfortable patient and substantial energy savings—energy associated with the water coil, the fan, and the absence of reheat.

*Challenges associated with O&M of Chilled Beam systems:*
One of the primary O&M challenges with the O&M of chilled beam systems is the need to address the issue of condensation. In most climates ventilation air and infiltration are the main sources of humidity. Hence, chilled beans need to work with DOAS and tight building envelope to mitigate potential condensation.

To avoid condensation on chilled beam surfaces, the air dew point temperature in each space must be maintained below the coldest surface temperature of the chilled beams. O&M staff must accurately and constantly monitor the indoor air dew points and chilled beam surface temperatures in each separate space. On a rise in room dew point temperature, swift action by O&M staff is needed to prevent condensation by quickly reducing the room dew-point temperature or warming the supply water temperature to the chilled beams. As such, design of a chilled beam system must include the ability of the O&M staff to be informed, under all operating conditions, that building pressurization is maintained (Bogarm and Setty 2011).

In addition, the design of a chilled beam system must specifically provide for ease of regular inspection and maintenance of valves, piping, insulation, terminal unit connections, and terminal heat transfer surface areas of the chilled beams. A chilled beam design must also include concise maintenance procedures, and inspection schedules.

Transpired solar collector:

| | |
|---|---|
| Building Type | Ideal for buildings with high outdoor air requirements<br>Restaurants, Offices, Schools |
| Building Size | Small-size, Mid-size, Large-size |
| Code Readiness | Mid Term |

*Definition:*

The concept of a transpired solar collector was developed by scientists at the National Renewable Energy Lab (NREL 1998) and engineers at Conserval in the late 1980's. Through funding from the Department of Energy, transpired solar collectors were brought to the market in 1992, and more than 35 systems have been installed since. In short, a transpired solar collector is a simple, passive system to preheat outdoor air. A dark colored perforated metal skin is installed offset on a south facing exposure, creating a plenum in which air moves slowly, gaining heat that the metal absorbs from the sun at nearly 80% efficiency (NREL 1998). An intake duct connects the solar collector to the air handling system of the building. Oftentimes solar walls are paired with economizers to maximize outdoor air intake.

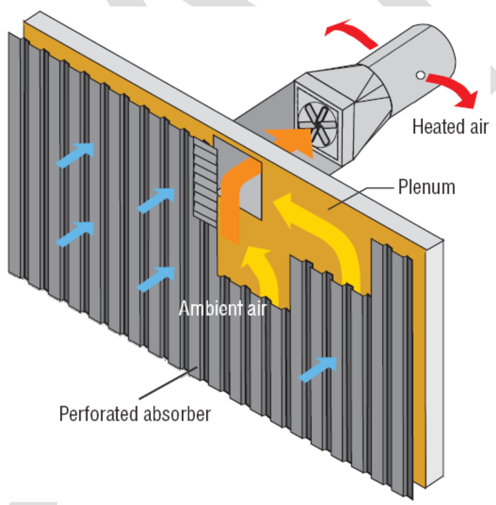


*Figure 8: Schematic diagram of Transpired Solar Collector*

*Reasons for using Transpired Solar Collectors:*

Benefits of transpired solar collectors are numerous. For new construction, the installed cost per square foot is only $6, which results in a very short payback period of 3-12 years (NREL 1998). For reference, a brick façade can cost up to $\$15/\text{ft}^2$. Because of their simple design, they are reliable and require little maintenance, and boast an estimated life span of 30 years (NREL 1998). Favorable conditions can result in up to a 40°F air temperature gain, which significantly decreases the energy required to heat outdoor air and results in significant savings. Due to these savings, there is a potential for increased ventilation air and reduced pollutants, which was proven to be beneficial to cognitive function by a Harvard study published in 2015 (Datz 2015).

*Applications:*
Solar walls are most beneficial for commercial, industrial, or educational buildings which require large amounts of outdoor air. Additionally, solar walls are most useful in climates with large amounts of solar radiation and long heating seasons. Several notable buildings on which they have been installed include the FedEx Company building in Littleton, CO, the Toyota Motor Manufacturing plant in Valenciennes, France, and NREL's Research Support Facility, which boasts a LEED Platinum rating.

Transpired solar collectors use common-wall construction with building material as the solar heat absorber. This makes installation simple and substantially reduces material costs for insulation. In addition, because this system does not use glazing, which reduces the amount of sunlight absorbed by flat-plate collectors, transpired solar collectors are more efficient (NREL 2006).However, because it does increase the temperature of outdoor air, it is not compatible with most classic energy recovery systems, as it limits their heat transfer efficiency.

*Operation in cold climate:*
Solar Collectors are an ideal technology for cold climates, due to the high number of heating days per year. Simply put, as long as there is sunlight, a solar wall will preheat outside air, and decrease the amount of mechanical heating needed. Because it is a passive system, no additional maintenance or challenges arise from location in a cold climate.

*Incorporating Transpired Solar Collector specifications in energy codes:*
According to WBDG (WBDG 2018), there are various local and national codes and standards for ventilated air systems. Ventilation rates are often established according to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 62. National electric code has requirements such as grounding for electrical components (fan and controls), International Building Code, and American Society of Civil Engineers standards regarding the building facade (such as wind loading). The Uniform Building Code regarding ductwork also contains standards applicable to common solar ventilation preheat installations. In addition, a professional engineer's stamp is recommended for wall structural attachment, ventilation system design, and electrical design. ASHRAE Standard 90.1-2016 does make references to Transpired Solar Collectors in Section 6.5.6.1 and 6.5.6.2.2, where outdoor air heating being provided site solar energy can be considered as an exception to certain requirements for economizer operation and capacities mandated by the standard ASHRAE 2016b).

*O&M challenges:*

As it is a passive technology, the solar wall itself presents few issues in operation and maintenance (EERE 1998). Except for servicing of air distribution units the system requires minimum maintenance as the collector in itself does not have any moving parts (EERE 1998, WBDG 2018). Most commercial solar walls have projected lifetimes of 30 years.

## Heat Pump Water Heaters:

| | |
|---|---|
| Building Type | Ideal for buildings with large hot water requirements<br>Restaurants, Hotels, Apartments, Healthcare |
| Building Size | Small-size, Mid-size, Large-size |
| Code Readiness | Near Term |

*Definition:*
Air-source heat pump water heaters utilize a vapor-compression cycle to extract energy from an air, ground or water source to heat water (ASHRAE 2015). Therefore, these type of water heaters can be three to four times more efficient than conventional electric resistance water heaters (DOE ND). During periods of high hot water demand, HPWHs switch to standard electric resistance heat (hence they are often referred to as “hybrid” hot water heaters) automatically (Energy Star ND).

HPWHs may be designed as a single package with the refrigeration and storage water storage tank as part of a single system, or as a refrigeration system alone refrigeration ‘add-on’ system which is connected separately to the storage water tank (ASHRAE 2015). Most HPWHs can generate HW temperature up to 140° F, with some models capable of higher outlet temperature of up to 180° F.

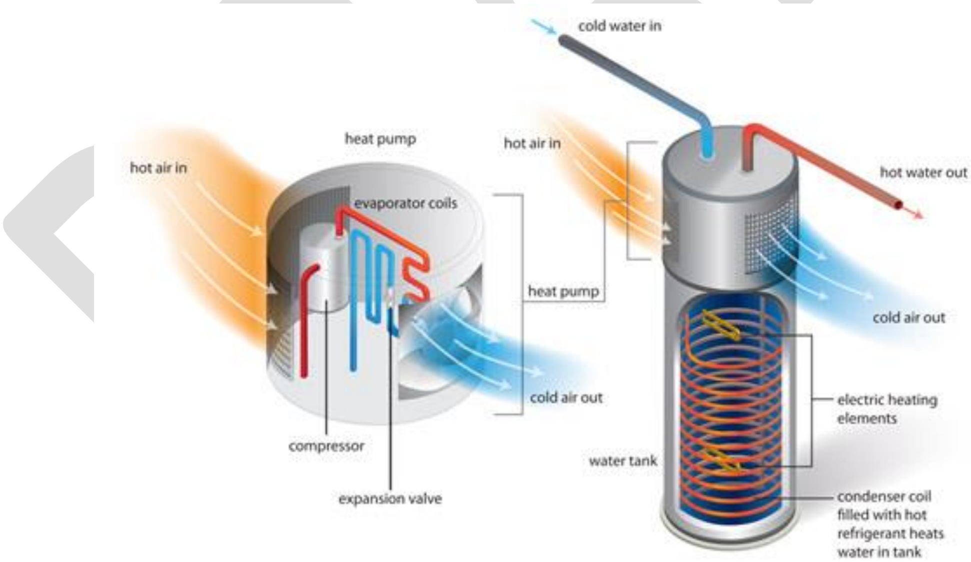


*Figure 9: Schematic diagram of a Heat Pump Water Heater (Source: DOE ND)*

*Reasons for using Heat Pump Water Heaters:*
Heat Pump Water Heaters are two to three time more efficient than conventional electric water heaters (Emerging Technologies 2018). These efficiencies can be higher with advanced technologies which include:

- Advanced variable speed compressors,
- Removing the heat pump function from conditioned space, and
- Carbon dioxide refrigerants.

*Applications:*
HPWH requires additional storage tank capacity because they have lower recovery rates than conventional water heaters (ASHRAE 2015) and thus should not be used in facilities with limited space. In the process of absorbing heat from the surrounding environment, the HPWH provides a cooling and a dehumidifying effect making them ideal for hot and humid conditions (ASHRAE 2015).

While primarily targeting residential markets, this technology can also be used in commercial applications that generate substantial waste heat and have a high hot water demand. In addition, operations with a high cooling demand could benefit from HPWHs because they capture ambient heat (Emerging Technologies 2018). Commercial kitchens, laundry facilities, hospitals, nursing homes and health clubs have simultaneous water heating and cooling needs, they are excellent applications for heat pump water heaters (Johnson and Shedd, 1992).

*Operation in cold climate:*
Heat pump water heaters have been effectively used in a variety of climates and facilities. However, since heat is extracted from the environment to heat water, these heaters work best in warm climates and can be challenging to use in cold climates. Heat pump water heaters require to be installed in locations where ambient temperatures are in the range of 40 – 90 F and require at least 1000 ft3 of air space around the water heater.

According to EPA Energy Star program (Energy Star ND), two issues related to HPWHs need to be considered when operating in colder climates:

- If placed in conditioned space, HPWHs will produce cool and dry air that is a benefit in the summer months but will lead to higher heating bills in the winter months.
- When operating in heat pump mode, HPWHs do not heat water as quickly as conventional electric resistance water heaters, particularly when recovering after a significant draw. Consequently, to maintain performance, HPWHs may switch to a less efficient electric resistance heating mode. During these times of recovery, colder ambient air and incoming water will lead to switching to a less efficient electric-resistance mode more often.

Given these issues, EPA recommends the following for colder climates:

- Avoid placing HPWHs in conditioned space if possible. If you must place the unit in conditioned space, do not install it near a thermostat or living spaces sensitive to colder temperatures.
- Avoid placing HPWHs in garages 4 or outdoors where the temperature can be consistently in the freezing range.
- Install HPWHs in unconditioned or semi-conditioned interior spaces, such as a basement, where temperatures remain above 50 degrees F most of the year. An ideal situation would be near a furnace in a basement that is relatively warm all winter.
- Consider HPWHs that meet Northern Climate Efficiency Specification developed by the Northwest Energy Efficiency Alliance (NEEA). NEEA has identified HPWHs that are efficient in colder climates by using a test procedure that uses lower temperature ambient air and inlet water to reflect conditions in colder climates. A prerequisite to qualify for the Northern Climate HPWH Specification is that the units must be ENERGY STAR certified. These HPWH units generally have larger compressors that cut off at lower temperatures to work more efficiently in colder climates.

*Incorporating Heat Pump Water Heater specifications in energy codes:*
ASHRAE Standard 90.1 2016 incorporates specifications of Heat Pump Water Heaters in the section on service water heating equipment in the standard.

*O&M challenges:*
Similar to air-source heat pumps, routine maintenance procedures and checks such as: cleaning of air filter, drain pans, evaporative coils, and checking temperature pressure relief valves, have to be performed for HPWHs. O&M challenges include effective management of condensate, maintenance of an adequate set point temperature, and maintenance of air filters to ensure operation of unit at optimum efficiency (Shapiro et al., 2012).

**Table 7.8 Performance Requirements for Water-Heating *Equipment*—Minimum *Efficiency* Requirements**

| *Equipment* Type | Size Category (Input) | Subcategory or Rating Condition | Performance Required [a] | Test Procedure[b,c] |
|---|---|---|---|---|
| Electric table-top water heaters | ≤12 *kW* | Resistance ≥20 gal | See footnote (g). | |
| Electric *water heaters* | ≤12 *kW*[e] | Resistance ≥20 gal | See footnote (g). | |
| | >12 *kW*[e] | Resistance ≥20 gal | $0.3 + 27/V_m$ %/h | Section G.2 of ANSI Z21.10.3 |
| | ≤24 Amps and ≤250 Volts | Heat pump | See footnote (g). | |
| Gas storage *water heaters* | ≤75,000 Btu/h | ≥20 gal | See footnote (g). | |
| | >75,000 Btu/h[f] | <4000 (Btu/h)/gal | 80% $E_t$ $(Q/800 + 110\sqrt{V})$ SL, Btu/h | Sections G.1 and G.2 of ANSI Z21.10.3 |
| Gas instantaneous *water heaters* | >50,000 Btu/h and <200,000 Btu/h | ≥4000 (Btu/h)/gal and <2 gal | See footnote (g). | |
| | ≥200,000 Btu/h[d,f] | ≥4000 (Btu/h)/gal and <10 gal | 80% $E_t$ | Sections G.1 and G.2 of ANSI Z21.10.3 |
| | ≥200,000 Btu/h[f] | ≥4000 (Btu/h)/gal and ≥10 gal | 80% $E_t$ $(Q/800 + 110\sqrt{V})$ SL, Btu/h | |
| Oil storage *water heaters* | ≤105,000 Btu/h | ≥20 gal | See footnote (g). | |
| | >105,000 Btu/h | <4000 (Btu/h)/gal | 80% $E_t$ $(Q/800 + 110\sqrt{V})$ SL, Btu/h | Sections G.1 and G.2 of ANSI Z21.10.3 |
| Oil instantaneous *water heaters* | ≤210,000 Btu/h | ≥4000 (Btu/h)/gal and <2 gal | See footnote (g). | |
| | >210,000 Btu/h | ≥4000 (Btu/h)/gal and <10 gal | 80% $E_t$ | Sections G.1 and G.2 of ANSI Z21.10.3 |
| | >210,000 Btu/h | ≥4000 (Btu/h)/gal and ≥10 gal | 78% $E_t$ $(Q/800 + 110\sqrt{V})$ SL, Btu/h | |
| Hot-water supply *boilers*, gas and oil[f] | ≥300,000 Btu/h and <12,500,000 Btu/h | ≥4000 (Btu/h)/gal and <10 gal | 80% $E_t$ | Sections G.1 and G.2 of ANSI Z21.10.3 |
| Hot-water supply *boilers*, gas[f] | | ≥4000 (Btu/h)/gal and ≥10 gal | 80% $E_t$ $(Q/800 + 110\sqrt{V})$ SL, Btu/h | Sections G.1 and G.2 of ANSI Z21.10.3 |
| Hot-water supply *boilers*, oil | | ≥4000 (Btu/h)/gal and ≥10 gal | 78% $E_t$ $(Q/800 + 110\sqrt{V})$ SL, Btu/h | Sections G.1 and G.2 of ANSI Z21.10.3 |
| *Pool* heaters, oil and gas | All | | See footnote (g). | ASHRAE 146 |
| Heat pump *pool* heaters | All | 50°F db 44.2°F wb *Outdoor air* 80.0°F entering water | 4.0 *COP* | AHRI 1160 |
| Unfired storage tanks | All | | R-12.5 | (none) |

*Figure 10: Excerpts from ASHRAE Standard 90.1 2016 efficiency requirements for Heat Pump Water Heater (Source: ASHRAE 2016b)*

Open loop geothermal heat pumps:

| | |
|---|---|
| Building Type | Not ideal for buildings with large heating and cooling loads<br>Offices, Retail, Schools |
| Building Size | Small-size, Mid-size |
| Code Readiness | Near Term |

*Definition:*

Ground temperatures tend to be stable below 30-50 feet below the surface. In Montana, this temperature is around 55 degrees Fahrenheit. As a result, there is almost always a temperature difference between the ground and the air. Ground source heat pump (GSHP) systems exploit this natural differential for heating and cooling purposes.

In an open loop system, groundwater is pumped into the system at ground temperature and passed through a heat pump. If the building system requires cooling, heat is rejected into the groundwater from system hydronics, and vice versa. The heated or cooled water is then re-injected into the ground or discharged at the surface.

Typically in commercial buildings, the building loop is isolated from the exposure to ground water by means of an isolation heat exchanger. This strategy eliminates dealing with issues pertaining to water quality within the building. However, variations to this configurations exist in smaller buildings where it is possible to circulate ground water through each heat pump at the risk of corrosion and fouling of heat exchangers (Kavanaugh and Rafferty 2014). In yet another variation, the ground water is circulated through a central chiller. The building is then heated or cooled with conventional chilled water and hot water distribution system (Kavanaugh and Rafferty 2014).

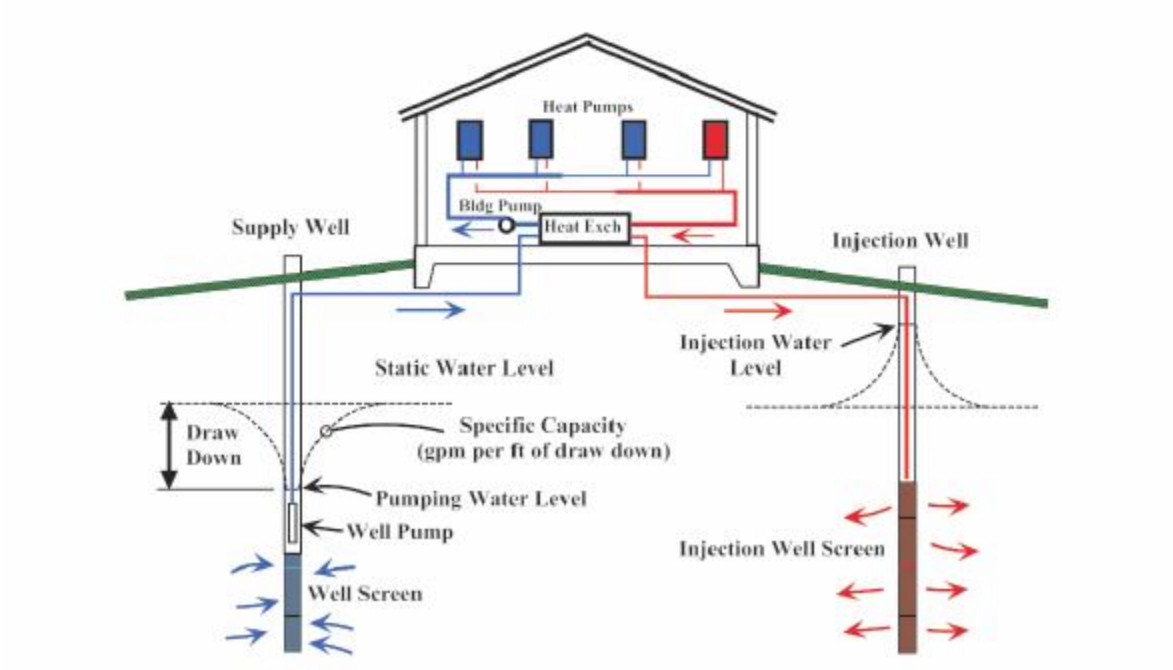


*Figure 11: Schematic diagram of an open loop ground source heat pump with isolation heat exchanger (Source: Kavanaugh and Rafferty 2014)*

*Reasons for using Open Loop Ground Source Heat Pumps:*
There are several reasons for using GSHP systems. These include (Orio 1999):

- Low operational cost
- Environmental benefits
- System efficiency
- Compactness
- Mature technology

The low operational costs are due mainly to relatively low fuel usage, as none is used other than for operating the system's pumps. As such, owners experience large energy savings and environmental benefits. Though open loop GSHP systems tend to be less expensive than their closed loop counterparts especially for larger systems, they still have a higher first cost than air-source heat pumps or comparable systems. The payback in energy savings is most often realized in 5-10 years, and average life varies from 25-50+ years (EERE ND).

Another advantage is system efficiency. Because of the large amount of thermal mass in the earth, the addition and removal of heat on this scale does not affect the temperature of the ground. A consistent source temperature means more consistent levels of operation as compared to air source systems, where the source temperature is much more variable.

Finally, the water wells associated with the open-loop GSHPs are compact, water well contractors are widely available, and the technology has been around for decades (Kavanaugh and Rafferty 2014).

*Applications:*
All types of GSHP systems can be tailored to fit residential, commercial, and industrial applications. Open loop systems, however, rely on the presence of a large, accessible aquifer or other water source. They also require an appropriate location to discharge the water they bring in, and this often poses small environmental issues.

*Operation in cold climate:*
Because there are a significant number of heating degree days in cold climates, a well temperature of 55 degrees is quite beneficial. The relatively high source temperature allows for significantly less mechanical input to heat air to acceptable levels, resulting in energy savings over a significant portion of the year. Because the ground is very insulated, there are little operational or maintenance issues that arise from location in a cold climate.

Open-loop GSHPs can be used for direct cooling or pre-cooling especially in colder climates such as Montana. With low-temperature ground water being circulated in the building in parallel to the heat pumps, cooling loads can be effectively addressed.

*Incorporating Heat Pump Water Heater specifications in energy codes:*
ASHRAE Standard 90.1 2016 incorporates efficiency requirements for open loop GSHPs in Table 6.8.1-15 & Table 6.8.1-16 for electrically operated DX-DOAS units; Table 6.8.1-2 for electrically operated unitary heat pumps in the standard; and Table 6.8.1-10 for electrically operated VRF and applied heat pumps.

*O&M challenges:*
A properly designed open loop GSHP requires much more maintenance than the corresponding closed-loop GSHPs. Open loop heat pumps are constantly bringing in source water. As such, there is increased well pump usage, especially if the pump is oversized or poorly controlled, resulting in more frequent replacements as opposed to a closed loop system. A major consideration of implementing an open loop GSHP system is the quality of the groundwater, as it could have major effects in the system, such as rapid fouling due to calcification, for example on the heat exchangers. In addition, water levels of injection wells need to be regularly monitored and pump capacities adjusted to meet the varying capacity of the well.

Another important consideration is the design of the discharge water. If budgets allow, injecting this water back into the ground is ideal. However, if that is not an option, discharging at the surface is possible under very controlled conditions.

**Table 6.8.1-2 Electrically Operated Unitary and Applied Heat Pumps—Minimum *Efficiency* Requirements *(Continued)***

| *Equipment* Type | Size Category | Heating Section Type | Subcategory or Rating Condition | Minimum *Efficiency* | Test Procedure[a] |
|---|---|---|---|---|---|
| Air cooled (heating mode) | ≥65,000 Btu/*hc* and <135,000 Btu/h (cooling capacity) | | 47°F db/43°F wb *outdoor air* | 3.3 $COP_H$ | AHRI 340/360 |
| | | | 17°F db/15°F wb *outdoor air* | 2.25 $COP_H$ | |
| | ≥135,000 Btu/*hc* (cooling capacity) | | 47°F db/43°F wb *outdoor air* | 3.2 $COP_H$ | |
| | | | 17°F db/15°F wb *outdoor air* | 2.05 $COP_H$ | |
| Water to air, water loop (heating mode) | <135,000 Btu/h (cooling capacity) | | 68°F entering water | 4.3 $COP_H$ | ISO 13256-1 |
| Water to air, groundwater (heating mode) | <135,000 Btu/h (cooling capacity) | | 50°F entering water | 3.7 $COP_H$ | ISO 13256-1 |
| Brine to air, ground loop (heating mode) | <135,000 Btu/h (cooling capacity) | | 32°F entering fluid | 3.2 $COP_H$ | ISO 13256-1 |
| Water to water, water loop (heating mode) | <135,000 Btu/h (cooling capacity) | | 68°F entering water | 3.7 $COP_H$ | ISO 13256-2 |
| Water to water, groundwater (heating mode) | <135,000 Btu/h (cooling capacity) | | 50°F entering water | 3.1 $COP_H$ | ISO 13256-2 |
| Brine to water, ground loop (heating mode) | <135,000 Btu/h (cooling capacity) | | 32°F entering fluid | 2.5 $COP_H$ | ISO 13256-2 |

a. Section 12 contains a complete specification of the referenced test procedure, including the referenced year version of the test procedure.
b. Single-phase, air-cooled heat pumps <65,000 Btu/h are regulated by the U.S. Department of Energy Code of Federal Regulations 10 CFR 430. *SEER* and *HSPF* values for single-phase products are set by the U.S. Department of Energy.
***Informative Note:*** See Informative Appendix F for the U.S. Department of Energy minimum.

*Figure 12: Excerpts from ASHRAE Standard 90.1 2016 efficiency requirements for open loop GSHP systems for electrically operated unitary and applied heat pumps (Source: ASHRAE 2016b)*

Closed-loop geothermal heat pumps:

| | |
|---|---|
| Building Type | Not ideal for buildings with large heating and cooling loads<br>Offices, Retail, Schools |
| Building Size | Small-size, Mid-size |
| Code Readiness | Near Term |

*Definition:*

Closed-loop GSHPs consist of a network of heat pumps that are linked to a closed heat exchanger that is buried in the ground. The temperature of the ground is fairly constant though out the year, which makes it an efficient heat source or sink. The loops typically are constructed from high-density polyethylene (HDPE) material and filled with either pure water or antifreeze solutions. The configuration of the closed-loop heat exchanger can be in form of vertical bore holes or horizontal configurations, with vertical bore heat exchangers being the most common (Kavanaugh and Rafferty 2014).

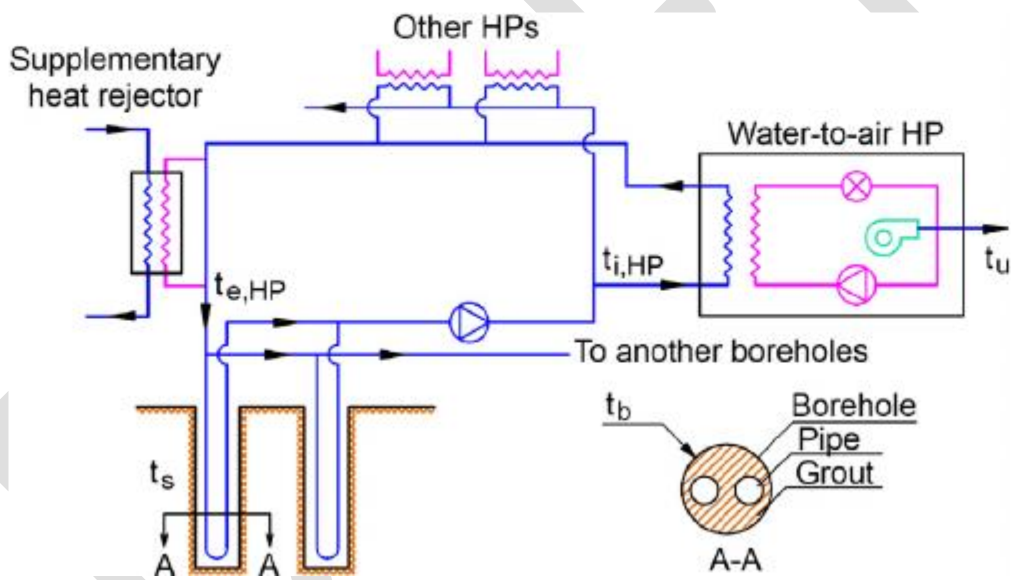


*Figure 13: Schematic diagram of a closed- loop GSHP with vertical bore ground heat exchanger (Source: Sarbu and Sebarchievici 2013)*

*Reasons for using Open Loop Ground Source Heat Pumps:*

The reasons for using closed-loop GSHPs are similar to that of open-loop GSHPs and include:

- Low operational cost
- Environmental benefits
- System efficiency
- Mature technology

Research reports that closed-loop GSHPs have the potential to reduce cooling energy by 30 – 50% and reduce heating energy by 20 – 40%. (Philappacoupoulus and Berndt 2001).

Advantages of implementing vertical bore heat exchangers is that they require relatively smaller plots of ground, and are in contact with soil of constant temperature, and require smallest amount of pipe and pumping energy while disadvantages would include higher installation costs (Kavanaugh and Rafferty 2014). When considering

*Applications:*
All types of GSHP systems can be tailored to fit residential, commercial, and industrial applications. Closed-loop systems are cost-effective in scenarios which include: new construction; climates characterized by high daily temperature swings and where winters are cold and summers are hot; in areas where electricity costs are higher than average and in areas where natural gas costs are higher than the cost of electricity (Sarbu and Sebarchievici 2013).

*Operation in cold climate:*
When operating in cold climates, closed-loop GSHPs may be subjected deteriorating efficiency and performance due to soil thermal imbalance (You et al., 2016). This imbalance is caused by conditions in which more heat is being extracted from the soil than is being injected into it. Hence it becomes important to address the thermal imbalance of the soil to ensure optimum performance of closed-loop GSHP. Solutions to address this issue include (You et al., 2016):

- Modifications to the ground heat exchanger such as increasing borehole space, length and depth, increasing the water content or conductivity of the soil and backfill.
- Modifications to the system such as integrating with natural gas heating, solar thermal, waste heat and heat recovery strategies.
- Modifications to the operation practices such as taking advantage of auxiliary energy in hybrid GSHP systems and implementing suitable intermittent operational strategies to increase downtime for the system.

*Incorporating Heat Pump Water Heater specifications in energy codes:*
ASHRAE Standard 90.1 2016 incorporates efficiency requirements for closed-loop GSHPs in Table 6.8.1-15 & Table 6.8.1-16 for electrically operated DX-DOAS units; Table 6.8.1-2 for electrically operated unitary heat pumps in the standard; and Table 6.8.1-10 for electrically operated VRF and applied heat pumps.

*O&M challenges:*

One of the benefits of closed-loop GSHPs is the low maintenance levels. The closed-loop GSHP system has very few components. The heat pumps are closed, packaged units that are located indoors. In addition, closed-loop GSHPs do not have a defrost cycle eliminating the components required for this function from the systems configuration. (Kavanaugh 1992). Regular maintenance regimens for circulation pump and ground loop are some of the typical maintenance procedures that need to be implemented to ensure proper system operation.

Radiant heating & cooling:

| | |
|---|---|
| Building Type | Ideal for buildings with high space sensible loads<br>Apartments, Schools, Offices |
| Building Size | Small-size, Mid-size, Large-size |
| Code Readiness | Near Term |

*Definition:*

When considering energy efficient alternatives to conventional all-air systems, radiant heating and cooling systems figure prominently. These systems actively provide heating and cooling by radiant transfer of heat from the hydronic element to the surrounding surfaces. Most radiant systems are actually hybrid systems with the air-side component designed to meet the ventilation loads in space as well as to satisfy latent loads, the water-side component is designed to primarily meet the sensible heating and cooling loads. (Price 2011).

Use of radiant systems is associated with energy efficiency and improved thermal comfort. Studies have indicated that radiant heating systems can achieve the same level of thermal comfort at lower temperatures and radiant cooling systems can achieve the same levels of thermal comfort at higher temperatures (Rhee et al. 2017, Karmann et al., 2017). In addition, since the radiant systems do not rely on forcing conditioned air into space, issues such as cold air draughts are mitigated thus improving thermal comfort (Rhee et al. 2017). Finally, characteristics of radiant heating systems which include small temperature fluctuations and vertical temperature gradients reduce the risk of draught and local discomfort.

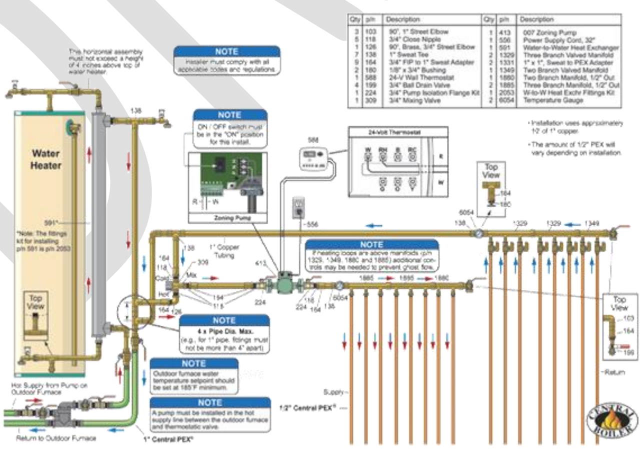


*Figure 14: Schematic diagram of a radiant heating panel configuration (Source: Dasmu.us)*

*Reasons for using Open Loop Ground Source Heat Pumps:*
Radiant systems are advantageous over other systems in spaces where a high priority is given to thermal comfort, areas with high sensible design, and energy conservation is desired (Price 2011). Advantages of radiant systems over other mechanical include: energy and system efficiency, reduced system horsepower, improved indoor environmental quality, reduced mechanical footprint and improved system hygiene.

Applications:
Hydronic systems have been successfully used in several applications which have very different characteristics. Applications include: hospitals, schools, data centers, offices, airports, cafeterias, and theaters.

*Operation in cold climate:*
There are no special consideration for radiant heating and cooling systems operating in cold climates.

*Incorporating radiant heating and cooling specifications in energy codes:*
ASHRAE Standard 90.1 2016 incorporates certain requirements for floor insulation when incorporating radiant heating (Refer to Section 6.4.4.1.5). Efficiencies for boilers are provided in Tables 6.8.1-6.

*O&M challenges:*
One of the benefits of implementing radiant systems is the elimination of several pieces of HVAC equipment including terminal units, fan coil filters or motors, all of which are high maintenance entities. Regular maintenance includes simple cleaning of the product at regular intervals. With the elimination of filters, ducts and drain pans, there is a reduced risk of mold or bacteria growth in the entire mechanical system.

When compared to conventional systems the operation of radiant heating and cooling warrant certain fundamental differences, which requires appropriate training of facilities staff. Longer system response time to change in zone set point temperature associated with these systems is because of the mass of heating/cooling water that needs to be brought up to desired temperatures. Radiant cooling systems need to be well coordinated with night setback modes, which are typical during unoccupied time periods in certain climates. The implementation of this mode causes humidity to rise past acceptable limits of the chilled water system and contributes to mold growth. In addition, high dewpoint in space causes the radiant system to shut down, which in turn causes temperatures in the space to rise. This situation can be avoided by coordinating the operation of radiant cooling system with the outdoor air ventilation system.

***Step 3b: Emerging Technologies***

In a report sponsored by the Department of Energy's Building Technology Office (BTO) a roadmap was developed to identify the research and development initiatives for high efficiency HVAC technologies (Goetzler et. al., 2014). Two of the emerging technologies: the cold climate heat pumps (CCHP) and seasonal thermal energy storage (STES) were selected for their energy saving potential in cold climates such as Montana.

<u>Cold Climate Heat Pumps (CCHP)</u>

In conventional scenarios, vapor-compression heat pumps have had limited use in colder climates due to decreasing heating capacity and COP as outdoor temperatures decrease. This deterioration in performance is because of the increased temperature lift across the compressor in the heat pump. Furthermore, in conventional heat pumps during low-temperature operation, back-up electric resistance heating is typically used to compensate for this performance drop in turn decreasing the efficiency of the heat pump. However, in recent years, manufacturers have designed electrically-driven HPs for cold-climate operation through the use of multi-stage, variable-speed, or booster compressors, advanced refrigerant management, improved defrost control, alternative refrigerants, and other features. Additionally, HPs using absorption and other thermally activated cycles can achieve higher efficiencies in low temperature operation than conventional fuel-fired furnaces and boilers.

The BTO report compiled a list of technical challenges that were currently faced by CCHP technology. These included issues such as: limited past success, where previous CCHP designs did not perform well; Practice of sizing equipment for cooling rather than heating even in colder regions; Low supply air temperature provided by heat pumps when compared to gas-fired products; and Natural gas as a lower cost heating fuel when compared to electricity. In order to bring the CCHP technology to market, the BTO has launched several initiatives to address the market barriers. These include, incorporating advanced compressor designs, defrost techniques, and other features to improve efficiency and capacity; conducting field demonstrations throughout heating dominated climates to verify performance. One such project includes the field testing of prototype cold climate heat pump (CCHP) using on tandem vapor injection (VI) compressors coupled with an inter stage flash tank (Shen et al. 2017). The project monitored the performance of a CCHP in Fairbanks Alaska under extreme cold conditions typical of the latitude. The study concluded that the prototype CCHP successfully operated at temperatures up to -30 F, the CCHP delivered 75% heat pump capacity relative to the capacity at rated conditions, and the heat pump COP was 1.8.

Seasonal Thermal Energy Storage (STES)

In yet another emerging technology for cold climates, the potential for residential and light-commercial seasonal thermal energy storage (STES) systems to effectively utilize renewable heating energy in U.S. market and support the development of lower cost, more standardized systems is explored.

In cold climates, building operators can use the seasonally available solar thermal energy for HVAC applications through STES. These systems collect the low-cost thermal energy in the summer and store it for use in the winter, offsetting a portion of the space and water heating energy use. System designers have used several STES variations including: highly insulated water tanks, open-loop aquifer systems, or closed-loop borehole systems where a GHP operates more efficiently as the increased soil temperature lowers the required temperature lift during the heating season.

While more popular in Europe, Canada, and other areas, STES has not achieved wide usage in the U.S. due to high first cost, the availability of low-cost natural gas, system complexity, unfamiliarity of designers, size/space considerations, etc. Additionally, borehole systems that would heat the ground in the summer would reduce the cooling efficiency of GHPs. Nevertheless, STES has significant potential both energy savings and greater integration of renewable resources for heating-dominated climates.

The BTO report compiled a list of technical challenges that were currently faced by STES technology. These included issues such as site-specific project designs where each project requires a unique engineering design to account for the available storage area, required space and water heating load, available solar or geothermal resources, distribution system and other considerations; uncertain cost and payback projections because of complex project design and unavailability of quick estimating tools; limited designer and contractor experience; and customer preferences for furnaces which add complexity on integrating air-side distribution systems with thermal storage systems.

In order to bring the STES technology to market, the BTO has launched several initiatives to address the market barriers. These include: examining case studies and projects in Canada, Europe and Japan to provide energy consumption and economic data to develop more detailed estimates for the U.S; compile best practices from other countries; develop standardized storage mechanisms, controls and system designs for less costly installations. A report on state of the art seasonal thermal energy storage published by International Energy Agency as part of Solar Heating and cooling program (IEA SHC Task 45) presents an overview of the state of the art seasonal thermal energy storage to summarize the further necessary research and demonstration work (Mangold and Deschaintre 2015).

### *Step 4: Survey Results*

A number of experts active in the field of HVAC system design were consulted to assess the selected HVAC technologies[1]. A list of the experts consulted is presented in Table 5. The criteria prepared by NEEA that has been outlined in the section on 'Process of Evaluating Advanced Design and Construction Practices' in this report (See Table 1 and Table 2) was used to conduct the evaluation. A sample screen of the survey is presented in Appendix E of this report.

**Table 5: List of Subject Matter Experts consulted in the first round of survey**

| Name | Affiliation |
| --- | --- |
| Kevin Amende | Associate Professor,<br>Dept. Mechanical & Industrial Engineering MSU |
| Costa Kapsis | Innovation and Energy Technology Sector CANMET Energy |
| Kyle MacVean | Harvest Solar |
| Andrew Moore | Lighting Engineer, CTA |
| Loras O'Toole | University Engineer, MSU |
| Alex Russel | Mechanical Engineer, CTA |
| Curt Smit | Consulting Design Solutions, Inc. |

For emerging HVAC technologies, the information presented in the report 'Research & Development Roadmap for Emerging HVAC Technologies' prepared by Navigant Consulting for DOE Building Technologies Office was referenced (Goetzler et al., 2014).

When considering energy saving opportunities, cost effectiveness, and measurability:

- Closed-loop GSHPs, open-loop GSHPs and VRF technologies provided medium to high energy savings. Implementation of these technologies proved to be marginally cost effective. Savings from implementing these technologies were readily quantifiable. GSHP technologies are characterized with minimal maintenance. On the other hand, VRF technologies require substantial involvement from the O&M staff.
- CB, TSC and RHC technologies provided low to medium energy saving potential. Implementation of these technologies proved to be marginally cost effective. Savings from implementing these technologies were quantifiable but with detailed measurement and evaluation.

[1] Given the existing small sample size of the survey, the results should not be considered indicative of the trends in technology adoption practices for Montana.

- HPWH and CCHP technologies provided low energy saving opportunities in Montana climates. STES works well in cold climates such as Montana due to its seasonal energy storage capabilities. Since CCHP and STES are emerging technologies, the savings from implementing these technologies currently cannot not measured. On the other hand, savings for HPWH are quantifiable. When considering cost effectiveness CCHP has high cost / saving ratio, while HPWH technology has marginal cost effectiveness. STES has high installation costs, but low payback period.

When considering market appropriateness in terms of the technologies being defined and available, market ready and market friendly:

- VRF, HPWH, and DOAS technologies have high degrees of market uptake and are currently available from numerous manufacturers. The heat-pump equipment component of the GSHPs too are available from numerous manufacturers. However, the installation of the ground / water heat exchanger in GSHPs is site-specific and requires customization. This group of technologies can be considered as mature and ready for both design and construction market. The implementation of these technologies can be considered in between medium and high cost. All technologies listed in this group have some non-energy benefits and meet code requirements.
- TSC technology is available from a single source. This technology is well researched, simple to install and maintain making it ready for the design and construction market. This technology can be considered as low-cost and has significant non-energy benefits.
- RHC and CB technologies are mature technologies and are currently available in the market from at least three sources. These technologies can be considered as design and construction market ready. These technologies have lower costs than all-air HVAC systems due to the elimination of ductwork and have significant non-energy benefits. However, additional dedicated ventilation systems need to be installed to meet code requirements. In addition, although RHC and CB technologies do not have good humidity control capabilities, in general these technologies are widely accepted in the cold-dry climates of Montana as humidity control in such climates is not a big concern.
- CCHP technologies are currently in the R&D stage, with minimal market penetration and relatively high costs. The CCHP technology is currently faced with operational challenges in the harsh winter conditions of Montana and has limited applications. Although the STES technology is considered mature and has proven to provide significant energy savings in climates similar to Montana, this technology has not gained traction in the cold climate regions (such as Montana) of the United States. Currently, neither of these technologies are referenced in the codes.

When considering program support:

- When considering code readiness, all technologies except CCHP and STES have been implemented on voluntary basis in numerous commercial buildings across the state as current above-code measures.
- Industry support to all these technologies can either be considered indifferent or supportive.
- When considering compatibility with utility programs and incentives by the utility programs, only HPWH has certain compatibility with utility programs and is provided with some incentives. As determined from the database of state incentives for renewables and efficiency (DSIRE) there currently are several programs that provide incentives for a variety of HVAC technologies in Montana. Certain technologies such as GSHPs and PV arrays are incentivized better than others. However, there are some technologies such as VRF, TSC, and DOAS aren't mentioned by programs found in DSIRE.

## Table 6: Scorecards for high performance HVAC technologies

### *Open-loop Ground Source Heat Pump System (GSHP)*

| | | | | | | |
|---|---|---|---|---|---|---|
| SAVINGS | Energy Savings Opportunity | | | 3 | | |
| | Cost Effectiveness | | | | 4 | |
| | Measurability | | | | 4 | |
| MARKET | Defined and Available | 1 | | | | |
| | Market Ready | | | | | 5 |
| | Market Friendly | | | | 4 | |
| PROGRAMS | Code Ready | | | | 4 | |
| | Industry support | | | 3 | | |
| | Compatibility with Utility Programs | 1 | | | | |
| | Currently Incentivized by Utility Programs | 1 | | | | |



### *Closed-loop Ground Source Heat Pump System (GSHP)*

| | | | | | | |
|---|---|---|---|---|---|---|
| SAVINGS | Energy Savings Opportunity | | | | | 5 |
| | Cost Effectiveness | | | | 4 | |
| | Measurability | | | | 4 | |
| MARKET | Defined and Available | 1 | | | | |
| | Market Ready | | | | | 5 |
| | Market Friendly | | | | 4 | |
| PROGRAMS | Code Ready | | | 3 | | |
| | Industry support | | | | 4 | |
| | Compatibility with Utility Programs | | | 3 | | |
| | Currently Incentivized by Utility Programs | | | | 4 | |

## Table 5 Continued: Scorecards for high performance HVAC technologies

### *Variable Refrigerant Flow System (VRF)*

| | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| SAVINGS | **Energy Savings Opportunity** | | | 3 | | |
| | **Cost Effectiveness** | | | | 4 | |
| | **Measurability** | | | | 4 | |
| MARKET | **Defined and Available** | | | | 4 | |
| | **Market Ready** | | | | 4 | |
| | **Market Friendly** | | | | 4 | |
| PROGRAMS | **Code Ready** | | | | 4 | |
| | **Industry support** | | | 3 | | |
| | **Compatibility with Utility Programs** | 1 | | | | |
| | **Currently Incentivized by Utility Programs** | 1 | | | | |

### *Heat Pump Water Heater (HPWH)*

| | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| SAVINGS | **Energy Savings Opportunity** | 1 | | | | |
| | **Cost Effectiveness** | | | 3 | | |
| | **Measurability** | | | 3 | | |
| MARKET | **Defined and Available** | | | | | 5 |
| | **Market Ready** | | | 3 | | |
| | **Market Friendly** | | | 3 | | |
| PROGRAMS | **Code Ready** | | | 3 | | |
| | **Industry support** | | | 3 | | |
| | **Compatibility with Utility Programs** | | | | 4 | |
| | **Currently Incentivized by Utility Programs** | | | 3 | | |

## Table 5 Continued: Scorecards for high performance HVAC technologies

### *Transpired Solar Collector (TSC)*

| | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| SAVINGS | **Energy Savings Opportunity** | 1 | | | | |
| | **Cost Effectiveness** | | | | 4 | |
| | **Measurability** | | | | 4 | |
| MARKET | **Defined and Available** | | | 3 | | |
| | **Market Ready** | | | | 4 | |
| | **Market Friendly** | | | | 4 | |
| PROGRAMS | **Code Ready** | | | 3 | | |
| | **Industry support** | | | | 4 | |
| | **Compatibility with Utility Programs** | 1 | | | | |
| | **Currently Incentivized by Utility Programs** | 1 | | | | |



### *Radiant Heat & Cooling System (RHC)*

| | | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| SAVINGS | **Energy Savings Opportunity** | | | 3 | | |
| | **Cost Effectiveness** | | | 3 | | |
| | **Measurability** | | | 3 | | |
| MARKET | **Defined and Available** | 1 | | | | |
| | **Market Ready** | | | | | 5 |
| | **Market Friendly** | | | 3 | | |
| PROGRAMS | **Code Ready** | | | 3 | | |
| | **Industry support** | | | 3 | | |
| | **Compatibility with Utility Programs** | | | 3 | | |
| | **Currently Incentivized by Utility Programs** | | | 3 | | |

## Table 5 Continued: Scorecards for high performance HVAC technologies

### *Chilled Beams (CB)*

| | | Score |
|---|---|---|
| SAVINGS | Energy Savings Opportunity | 2 |
| | Cost Effectiveness | 4 |
| | Measurability | 4 |
| MARKET | Defined and Available | 1 |
| | Market Ready | 5 |
| | Market Friendly | 3 |
| PROGRAMS | Code Ready | 3 |
| | Industry support | 3 |
| | Compatibility with Utility Programs | 2 |
| | Currently Incentivized by Utility Programs | 2 |

### *Dedicated Outdoor Air System (DOAS)*

| | | Score |
|---|---|---|
| SAVINGS | Energy Savings Opportunity | 1 |
| | Cost Effectiveness | 3 |
| | Measurability | 1 |
| MARKET | Defined and Available | 5 |
| | Market Ready | 4 |
| | Market Friendly | 3 |
| PROGRAMS | Code Ready | 3 |
| | Industry support | 5 |
| | Compatibility with Utility Programs | 1 |
| | Currently Incentivized by Utility Programs | 1 |

## Table 5 Continued: Scorecards for high performance HVAC technologies

### *Cold Climate Heat Pump (CCHP)*

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

### *Seasonal Thermal Energy Storage (STES)*

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

* "Because of the complex design, building owners and system designers are not able to conduct a quick analysis to determine whether STES is a viable option for their projects. " – There is no real life cycle cost analysis. There is also no analysis on time till payback.

## *LUMINAIRE LEVEL LIGHTING CONTROL (LLLC)*

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

## CONCLUSIONS

This report identifies and evaluates 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. The High performance environmental control technologies identified for High performance commercial buildings across Montana were shortlisted and evaluated 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.

A final decision on the feasibility and affordability of the selected HVAC technologies for future codes in Montana will be made after the survey is completed.

In addition to surveying HVAC technologies, several cutting-edge technologies for lighting and building envelope were identified and a similar survey was conducted to evaluate the potential of these technologies. A discussion outlining the characteristics and benefits of these technologies along with the results of the preliminary survey are presented in Appendix D of this report.

Four technologies were selected, which include:

- Dynamic lighting (DL)
- Luminaire Lighting Level Control (LLLC)
- Building integrated photovoltaics (BIPV)
- Dynamic windows (DW)

When considering energy savings:

- DL, LLLC and BIPV technologies provide sound cost effectiveness and measurability. BIPV provides high energy saving opportunities, while no unitized energy savings are available for DL and LLLC.
- DW technologies are not associated with high energy saving opportunities, cost effectiveness and measurability in commercial situations.

When considering market potential:

- Both DL and BIPV technologies are considered to be defined and available. Although these technologies are associated with high costs, both technologies have numerous non-energy benefits making them market friendly. However, these technologies are considered in the pre-commercialization stage and are rated low in terms of market readiness.
- LLLC technologies are considered defined and available. Although these technologies are associated with high costs, it has non-energy benefits making it market friendly. These technologies are rated high in terms of market readiness.

- DW technologies are available through unique sourcing. However, these technologies are in nascent stages of commercialization and are rated low in terms of market readiness. High costs associated with these technologies does not make them market friendly. However, certain DW technologies such as Liquid Crystal Device and Suspended Particle Device have non-energy benefits and can be considered market friendly.

When considering compatibility with code and utility programs:

- The DL, DW, LLLC, and BIPV technologies can be implemented as above-code measures and voluntary requirements proposed by various building jurisdictions in the state. These technologies have significant industry support. However, these technologies are currently not considered for any utility programs and are currently minimally incentivized.

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