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Executive Summary

This Mechanical System Optimization Guide was funded by the Vermont Housing Conservation Board (VHCB) via a MacArthur Foundation Grant for the development of a comprehensive roadmap for affordable housing. The roadmap includes an architectural "Roadmap for Housing Energy Affordability" outlining the path towards high performance building envelope construction and this guide which addresses optimization of building mechanical systems. The Mechanical System Optimization Guide (MSOG) provides direction on the approaches and systems that satisfy the energy goals established for affordable housing. This guide is organized in three sections.

- ***Research and Findings*** documents the research, modeling and findings that informed the guide's development
- ***Process Guide*** outlines the opportunities to improve energy performance by taking specific actions over the project lifecycle from procurement to operations.
- ***Mechanical Design Guide*** details the process needed for appropriate selection and sizing of mechanical systems that will meet the established $75 per unit per month (PUM) affordability criteria

Modeling was performed on three typical building types (duplex, townhouse and double loaded corridor buildings) to identify the systems and control approaches that, coupled with high performance envelopes, will satisfy the PUM affordability criteria and meet building comfort, operations and air quality requirements. For townhouses and double loaded corridor buildings, long term energy affordability (defined in Appendix A- glossary) is achievable using condensing fossil fuel boilers, pellet boilers or premium efficiency air source heat pump systems. The duplex style housing could not achieve the long term affordable operating costs; however, with a pellet fired heating system the Duplex PUM meets the near term affordability standard. Where air conditioning is provided, high performance air source heat pump systems were found to meet the affordability criteria for delivering heat and hot water; when cooling costs are included, this equipment exceeded even the near term PUM for all building types.

One of the guide's objectives is to address the barriers to right-sizing of mechanical equipment. Lack of feedback regarding building performance was identified as a missing link in the advancement of energy efficient affordable housing. In particular, design engineers only hear about mechanical system performance when there is a problem associated with under sizing; this cycle contributes to over sized equipment. This guide documents a fully integrated process that includes specific energy performance goals from the project inception, monitors the design and construction relative to the goals, evaluates the project's actual performance, and gives feedback to the project team to help shift the design paradigm toward optimum system performance.

Many buildings in Vermont have oil heat. Even the most efficient oil heating equipment has limited or no ability to modulate to match the building loads in off peak conditions. Thermal energy storage is needed to prevent boilers, even those that are accurately sized for the building peak load, from short cycling in part load conditions. The addition of thermal energy storage to the heating system allows systems to meet peak and part-loads while eliminating boiler short cycling, and providing a buffer that reduces the impetus to oversize boilers.

High performance buildings do not readily allow internally generated heat to escape, increasing the potential for overheating. This effect is mitigated when occupants use operable windows to provide an exit path for the unwanted heat. Low energy building envelopes include casement windows which do not allow for the installation of window air conditioning units. When cooling is not included in the project scope, the project team must consider how occupant comfort will be maintained during the shoulder and summer seasons and potentially include accommodation for occupant provided cooling equipment in the design.

Introduction

The affordable housing community in Vermont is a forerunner in the nation in developing a comprehensive approach to affordable housing and community development linked with land conservation and historical preservation. Vermont's affordable housing community has been committed to addressing the impact of energy costs on housing affordability and is proactively working to address the issue through the development of housing that is designed and built to minimize energy costs in an uncertain energy future.

Residents of affordable housing typically pay a significantly higher percent of their income for energy and have little flexibility to accommodate rising fuel costs. Natural gas service is limited to Vermont's Northern Champlain Valley in Vermont. Unregulated fuels (oil and propane) heat much of the state's affordable housing stock increasing the volatility and risk associated with heating costs. In order to maintain long term affordability, buildings need to drastically reduce fuel consumption by installing high performance building envelopes and low energy mechanical systems capable of providing comfort, hot water and ventilation with a high degree of efficiency.

Cost Criteria:

Near Term Affordable: Total per unit monthly (PUM) heat and hot water energy cost of $75 in 2025

Long Term Affordable: defined on an iterative basis comparing traditional energy costs against generation via solar photovoltaic

Assumed fuel cost escalation rate of 5%

The goal of this guide is to identify optimal mechanical system approaches for common building types in the affordable housing inventory, and provide guidance for their efficient design, construction, and operation which will result in buildings that meet or exceed the established cost criteria.

This guide covers the analysis that went into identifying the optimal mechanical systems, processes that will help project teams achieve optimized energy performance in their buildings, and guidance on sizing and selecting mechanical systems that meet the PUM goals.

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Research and Findings Overview

Stakeholders from several housing agencies provided input and assistance throughout the process. These groups include Housing Vermont (HVT), Champlain Housing Trust (CHT), Cathedral Square, Addison County Community Trust (ACCT), VHCB and VHFA. An initial meeting was held to define the project objectives and determine the criteria and key characteristics for optimal mechanical systems. On site investigation of buildings with good and poorly performing mechanical systems was completed by the team. Building operators and design engineers were interviewed. eQuest Modeling was used to simulate building performance and the operating costs of a variety of systems. The models were based on a variety of envelope models developed by Energy Balance and were calibrated to the Energy Balance Models. Spreadsheet analysis was used to develop hot water loads and perform integrated sizing calculations.

Site Visits

The team visited five affordable housing sites. The sites were selected to represent the best performing systems and those with significant issues to allow the team to identify what is currently working and what goes wrong with building mechanical system designs. Projects ranged in size from two to more than thirty units and included new construction and major renovation projects. Site visits included the investigation of central plant heating and hot water equipment, in-unit and common space terminal equipment, ventilation and energy recovery equipment.

Table 1: Site Visit Summary

Site	Location	Building Manager	Type	Project Type	No. Units	Central Plant Equipment	DHW	Site Visit	Model
Salmon Run	Burlington	CHT	3 Story Townhouses	Remodel	8	Weil McLain Ultra, condensing gas	Indirect + SDHW	√	√
Waterfront Housing	Burlington	CHT	Double-Loaded Corridor, 3 story	New	40	Weil McLain Gold, non-condensing gas.	Triangle Tube condensing	√	
Middlebury South	Middlebury	ACCLT	Double-Loaded Corridor, 3 story	New	32	Weil McLain standard oil boiler, 81.3% Efficient	Indirect	√	√
George Street	Morrisville	LHP & HVT	Duplex	Remodel	2	Oil boiler.	Indirect		√
Town Meadow Senior Housing	Essex Junction	Cathedral Square	Double-Loaded Corridor, 3 story	New	42	Boiler/Tower Loop, Terminal Heat Pumps—use boiler water in winter, DX in summer	Indirect.	√	
Pleasant Street	Enosburg Falls	CHT	2 Story Townhouses	New	24	Froling P4 Pellet Boiler, 85% Eff with oil boiler backup	Indirect + SDHW	√	

After reviewing equipment and systems present at a given site, the owner's representative (usually a building operator) was interviewed regarding building operation and performance.

Field Observations

The following summarizes the findings from the site visits.

Staff Training & Communication

- In some cases, complete system documentation—including recommended maintenance schedules, complete systems drawings, etc—was found to be on-site, yet building operators were unaware of or unfamiliar with the documentation.
- Routine maintenance, such as filter changes, was observed to be past-due at several locations.
- Building automation system "head-end" computers were found to be off, and in one case, no individual at the organization was in possession of the password; the controls company was required to restore the system.
- Operations staff expressed skepticism about the benefits vs. perceived maintenance headaches of solar hot water. Maintenance requirements of these systems are low and payback is very quick: as new technologies are introduced, organizations need to work to bring staff up-to-speed to achieve buy-in proactively.
- Staff identified issues in building handoff training—training occurs at completion of project, but warranty period extends typically for 1 year, at which time training is difficult to remember.

Equipment Issues

- Odor migration in building energy recovery ventilation units (ERVs) - Several building operators indicated that ERVs with enthalpy wheels were causing odor migration issues, most notably from cooking odors, and were leading to significant occupant complaints.

- Window Air Conditioners - Occupant installed air conditioners were identified at multiple building sites. These units are far less efficient than central systems and can cause damage to windows in the annual installation and removal.
- Thermostats were found to be manually operated with no setbacks. Operators and owners indicate they have advantages over programmable units due to simplicity and lack of batteries. Battery replacement and tenant difficulty with programming were identified as barriers to programmable thermostats.

Findings from the site visits and interviews are incorporated into the recommendations of the report.

Modeling

The modeled mechanical systems included systems that are known to perform well in affordable housing and those which were likely to meet the performance criteria. Because of the high performance building parameters developed in the RHEA, mechanical system sizing was found to be a key factor in limiting energy use and controlling first costs.

Modeling was conducted using eQuest version 3.64, which is a building energy simulation tool based on the US Department of Energy's DOE-2 energy modeling engine. eQuest is a *Whole Building Performance Analysis* platform, which recognizes that buildings are systems and accounts for the interactive effects between building envelope, heating and other systems. The program performs analysis on the building every hour of a year, using the specified building characteristics specified the climate using Typical Meteorological Year version 3 (TMY3) data from the National Oceanographic and Atmospheric Administration (NOAA). TMY3 data is the most current available data reflecting Burlington's typical climate over the period between 1991 through 2005.

Envelope modeling was performed based on the "near term or "long term" affordable building parameters developed under the "Roadmap for Housing Energy Affordability" (RHEA) to optimize the performance of the building shell. Using the building shell inputs provided by the RHEA team, prototype eQuest models were developed for three building types – duplex, townhouse and double loaded corridor (DLC) to evaluate proposed HVAC systems. The models were correlated to the RHEA team models and results were found to be highly consistent.

Systems Modeled Included:

- Conventional Non-Condensing Boilers
- High Efficiency Boilers
- Multiple boiler quantities as central plant equipment
- Thermostat setpoints from 60F to 80F
- High Efficiency Water-Sourced Heat Pumps

Findings

High efficiency condensing boilers, with a minimum AFUE efficiency of 91% (Oil) and 96%[1] (gas) were found to be optimal in comparison to any configuration of standard efficiency equipment. Modeling was done for 1, 2, 3 and 5 boiler systems on buildings with 4 or more units to determine the incremental performance improvements associated with modular boiler systems.

[1] AFUE for oil and gas boilers <300,000 Btu/h test procedure: 10 CFR 430

Table 2 - Multiple-Boiler Efficiency Gains

Condensing Boiler 91% Efficient, Space Heat Only			
Double Loaded Corridor Type			
# of Boilers	Annual Fuel Use (MMBTU) Modeled	Savings Over Single Unit	Incremental Savings
1	194		
2	170.5	12.1%	12.1%
3	164.8	15.1%	2.9%
5	162	16.5%	1.4%
Townhouse Type			
# of Boilers	Annual Fuel Use (MMBTU) Modeled	Savings Over Single Unit	Incremental Savings
1	85.7		
2	78.6	8.3%	8.3%
3	76.8	10.4%	2.1%
Duplex Type			
# of Boilers	Annual Fuel Use (MMBTU) Modeled	Savings Over Single Unit	Incremental Savings
1	34.9		
2	33.8	3.2%	3.2%

Modulating, condensing boilers showed a significant energy reduction going from 1 to 2 boilers, roughly 9%, with a further, incremental increase of only 2% when a third is added. This assumes a control strategy that modulates all boilers in parallel, until minimum fire is reached at which point one boiler is dropped out. Because these boilers have the ability to significantly reduce their firing rates, they are able to operate more efficiently at part load due to the increased area of the fuel-to-water heat exchanger area per BTU delivered. Modular design enables matching total boiler capacity closely to the building loads, provides part load redundancy in the event of a boiler failure and allows boilers to serve building loads and domestic hot water simultaneously.

As building size and loads decrease, boiler sizes are not available to allow cost effective modular boiler installations. In duplex-style housing, a 3% reduction was realized using two modulating, condensing boilers vs. one. However, the boiler size needed for this type of system is not currently available on the market.

Where a single boiler system is used with limited or no turndown, thermal energy storage (TES) tanks were found to increase efficiency and boiler performance. This is most applicable to duplex style housing where heating loads can be low enough to fall below the minimum capacity of readily available boilers. TES will allow the boiler to fire at or near full capacity, for a longer duration but with extended dwell times in between firing when compared to the same system without TES. Extending the time between firing also extends the operating life of the burner. TES is typically a well insulated water tank in series with the system piping and a control strategy that ensures the energy storage never drives the boiler to fire, but instead provides a thermal reservoir which allows the boiler to fire efficiently when there is a call for heat.

Effects of Temperature Setpoint

Buildings with low energy envelopes result in a much higher correlation between building heating fuel use and building temperature set point. The reason for this higher sensitivity is that the external and internal heat gains meet a significant portion of the buildings total heating demand. These include solar gains through windows, heat generated by occupants, equipment loads, lighting and cooking loads. The heating load not met by these gains is the load requiring input heat from the central plant. In typical buildings, that is most of the load. In low energy buildings, that load increases rapidly as thermostat set points increase. Figure 1-Middlebury South Fuel Use depicts the change in fuel use at three different space thermostat setpoints in a double loaded corridor building.

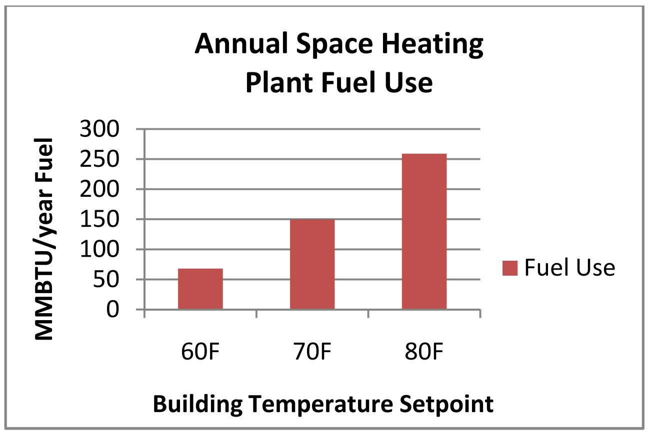

Figure 1-Middlebury South Fuel Use

The internally sourced gains are included in Figure 2 - Middlebury South Fuel Use Plus Internal Gains as a "fuel use equivalent" to demonstrate the large impact of internal gains on the total site energy use.

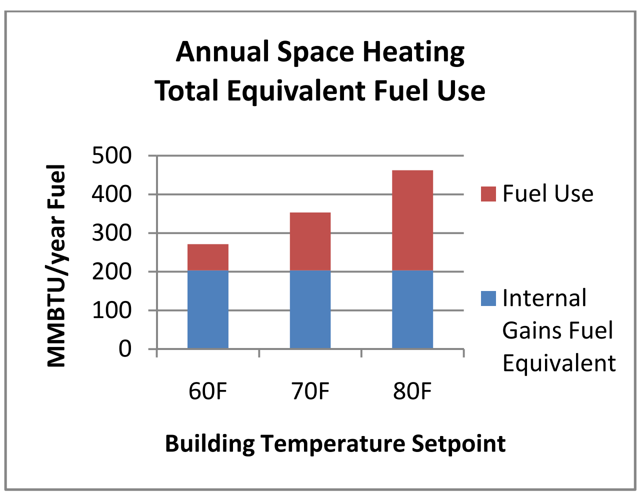

Figure 2 - Middlebury South Fuel Use Plus Internal Gains

Occupant issues with programmable thermostats have lead developers and owners to avoid them. However, the modeling provides compelling evidence that significant cost savings could be realized if programmable thermostats could be implemented effectively.

Cooling Modeling

In buildings built as outlined in the RHEA—with tight envelopes, high R value wall and roof assemblies, and low window U values—internal gains can lead to changes in indoor temperature profiles during the summer and shoulder months. Modeling indicates that with these better envelopes, cooling energy is reduced slightly from May to September overall, but there is some increase in cooling energy required in the shoulder season.

Options for modeling VRV systems at the moment are extremely limited. As a result, and to predict a worst-case scenario, modeling of ASHP's was conducted using a system per zone, and neglecting the advantageous interactive effects possible with multi-zone VRV system. The ASHP systems modeled were based on efficiencies found in current model Mitsubishi high efficiency ASHP systems, and were based upon and ARI rated EER of 12.25 and COP of 4.2. Modeling results indicate that while high efficiency ASHP's can meet year 15 PUM requirements for heating and DHW. When cooling energy is included, they overshoot the near term PUM target significantly for duplex units and by a smaller margin in townhouse and double-loaded corridor buildings.

High efficiency water source heat pumps were also modeled. It was found that water source heat pump systems cannot meet the near term affordable PUM in year 15.

Modeling of space temperatures in the shoulder and summer seasons in buildings without cooling systems yields space temperatures which sometimes exceed 110^{o}F indoors. This is attributable to the fact that the modeling does not take into account any of the effects of natural ventilation resulting from the occupants' ability to open and close windows as necessary. However, it indicates the potential for overheating in these buildings in the shoulder season. When cooling is not provided the architect should design for passive cooling and accommodation should be made for occupant provided window air conditioning, if such equipment will be allowed.

Design Engineer Surveys

A group of selected design engineers was surveyed to discuss approaches to system selection and sizing and factors that contribute to over sizing. The following responses were from principles of three different engineering firms who are currently among engineers selected to design mechanical systems for multi-family housing in Vermont:

- Engineers want to size equipment to match the building load.
    - In all cases engineers noted that depending on the team: owner, architect and contractor, they have different comfort levels regarding the realized envelope performance
    - Where the mechanical engineer is not confident that a team can achieve a high performance envelope, they increase the size of the heating plant to cover the likely lower performance of the building
- Factors that increase comfort with right sizing:
    - An energy consultant on the team – this person advocates for the envelope design, construction and testing and independently presents the potential risks associated with non-performance of the envelope

    - Engineers responsible for modeling – this enables the engineer to review the envelope details and determine the impacts of construction variation on heating loads
    - Envelope commissioning – in particular blower door tests should be performed if design is to a low air change per hour specification. Engineers noted infiltration rates as the greatest unknown. In order to ensure that a right sized system will satisfy the comfort requirements of the building, the integrity of the envelope must be verified
    - Developing a written contract about envelope performance that includes the owner, architect and builder would help mitigate concerns regarding envelope performance risk. Such a document that contractually guaranteed envelope performance would increase engineer comfort in sizing close to the building design load.
        - One respondent recalled a situation where the system sizing was just adequate for the modeled load and he was concerned that the building envelope might not perform as expected. Provision was made for an additional boiler in case the actual loads exceeded the modeled loads. The building did in fact have difficulty maintaining comfort in design conditions and there was dissatisfaction expressed with the engineering approach. No additional heating was added.
        - There was general agreement that in spite of upfront agreements, clients fundamentally rely on their engineers to get sizing right the first time.
- Different approaches were discussed relative equipment sizing practices:
    - Two firms indicated that they do not use a safety factor. One indicated a preference for modular boiler systems, such as two boilers each sized at 2/3 of the load. This provides redundancy and additional capacity for warm-up in the event that night set-back is used.
    - Another firm indicated the use of a 15-25% safety factor on peak load depending on their confidence in the team.
    - One firm indicated that for high performance buildings where their clients want no onsite fossil fuels, they are moving to variable refrigerant volume systems, except in the very coldest locations in Vermont. They have seen these systems perform well down to -18 degrees F and are comfortable that if the units shut off due to temperatures below their operating threshold, a building with a high performance envelope could ride through until temperatures warmed with no negative impact. In addition, these systems perform better when moderately oversized.
    - "Value engineering" was noted as a point in the process that can do the most damage to the energy performance of a building. If envelope changes are made due to VE, the boiler size may not be reevaluated; this possibility can lead to preventive over sizing during design.
    - No engineers had received feedback regarding systems they have over sized. Some engineers had received negative feedback regarding systems that were not meeting comfort conditions.
    - In general, the engineers surveyed receive no feedback on how their designs perform.
- The respondents were generally not supportive of the concept of standardization. Issues include:

  - Loss of competitive bidding on sole sourced equipment
  - Systems and equipment are evolving, such as VRV and condensing oil boilers, and standardization is too early
  - Too prescriptive, doesn't allow for optimization and customization of design to the specific application
- Incentives are not a solution
  - The designers intent is to provide design services that meet the needs and expectations of the project developer
  - Incentives were universally thought not to be a useful tool to improve sizing

Process Guide

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Process Guide Overview

High performance buildings, those that are comfortable to inhabit, use minimal amounts of energy and have good longevity, require an integrated design and construction process. The process required to achieve optimal performance can impact the project design and construction cost and schedule. In order to minimize these impacts, *The Roadmap for Housing Energy Affordability* (RHEA) and this *Mechanical System Optimization Guide* (MSOG) have been developed to provide detail and clarity regarding the approaches that will result in low energy buildings. These documents are also referred to collectively as the roadmap in the following narrative.

The following process guide will assist team members in achieving the desired building performance goals. Key process steps include:

- Clearly state the Developer & Owner expectations regarding building performance and operating costs in addition to the construction budget
- Select design teams with demonstrated ability in integrated design and high performance buildings
- Design Contracts include

    - Mandatory requirements
    - Fee schedule tied to key deliverables at designated stages in the process
    - Adequate fees to compensate the design team for the effort required to meet the project design requirements

- Design review process includes key deliverables and a schedule with adequate time for review and response
- Include performance requirements in the bid documents
- Ensure training and project documentation is adequately developed and that appropriate people receive training
- Verify installation and performance
- Provide feedback to the design and construction team regarding building performance

This section outlines recommendations in each of these areas and identifies areas that may warrant development of specific tools or documents in addition to the RHEA and MSOG. The recommendations of this section are summarized in Appendix E - Process Guide Flowchart.

Define Owner's Project Requirements

The owner's team should start each new construction or renovation project by developing a comprehensive document outlining the project requirements, typically referred to as the Owner's Project Requirements (OPR). The OPR ensures that the development team, owners, design team, contractors and even building occupants understand the expectations for the building.

Develop the OPR as part of the initial funding documentation and use it to review the project throughout the design, construction and turnover process to increase the likelihood that the constructed building reflects the original vision of the project. In many projects, the vision of a successful final project is unstated and each member of the team makes assumptions based on what they understand, often from verbal communications, their experience and the constraints that they find most relevant. The OPR focuses the team on the critical requirements for project success from funding through turn-over.

The developer drafts the OPR during the funding stage and incorporates it into the project documentation from RFPs to Bid Documents. The OPR is refined as the project progresses so that it reflects the evolution of the project requirements as trade-offs are made due to site, budget, material availability or other constraints.

Example: OPR Evolution

At the time of funding, a 50 year roof life is required and specified in the OPR. During design development, the architect selects a roofing approach that meets this criterion.

The DD cost estimate indicates that the 50 year roof life is not within the project budget and a 40 year roof alternative is identified as the best option of the project.

The OPR is updated to reflect the revised roof life expectancy and design and construction proceed with the 40 year roofing material.

At turnover the operator receives an OPR that reflects the expected 40 year roof life so that property maintenance funds can be managed accordingly.

Sample OPR language is provided in Appendix C; this is not a comprehensive OPR, but rather a starting place for the development of a project specific OPR. The OPR should state:

- Owner and User requirements of the project such as the occupancy information, number of units, accessibility needs and the expected lifetime of equipment and components.
- Project sustainability goals – this may relate to achieving a specific recognition such as LEED certification, or it could define specific areas such as LEED prerequisites and credits that are to be addressed in a project that may not be pursuing certification. Address requirements for construction waste recycling, on site recycling and composting facilities, site septic and other environmental requirements.
- Energy Performance Requirements – state the PUM cost, the requirements for design, construction and operation in accordance with the RHEA and MSOG and identify other efficiency requirements such as use of Energy Star appliances.
- Describe requirements for indoor environmental conditions such as temperature requirements in units and in common areas, time for elevator turn around, time delay for hot water in winter, VOC limitations during construction and maintenance.
- Address building occupant and O&M personnel requirements – identify whether the project will be maintained by owner personnel or contracted maintenance, indicate acceptable frequency of in unit maintenance, address access requirements - particularly for equipment located in units.

The OPR is distributed as follows:

RFP	Include OPR and reference the requirement that the team works with the owner to refine and ultimately meet the OPR
Design Contract	Include OPR and language similar to the RFP
Construction Contracts	Include the OPR in the Bid Specifications
Project Documentation	Provide OPR in electronic format to the building operator and reference in maintenance contracts

Design Team Procurement

The acquisition of design services that meet the project budget, schedule, and performance requirements is facilitated by establishing clear selection criteria and issuing RFPs and contracts that define the project requirements and the expectations for design team deliverables and scope. The elements discussed below should be included in both the RFPs and Contracts to ensure design proposals reflect the project scope and design contracts clearly define the team's responsibilities.

Selection Criteria

Investing in design services from firms that demonstrate their understanding of and commitment to the concepts outlined in the roadmap documents is essential to achieving the energy affordability goals. Achieving the goal of long term affordable housing requires designs that are not "typical." Lower cost design proposals are often based on applying "tried and true" approaches, even when proposed by prequalified firms.

While rising soft costs are a concern, the design team, even when drawn from a prequalified pool, should be selected based on criteria that include their demonstrated ability, understanding and commitment to achieving the project budget and energy goals as well as the cost of design services. Selection criteria for consideration include:

1. Team's demonstrated understanding of the design and construction approaches necessary to achieve the OPR, including the building energy performance goals and the approaches outlined in RHEA and MSOG. (30)
2. Team's demonstrated ability to design high performance buildings that are constructed within budget. (25)
3. Team's success in delivering energy performance coupled with building indoor environmental quality on prior projects. (25)
4. Proposed pricing, including the reasonable allocation of design resources among team members. (20)

Design Firm RFP and Contract

The introduction of the roadmap should result in increased focus on critical energy and performance goals for affordable housing. To ensure that project teams have read and understand the OPR, RHEA and MSOG, we recommend the following additions to design firm (architectural and engineering) RFPs and contracts:

- The following RFP requirements will facilitate review of proposals relative to the Selection Criteria outlined above:
    1. The team shall describe how they will approach the development of a design that is in full compliance with the OPR and address the recommendations of the RHEA and MSOG documents. The response shall include information from the architect and mechanical engineers at a minimum and other team members' input should be included where relevant. The response shall include a clear statement of the design process and timeline that will be used to ensure fully integrated design, including but not limited to
        a. Development of the Basis of Design
        b. Building modeling and or load calculations
        c. Interactive review of building components and design approaches, method for prioritizing and selecting the final building components and design approaches

       In reviewing proposals for scoring relative to item 1 above, look for integration of the responses as an indicator of a team with better communication which will more likely result in the collaboration required to meet the energy performance goals. Also look for a timeline that includes early modeling.
    2. The team shall provide at least one and not more than three examples of recently completed projects (in the past 5 years) that were designed to meet specified project energy goals, completed within budget and achieved energy performance consistent with the goals. Information required includes:
        a. Project name and facility type
        b. Project team including owner, architect, engineers, general contractor, mechanical subcontractor
        c. Gross conditioned square footage and unconditioned area (separate)

    d. Building construction budget, actual construction cost, total design costs and other soft costs
    e. Overview of the design and construction timeline including design start, DD complete, CD complete, construction start, construction complete, occupancy
    f. Project energy goal(s) – numeric, modeled energy use for the building, measures used to achieve the building energy goals
    g. Project energy and indoor environmental quality performance – provide information on the actual performance of the building and describe the team's role, if any in post occupancy monitoring, addressing issues relative to energy, shell performance or comfort
    h. Discussion of actual building performance relative to goals
  3. Provide proposed pricing by design phase, including the breakdown of fees by sub-consultant and a list of deliverables at the conclusion of each phase.

- Require team members to certify in writing that they have read the OPR, RHEA and MSOG and that their proposal is based on developing a design that will satisfy the OPR and will use approaches that are consistent with RHEA and MSOG. Include similar language in contracts.
- Ensure the critical energy and other performance goals are part of the design contract language. If the engineer is subcontracted to the architect, include a statement in the architect's contract that this energy performance target is a collaborative target required of all team members.
- Interactive design requires early collaboration of the design team as they apply the strategies outlined in the RHEA and MSOG to the building design. To ensure that this early collaboration occurs, spell out milestones and deliverables in the RFP and Contract and tie payment to completion of these milestones. Milestones may include:
  1. Design charrette in which the team discusses and refines the project requirements, establishes responsibilities and communication protocols for addressing interactive effects and brainstorms on strategies. Complete by SD
  2. Early completion of building modeling (where included) and HVAC load calculations for review against building envelope tradeoffs. First iteration by 50% DD and final iteration submitted as part of 100% DD documents. Includes submission of Mechanical Modeling/Load Calculation forms in Appendix B
  3. Complete a draft BoD at 100% SD and a full BoD at 100% DD. The BoD should be updated to reflect changes in approach through bid documents
- One of the missing links in the current process is the lack of an effective feedback loop – the design team has no way of knowing how their designs perform in the real world. Without a mechanism by which the design professionals can see how these buildings and systems actually perform, learning about realized performance relative to modeled or predicted performance does not occur. Require the team to provide a fee for post occupancy performance verification; seek additional funding from Efficiency Vermont or other sources to support the additional verification effort and include it in contracts. Another means of facilitating feedback would be to develop project specific case studies and distribute them to the developers, design and construction teams on a regular basis.

Mechanical Engineer Selection

High performance building design necessitates more care and attention to equipment selection, control systems, and the sequences of operation to achieve optimal efficiency than a code baseline building. Mechanical engineers have traditionally prioritized designing to satisfy "design day conditions." Achieving perpetual energy affordability requires the engineer apply more rigor to addressing "off-design" part load operation, which is where operating efficiencies and cost savings are captured. The design fees for a high performing building must reflect that effort.

A common design team acquisition method is for the architect to effectively bid the engineering sub-consultants and carry their selected firms in their proposal. Because the architects recognize that the overall price is the primary selection criteria, this approach creates a financial incentive for the architect to use the lowest cost design sub-consultants. The lowest cost engineer may not result in the best team to most cost effectively achieve the project performance goals.

While the approaches outlined above should help ensure the commitment of the design team to the performance objectives, cost may still be a significant factor in engineering selection. To help address this issue, architects could include the average fee for the mechanical design in their proposal. Once selected, the architect could then present the mechanical proposals including fees and responses to the selection criteria questions for review and selection in collaboration with the owner. The architect's fee would then be adjusted to reflect the difference between the initial average fee and specific fee for the selected mechanical engineer[2]. This practice can be used for any key member of the design team.

Design Phase Activities

Design phase activities outlined below must be addressed in the RFP and contracts then monitored for successful completion by the project manager as the design progresses. Where specific contracting recommendations are needed, they are included below, otherwise, it is expected that the RFP and contracts will clearly describe the deliverables and timelines needed to ensure the team completes the activities necessary for building design and construction.

Basis of Design

The Design Team uses the OPR to develop a Basis of Design (BoD) which describes how the design will meet the owner's project requirements. Where the OPR is prescriptive, such as *the roof life shall be 50 years*, the BoD clearly restates the prescriptive requirements and states the roofing system that has been selected to meet that criterion. Where the OPR states a broader goal, such as *maximize the use of natural light*, the BoD clearly identifies the design approaches, such as building location on the site, orientation, shading, glazing selection, hard wired lighting selection and lighting controls that are being employed to meet the requirement. The BoD states the Owner Requirement, delineates the reasoning for system and component selection relative to satisfying the stated requirement, documents the limits of the selected approaches and states the underlying assumptions that inform or constrain the design such as codes and standards.

During Schematic Design a BoD is developed by each member of the design team. The BoD draft is part of the SD submission and should be reviewed and approved by all of the project team, the building owner, and the commissioning agent (if present); the BoD should be updated and submitted at the conclusion of DD.

[2] The development of this practice is attributed to William Mclay Architects and Planners in 2009. It was proposed by WMAP and used by the State of Vermont for commissioning provider selection for the Bennington State Office Building.

The BoD describes the building systems, outlines all design assumptions and specifically addresses how the system design will meet the owner's requirements. The BoD will evolve as the design is developed. The BoD document is made for the life of the facility and should be included in the project contract documents.

A well written BoD includes the following information:

- General Project Information
    - Type of building
    - Location
    - Square footage
    - Number of stories
    - Types of occupancy
- Primary design assumptions:
    - Design conditions
    - Interior conditions for various types of rooms
    - Space use
    - Occupancy density
    - Ventilation rates
- Standards and Codes – Reference the specific applicable codes (version), regulation, guidelines and other references that will be used for the project. The BoD should include as a minimum:
    - Specific applicable code, including the version referenced for the design
        - Building codes
        - Fire and Life safety codes
        - Plumbing codes
        - Energy codes
    - Standards (Example: ASHRAE Ventilation Standard 62.2-2010)
    - Guidelines
- Narrative descriptions
    - Description of performance criteria for building envelope, HVAC systems, lighting, domestic hot water, on-site power, etc. and specifically indicate how these systems and the design approaches satisfy the project requirements articulated by the Owner. A well written BoD should include:
    - Lighting types, design foot-candles, lighting design LPD, types of lighting (interior/exterior), lighting controls
    - HVAC design loads, diversity factors, zoning
    - Number of Boilers, boiler redundancy, type of boilers, operating efficiency,
    - Pumping systems: Number of pumps, arrangement (primary/secondary), variable flow, diversity factors, full load and part efficiency, fluid design temperature difference
    - Type of airside distribution, airside and ventilation, loads, coils, delivery temperatures, economizers, exhaust systems, energy recovery systems, fan power , fan efficiency (performance metrics)
    - Domestic How Water system type (direct/indirect), full load capacity, full and part load efficiency, design entering/storage/delivery temperatures, DHW recirculation sizing
    - Control and operational concepts for each system
    - Operations and maintenance requirements to be included in the specifications

The owner should review the discipline specific Basis of Design documents, provide comments and sign off on the agreed upon approach at each phase of design review.

A sample BoD is included in Appendix G.

Key Milestones for BoD

RFP and Contract	State that a BoD is required
100% SD	Design team submits draft BoD for review
100% DD	Design team updates and resubmits BoD. If the project includes commissioning, the CxA should be included in the BoD review
Design and Construction	BoD should be updated to reflect any major changes in design approach based on pricing, alternates or other changes
Turn over	Provide the BoD to the building operator

Design Review

Design reviews provide quality control and verify that the proposed design is meeting the owner's requirements. Design schedules are often compressed due to cost of money and the pressing need for housing. However, studies have shown that investing more time during design can pay off with lower construction costs, fewer change orders and better overall building performance. A thorough design review process typically requires three weeks to complete including review, comment distribution, responses and meetings to determine action items. Scheduling design reviews at 100% SD, 100% DD and at an appropriate time during the CD phase (at about 95% CD with all HVAC and lightings controls 100% complete) will enable the project manager, building owner/operator, commissioning agent and others time to ensure the design meets the Owner's Project Requirements.

This guide focuses on the mechanical system design review which should include:

Schematic Design – review BoD, schematic diagrams and modeling or sizing input documents.

50% Design Development – team review of preliminary modeling or load analysis including inputs and outputs to identify opportunities for cost effective tradeoffs to optimize energy performance. Check sizing inputs, outputs and equipment selection against criteria in this report and address deviations with the team.

100% DD – review updated BoD, updated modeling/sizing calculation inputs and outputs, system schematics and draft sequences of operation for building controls. Check sizing as at 50% DD.

During CD – review for consistency with the BoD and OPR, equipment sizing in accordance with model/load calculation results, size and number of pumps, compliance of system designs with this guide. Ensure training and documentation requirements are included in the specifications. Ensure the design documents include one line schematic diagrams of each system with a narrative indicating how the system is intended to operate.

The following chart illustrates the timeline of one phase of the design review process.

ID	Task Name	Start	Finish	Duration
1	100% SD Review OPR, BoD, schematic diagrams, modeling/ sizing	3/1/2011	3/14/2011	14d
2	Designer responds electronically in design review (DR) table; returns file to CxA	3/15/2011	3/17/2011	3d
3	CxA and Owner review responses; highlight issues requiring discussion	3/18/2011	3/19/2011	2d
4	The team meets with the Owner to discuss the varying perspectives on issues and agree on approach	3/21/2011	3/21/2011	1d
5	Agreed upon changes are incorporated in the design; documented on the Design Review Log	3/21/2011	3/21/2011	1d
6	CxA performs a review at next DR phase to ensure that the agreed upon changes have been incorporated into the plans and specifications.	3/22/2011	3/22/2011	1d

Feb 27 2011 | Mar 6 2011 | Mar 13 2011 | Mar 20 2011

27 28 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26

An example design review is included in Appendix H.

Commissioning

Commissioning is a quality assurance process that is intended to verify that the design and construction of the building and systems comply with the OPR. For larger projects, commissioning can help the project manager by providing a team member independent of the design team who can assist in verifying the compliance of the design with the OPR and the concepts in the RHEA and MSOG documents.

One concern that contributes to over sizing is that the engineers are not sure that the envelope will be constructed as designed. Envelope commissioning, which is a relatively new practice, can provide an additional degree of confidence to a mechanical design engineer.

Where commissioning is part of the project approach, contract with a commissioning agent who is independent of the design team early in design development and include a review of the DD documents against the OPR and this guide as part of the commissioning design review scope.

Discrepancies in Capacity

Should the team arrive at an impasse relative to equipment sizing where the engineer states that they are legally responsible for the system and are not willing to size boiler, DHW or cooling systems as prescribed in this document, two options should be considered instead of increased boiler capacity:

- Provide additional thermal storage for DHW and/or heating
- Leave space and interconnection point provisions for a planned, orderly addition to central equipment capacity. Ensure funding is available for additional equipment should it be required

Provisions for additional capacity may also be warranted if future expansion or building use change is expected (such as change from family to elderly occupancy) in the future.

In a project at 110 North Champlain, provision for additional DHW capacity was included in a domestic hot water retrofit – the design engineer believed that three DHW heaters were needed, the energy team was certain that a single unit would meet the building load. Two units were installed and the pad and piping were provided for a potential third unit, which was never required. Project budget was available in case an additional unit was required.

As-Built Documentation

The investment in the soft costs of the project yields detailed documents of the building and components. These documents, frequently costing hundreds of thousands of dollars to develop, are often treated as having no value once the project is built. Using the design documents as a basis for as-built documents and then maintaining accurate records of the building and systems as they change over the life of the building is cost efficient and an important part of operating and maintaining high performance buildings.

The operator should take responsibility for maintaining the documents in accurate condition incorporating all building changes over the life of the building into the documents. As is evidenced by the number of major renovations of buildings, the lifespan of these facilities will exceed that of the installed systems; well maintained project documents will keep renovation soft costs and change-orders to a minimum. Creating drawings from scratch, after the fact, is difficult, expensive and often inaccurate.

The development and maintenance of accurate as-built documentation will be facilitated by the following:

- Design contracts should include a requirement for the electronic format in which the design team will provide to the contractor electronic copies of all design documents for the contractor's use in generating as built drawings. Contracts should state that the project Owner has full and complete ownership of electronic copies of the project documents. The design team should also be required to provide periodic review of and reports on the as-built documents during their construction site visits.
- The Construction contract should stipulate a requirement for submission of updated as-built documents with invoices and that if as-built documentation is not provided, invoices will be held until the contract terms are met.
- Where commissioning is included, the commissioning provider scope should include regular review of and reports on the mechanical system as-built documentation during site visits.
- After construction, a commitment should be made to maintain these documents with future changes to the building or systems. Any subsequent work to the building should be documented on the electronic building plans.

Key As-built milestones include:

RFP/Contract	Specify electronic format for design documents and require electronic documents be transferred to contractor for as-built development
Bid Documents	Require electronic as-built documents. Tie payment to receipt of updated as-builts
Turn-over	Verify completeness and adequacy of as-built drawings

Operations	Implement a process to ensure project documentation is accurately maintained

Operation and Maintenance Staff Training

System orientation and training should be required for all building operators, and is recommended for owner's facilities management/project managers, especially as new technologies are introduced. For new buildings and major renovation projects, training typically occurs at the end of project construction. Operators often do not assume full responsibility for the system until the system warranty period expires one year later. It is recommended that additional training be provided as the end of warranty period approaches to ensure the operating staff have the opportunity to apply what they've learned shortly after the training is completed.

Comprehensive training on the required maintenance and proper operation of the building's mechanical systems is critical to achieving persistent operation and the expected longevity of the systems as designed. A significant discrepancy was apparent in the retention of training between in-house maintenance staff and contracted maintenance staff. While training quality was found to vary from project to project, nearly all the in house maintenance staff interviewed indicated that they had received at least some level of training and remained in a position of operating and maintaining the systems on which they were trained. In contrast, the contracted maintenance staff we interviewed received no formal training on the systems and equipment they were hired to operate.

Comprehensive training that results in persistent, high-quality operation and maintenance can be achieved by including training requirements in the OPR, RFP and contracts. See example in Appendix I. In project RFPs require that training for each system or piece of equipment be spelled out in the project design documents. Details should include who the expected trainer should be e.g. factory rep or installer, the duration of the training, the location of the training e.g. on site & hands on or classroom and the number of required sessions if second or third shift staff will also require training.

Design review should include O&M staff review of the specified training requirements before documents are put out to bid. If the project is intending on contracting out the O&M work, contract with the provider during the design stage to obtain their input as well as that of in-house O&M staff.

As part of the contract documents, the engineers should include a requirement for the development and approval of training agendas prior to training occurring. The contractor responsible for training should be asked to indicate what specifically will be covered and approval from the trainees on that scope should be sought. If a discrepancy exists, i.e. the O&M staff does not feel what is proposed will be adequate, this process allows for adjusting the agenda before training occurs. For facilities that will outsource O&M, include in the contract documents a requirement for training to be repeated after the warranty period is up or after the O&M contract is awarded.

Another aspect of training that is rarely included in projects is for the mechanical engineer to instruct the building operators on the concepts behind the design and efficient operation of the building system. Such instruction should use one line riser diagrams of the system(s) and controls. The training should address the critical system interactions and the operating approach that will result in the delivery of amenities with the lowest energy cost. Such training is not part of a typical engineering contract and would be provided as an additional service unless it is specified in the RFP and contract.

Training Milestones include:

OPR	Include training requirements, specify in house or third party O&M, O&M provider input on

	training
RFP/Contract	Explicit language regarding training documentation requirements
Design Review	Ensure specs address training
Construction	Obtain training plans and review, ensure O&M staff are available for and attend training
Post occupancy	Schedule training at close of warranty period

System Operation and Maintenance

A building can be turned over to the Owner perfectly tuned and operating at optimal efficiency. However, all buildings experience performance degradation and on average buildings experience an energy efficiency depreciation of 2% to 3% annually, according to a study conducted by LBNL[3]. A building can provide good comfort, but unknown to building Owners and operators, is actually using far more energy to do so than in past years. The causes range from equipment deterioration to maintenance issues to control overrides.

There are two primary aspects of Operations and Maintenance. Preventative maintenance and repair refers to the regular steps necessary to keep systems running reliably. Operations ensure that the systems perform as intended and that they do it optimally.

Preventative maintenance (PM) is often outsourced. The PM contractor may not be familiar with the building, equipment controls of the operating strategies that maximize energy performance. During our site visits, systems were sometimes found to be past due for standard in-house maintenance such as filter changes and pump switchovers. Delayed maintenance can have significant energy impacts.

Preventive Maintenance

In order to maximize the benefit of preventative maintenance expenditures, include in the contract documents the development of an O&M matrix by the installing contractors that lists each piece of equipment requiring regular maintenance, the type of maintenance required e.g. filter changes, belt replacements, and the frequency. This provision should require that the O&M matrix reflect the as-built conditions and not necessarily those on the design drawings. It is often the case that equipment locations are adjusted during construction and room names or numbers change as well. A sample matrix is provided in Appendix J. Use the matrix as part of the maintenance contract when the work is outsourced and review it periodically within house maintenance personnel.

Groups managing many buildings may find preventive maintenance software useful in tracking and scheduling maintenance and repairs. Computerized maintenance management systems (CMMS) systems are available for purchase and operation on an office server or with remote servers and internet access. The lower end of the price scale for these systems is about $1,000 or $40/month for remote hosted systems. A shared Google spreadsheet may be adequate for tracking and assigning maintenance tasks for most projects.

[3] Lawrence Berkeley National Laboratory; Evan Mills. 2009. "Building Commissioning: A Golden Opportunity for Reducing Energy Costs and Greenhouse-gas Emissions"

Optimizing Operations

In order to ensure buildings are operated in accordance with the design, the building operators and the occupants need to understand how the building is intended to work, what the expected comfort ranges are and what to do when things seem to be going wrong. It is often at the time of a critical system fault that energy efficiency measures are overridden in an attempt to address a crisis. Systems are rarely returned to the correct settings once the issue has passed.

Engineer provided training on system concepts and the presence of clear single line riser diagrams in the mechanical rooms will help the operators understand the design intent for building operation.

Occupant education regarding the expected building performance may help mitigate complaints and can assist with identifying building operations outside of the expected parameters.

Monitoring and tracking energy use is the best tool for maintaining building performance over time. Meters with the ability to be read remotely are increasingly cost effective. Monitoring the energy data from the affordable housing stock on a regular basis would help identify anomalies that could then trigger an operational investigation. A system that included alarms when energy use in a given facility exceeded expectations would provide real time feedback regarding increasing energy use and could also identify underperforming equipment. Annual energy performance reports would enable comparison between buildings and help identify the buildings needing the most attention for energy tuning.

An approach that should be considered includes the bidding of a contract to install BTU meters on boiler and DHW systems and kW/kWh meters on the common area electric service. Such meters can be connected to the internet via standard router technology (connected to various stand-alone equipment controllers, such as Tekmar©, Btu meters, pump VFD's, etc.) and would cost approximately $6,500 per building installed. A separate service contract could be executed for remote energy monitoring, including set up and response to alarms and production of annual reports. Such a system would help catch issues early, enable communication with operations staff so that issues are addressed, verification of return to expected performance after issue resolution and reporting to design teams and developers on realized performance relative to goals.

Recommissioning

Larger buildings with multiple boilers may benefit from a periodic commissioning process. This includes *performance checkout* of main building systems and controls during construction and periodically (every 3-5 years) after occupancy. Studies[4] have shown that systematic, methodical recommissioning to maintain existing building performance has a median simple payback of .7 years, depending on building complexity.

Performance checkout includes equipment/device checkout and functional performance testing.

Equipment and Device Checkout should include:

- Sensing devices are accurate to within pre defined tolerances.
- Devices function as expected: they are verified to be in the position expected. Examples include outside air dampers fully closed when so commanded, heating hot water temperature sensor accuracy, a valve closes fully when off, etc.

[4] Mills, E., H. Friedman, T. Powell, N. Bourassa, D. Claridge, T. Haasl, and M.A. Piette, "The Cost-Effectiveness of Commercial-Buildings Commissioning" (2004), Lawrence Berkeley National Laboratory, http://eetd.lbl.gov/EMills/PUBS/Cx-Costs-Benefits.html

- Create a set of device check-sheets to list all the devices to be checked for a respective system. (These can be acquired in electronic format from new construction or renovation commissioning checkout documents, when included in contract documents as a commissioning service provider deliverable). Document the initial findings and accuracy of a device; document the final results after device calibration or repair/replacement.

Functional performance testing (FPT) should include verification of the sequences of operation in all modes of operation. This will include full and part load operation.

- Edit the FPT documents developed by the initial commissioning service provider to expand the testing scope or rigor as needed to ensure all operational conditions are tested.
- Document and record the performance. Clearly describe any performance deficiencies observed on the test documents and identify the necessary corrective actions.
- Include energy performance metrics in the FPT process. Include basic metrics such as pump inlet/outlet pressure, pump kW, amps, voltage, temperature and pressure setpoints, etc. Include space in the FPT documents to record these metrics. Also include simple, basic energy performance metrics, such as gpm per kilowatt, watts per cfm, etc. at full load and most importantly, during normal, part load operation.
- Compare the performance metrics to previous FPT records to determine if performance is degrading. If it is, determine what is causing the performance drift.
- Develop a corrective action spreadsheet log to track any deficiencies identified during device checkout or functional performance testing. The log will briefly note the system/equipment name, date, brief description of the deficiency, description of the necessary corrective action, the responsible party for correction, space for the party making the correction to state how the problem was remedied, and date corrected and a final “Issue Closed” column. The big benefit of a corrective action log is avoidance of issues “falling through the cracks” where they end up unaddressed due to normal human forgetfulness or miscommunication: assuming someone else was to deal with the issue.

Building operations and maintenance personnel should participate in periodic performance checkout process. This process is an excellent training and refresher mechanism.

Systems Operation and Maintenance considerations include:

OPR	Identify the planned O&M provider and limitations or expectations for the design relative to O&M (such as include remote read BTU and kWh loggers)
Commissioning Contract	If commissioning is part of the project scope, ensure recommissioning documents are a deliverable
Design Team Contract	Require a preventive maintenance matrix and one line schematics and system operating narratives, consider contracting for training
Bid Documents	Verify that the preventive maintenance matrix and remote read meting are specified. Tie payments to the delivery of the matrix

Construction	Ensure operations and maintenance personnel receive training during construction and at the end of the warranty period, verify operation of remote read energy loggers
Occupancy	Contract for remote monitoring of energy use, set up preventive maintenance tracking and schedule system, set up occupant complaint tracking, teach occupants about what to expect from the building

Additional Development Efforts to Support Permanent Affordability

Some of the recommendations above would be easier to implement with additional development work. The following items are areas that should be considered for further investment to support the evolution of the design, construction and building operating process towards permanent affordability:

A master OPR should be developed by the stakeholders including developers, owners, operators, residents and others such as Efficiency Vermont. The master OPR can then be used as a model on every new project. Once the master OPR is developed, training should be provided to project managers and building operators about the value of using and maintaining the OPR.

Develop standardized training programs for common systems and controls. Training could then be delivered directly to the responsible parties on an ongoing basis. Operator certification could also be pursued as part of an ongoing training program. Common training could provide an opportunity for operators to interact and identify local resources to help them should they have a building issue.

A resident training program could be developed to help residents understand how their buildings work. Training could address issues as diverse as the potential for overheating in the shoulder season and how to mitigate that through window use, occupancy sensors in hallways and thermostat use.

Further investigation of the remote monitoring concept to define the scope, costs and benefits would enable pursuit of funding to support implementation.

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Introduction

This section focuses primarily on buildings that have central heating plants as air conditioning has not traditionally been considered a necessity in affordable housing. As the analysis of these buildings progressed, the issue of potential overheating due to the interactive effects of a high performance envelope and the internal building loads was identified. Modeling, which does not reflect the use of operable building windows, showed a particularly high impact in the shoulder seasons. Design teams need to pay particular attention to issues associated with maintaining comfort during non-heating hours in high performance buildings. When cooling is not provided, the architect should design for passive cooling and accommodation should be made for occupant provided window air conditioning, if such equipment will be allowed.

Determination of Loads and Fuel Use

Modeling Approach Abbreviations

The modeling abbreviations correlate to each building type. The building types are: "D" for Duplex-style, "T" for Townhouse-style and "DLC" for Double-Loaded Corridor-style.

Modeling Approach D T DLC

Load and energy calculations should be performed using an ASHRAE or IECC compliant analysis method. Appropriate tools include:

- Manual J software or spreadsheets for load calculations – typically appropriate for duplex and townhouse style buildings
- 8760 modeling software for energy analysis and loads – typically appropriate for optimization of double loaded corridor buildings, may also be used in smaller buildings

The development of the RHEA long term affordable envelope was based on a process of optimizing the envelope for energy affordability over time. Any additional optimization should use the RHEA envelope parameters as the minimum and use the RHEA cost effectiveness screening approach in comparing building design approaches. The modeling approach should always seek to minimize loads through building orientation, envelope optimization, and shading, then select the most efficient systems to satisfy the building loads. The process will be iterative in order to ensure the optimal solution is achieved. The outcome will be the lowest first cost system that achieves the goal of $75 PUM cost in 2025. Analysis must begin in the Schematic Design phase to evaluate impacts of building orientation on energy use and should be largely completed at the completion of Design Development.

The findings from the extensive modeling performed to develop this guide and the building envelopes meeting the ""near term" or "long term" affordable" option in the RHEA are provided below to serve as a comparison when sizing mechanical systems for long term affordable housing. Project specific system sizing will vary depending on the specifics of each building; however, significant deviations from these results must be explained by the design team. Loads that significantly exceed the loads established in the development of this roadmap will likely result in over sized equipment and energy use in excess of the long term affordable goal.

- *Important information to review on a project-by-project basis is outlined in Appendix B and includes:*
  - *Envelope R-values*
  - *Infiltration rate – The infiltration rates modeled are very low. An increase of 0.1 ACH doubles the infiltration heating load.*
  - *Wall to Floor Area ratio*
  - *Window Area to Wall Area ratio*

The following tables summarize the results of the Roadmap modeling effort. As noted in the modeling section of this guide, the results were correlated between two independent models. The numbers in these tables serve as a metric for evaluating building specific analyses. The following envelop and ventilation values were included in the models and impact the results.

Model Envelop Inputs			
	Duplex	Town House	DLC
Attic	R-59	R-50	R-59
Wall	R-40	R-27	R-25
Window	R-5	R-5	R-5
Nat ACH	0.1	0.2	0.1
Total ACH (Nat + HRV)	0.29	0.3	0.21

Energy Use Index - No Cooling	Duplex	Town House	Double Loaded Corridor
Number of Units	2	12	32
Building Floor Area (sq-ft)	2,498	12,670	33,000
Modeled Space Heat Fuel Use (MBTU/yr)	37,000	87,000	168,800
Modeled DHW Heat Fuel Use (MBTU/yr), with 50% by SDHW [1][2]	28,550	117,500	276,885
Total Heat & DHW Fuel Use (MBTU/yr)	65,550	204,500	445,685
PUM Today	$59	$31	$25
PUM Year 15 Low Esc.	$123	$64	$52
PUM Year 15 High Esc.	$246	$128	$105
Modeled Peak Boiler Space Heat Load (MBTU/hr)	35.6	111.0	207.1
Modeled Peak DHW Generation Load (MBTU/hr)	50.0	105.0	210.0
Heating/DHW Energy Intensity (MBTU/sq-ft/yr)[1]	26.2	16.1	13.5
Peak Heating Load Intensity (BTU/hr/sq-ft)	14.3	8.8	6.3
Boiler Number and Size	1 @ 90 MBTU/hr	2 @ 105 MBTU/hr	4 @ 105 MBTU/hr
Notes: [1] DHW Fuel number represents fuel required to supplement solar DHW heating at 50% capacity. [2] Based upon 30 gal/person/day average DHW use.			

Energy Use With ASHP's & Cooling	Duplex	Town House	Double Loaded Corridor
Number of Units	2	12	32
ASHP Heating kWH	3,900	9,800	21,800
ASHP Cooling kWH	2,180	14,400	42,400

ASHP Heating & Cooling kWH	6,080	24,200	64,200
Heat/Cool PUM Today	$38	$25	$25
DHW PUM Today	$26	$18	$16
Total PUM Today	$64	$43	$41
PUM Year 15 Low Esc.	$132	$89	$84
PUM Year 15 High Esc.	$266	$179	$170

Modeling/Calculation Inputs D T DLC

The modeling/sizing input worksheet in Appendix B should be used to document the building characteristics input to the analysis. When performing calculations early in the design, identify the parameters that may vary as the design progresses, such as window area or roof configuration, and identify the values or range of values used to evaluate building optimization or equipment size.

- Building modeler should prepare the modeling input worksheet prior to commencing any calculations.
- Provide the inputs to the design team, including owner
- Design team and Owner acknowledge impact of input values on sizing and agree in writing that the input values reflect the building that as it will be constructed

Sources for input values must be clearly identified, all assumed values noted as such and the document annotated to facilitate third party review by a commissioning engineer or other design professional.

- The building envelope should meet the long term affordable option described in RHEA. If in the course of developing load calculations or building models, the engineer identifies discrepancies between the architectural documentation and the envelope requirements for the building, these issues must be brought to the attention of the team.
- Where input values are unknown, the modeler should obtain signoff on all assumed values by those members of the team responsible for affecting those inputs.
    - For example, if the roof color or emissivity of a large, DLC building is not known at the time of initial modeling, the assumed color in the model then becomes an input the architect must consider when roof color is discussed. It should not necessarily fix the decision but the modeler should be prepared to discuss the impacts that various decisions may have.

Internal space temperatures play a significant role in determining the calculated loads for a building. Particular attention must be paid to this in elderly housing as their needs are often 5 to 7 degrees higher than the general population. Results of data logging metering of actual thermostat set points in apartments with older adult occupants have found 73F to 76F settings common.

- The Vermont Residential Building Energy Code does not have any specific requirements for internal design temperatures.
- ASHRAE 90.2-2007 Energy Efficient Design of Low-Rise Residential Buildings
- Energy consumption and system sizing for modeled buildings in this guide are based on an internal heating temperature set point of 70 deg F.

  - Discuss and agree upon the internal design temperature for each specific project with the architect, developer and owner. Ensure consensus is reached on the appropriate design temperature.
    - Engineer should provide input regarding the impact of a decision that is higher than the modeled set point noted above. Input should include first cost, mechanical room size and operating cost implications.
- For housing intended for the elderly, the internal temperature setpoints should be clearly defined in the OPR by the owner; particular attention must be paid to the higher expected set points.

Right Sizing D T DLC

Right-sizing of mechanical systems is a known mechanism to achieve improved comfort and energy performance. ***While it is often perceived that the sizing cushion or safety factor achieved by over sizing equipment will ensure comfort, it frequently results in systems that short cycle and cannot effectively maintain building comfort at part loads. Right-sized systems will perform equally as well under design conditions as their oversized counterparts and will certainly perform better under part-load conditions.***

Significant efficiency savings in both heating and cooling seasons can be achieved through right sizing central equipment. In addition, right sizing reduces first costs and ensures the benefits resulting from investments in the building envelope are realized.

- Oversized central equipment that does not have high turndown capability will cycle even under peak load and short cycling will occur frequently in off-peak conditions thereby appreciably reducing the equipment efficiency and life.
- Oversized central equipment that does have high turn down capability will be less affected by marginal over sizing, but this should not justify simply adding capacity to a system without good reason.
- Thermal Energy Storage offers an energy efficient and cost effective way to overcome concerns about envelope performance, provide a safety margin due to uncertainties regarding building use and to address over sizing due to unavailability of equipment that meets the load.
- Oversized central equipment adds first cost to a project and increased replacement cost in the future.

Another contributor to over sizing is the use of a blanket safety factor. Often, this is in the form of a percent added to the calculated heating and hot water load. For example, the load is calculated at 70,000 BTU/hr and the engineer adds a 10% safety factor. That brings the sizing criteria up to 77,000 BTU/hr. In addition to blanket safety factors, many systems designers use specific safety factors although they are not noted as such. For instance, if given an ACH rate of 0.10, a designer might choose to increase that in his or her model to 0.20, "just to be safe."

- Boilers come in discrete sizes. In systems where one boiler will be installed, it is likely that the available boiler sizes will already impart some measure of additional capacity.
  - In the example above, a 75MBH boiler would suffice and provide a built-in 7% margin. On paper, though, this boiler will not meet the requirements when the 10% safety

factor is added. Installing the next sized boiler will result in one with significant capacity beyond the actual peak heating load.

- Specific building component safety factors will incorrectly adjust the calculated load in a similar manner to blanket safety factors.
- Very often, both types of safety factors are used when calculating loads and it is not always obvious, even to the designer, that this is happening. When this is done it compounds the issue of over sizing the central heat & DHW equipment.
- Any safety factors used in the analysis must be expressly stated in the Modeling Inputs Document.
- In order to waylay concerns the mechanical systems designer may have that would otherwise result in the use of safety factors, agreement on the testing procedures used to verify the efficacy of the building envelope and the process for ameliorating any deficiencies should be agreed upon by the mechanical systems designer, architect and owner upfront.

Contingency Planning for Additional Capacity

Contingency planning involves making provision for the addition of future heating or domestic hot water equipment. This additional capacity could be due to a potential change in occupancy such as a transition from family to senior housing.

Another reason contingency provisions have been included in projects is the mechanical designer's skepticism that the envelope will perform as expected. As explained earlier, this skepticism should be addressed early in the project by the entire team via a well thought out plan for testing the building envelope, because even if the contingency is provided for, funds may not be available to purchase additional equipment after construction. If the team agrees on this approach to deal with uncertainty regarding loads, a written agreement should be documented.

An example of provisioning for additional capacity can be found in the Waterfront Housing building in Burlington, VT, which is a LEED certified, three-story, double-loaded corridor apartment building on the waterfront. The central plant equipment consists of Weil-McLain Gold condensing boilers. In this installation, four boilers were installed in parallel connected to common supply and return headers. An additional concrete pad, interconnection fittings, vent pipe connections as well as additional controller channel capacity were included in the event that additional capacity were determined to be needed—either after the initial heating season, or down the road.

Fuel Selection

Fuel type availability, need for cooling, familiarity of operating personnel with technologies and load/equipment sizing are factors that need to be considered in selecting the right fuel.

- Where natural gas is available, it is the preferred fossil fuel source, unless the building program includes cooling in which case an all electric system should be evaluated.
- For buildings without cooling outside of Vermont Gas service territory fuel should either be biomass or oil.
    - Biomass is a suitable option for all affordable housing provided the delivery and storage of fuel can be accommodated. See Bio Mass Fired Boiler section for more detail.

    - PFI[5] Premium grade wood pellets are the recommended choice for all affordable housing projects.
    - While neither pellet pricing nor pellet energy content is regulated, the physical properties of pellets are[6]. This ensures consistent size, mass, moisture and ash content as well as other physical properties thereby allowing for choices when specifying pellet boilers.

- No 2 fuel oil should be utilized where natural gas is not available and the choice has been made not to use biomass.
- Electricity is an appropriate choice for low energy building space conditioning only when both heating and cooling are required and the building envelope meets the long term affordability standards outlined in RHEA. The cost of electricity per btu is significantly higher than that for fossil fuels, so electricity can only compete from a cost perspective when very high efficiency equipment (EERs > 11.9 and COP > 3.5) are applied.
- Propane is not a recommended fuel source because the cost per Btu of propane is significantly higher than that for fuel oil. When both propane and oil are at the same cost per gallon, the cost per Btu is actually about 50% higher for propane. When accounting for premium efficiency propane heating equipment – the cost per delivered Btu of heat for propane is still about 40% higher than the cost for less efficient oil heat.

[5] Pellet Fuels Institute

[6] The pellet industry currently self-regulates the quality of their pellets; there are no independent testing requirements yet

Cooling Systems D T DLC

The need for building cooling should be evaluated at two points during project development:

- During project scoping and pricing the team should determine whether the project will require cooling for space conditioning
- During modeling the design team should provide feedback to the developers regarding any potential issues with overheating so they can be addressed

One of the concerns regarding cooling is the fact that the high performance envelope necessary to achieve the near term affordability goals does not enable the installation of occupant supplied window air conditioning units. If occupants attempt to install window mounted air conditioning equipment in high performance casement windows, damage to the building envelope is inevitable and the high performance aspects of the building will be compromised. For projects without cooling, teams should consider including accommodation in the building envelope for occupant supplied cooling equipment; otherwise the tenant leases should specifically indicate that cooling, even occupant supplied cooling, is not allowed in the building.

The cooling system determined to meet the established affordability criteria (for heating and DHW) is a very high efficiency air source heat pump (ASHP) system. These systems are fundamentally different from water based systems in that they use refrigerant to transfer heat from inside to outside and vice versa.

Considerations for Use of ASHP Systems

- The design and installation of refrigerant based systems must adhere to ASHRAE Standard 15.
  - ASHRAE 15 places limits on the quantities of refrigeration that may be released into enclosed spaces
  - These limits must be reviewed, particularly in the case of large, central VRF-style systems particularly relative to the potential for refrigerant release into sleeping quarters, when occupants may be sleeping.
- Refrigerant piping length is limited by manufacturers. The limits are dependent on many variables and must be confirmed with the manufacturer relative to each specific installation.
- Refrigerant based systems are inherently proprietary. Unlike water based systems where equipment is interchangeable from one manufacturer to the next, once a manufacturer is chosen for a refrigerant based system, only that manufacturer’s system components may be used when replacements are necessary.
- Very often maintenance on refrigerant based systems must be done by “qualified” maintenance staff which can reduce the field of available vendors and increase costs.
- Large VRF systems cannot be easily zoned to isolate a system leak. A leak in a VRF system is likely to require the entire system to be taken down in order to repair the leak.

Cooling Equipment

The systems will consist of in-unit evaporators aka fan coils and remotely located condensing units. These systems can be broken into two categories:

- Individual - One system per unit where a “system” consists of one or more evaporators connected to one outdoor condensing unit.
    - Consideration for sharing loads, where one evaporator would be heating and another cooling is not an expected mode of operation for these systems.
- Central – Multiple evaporators serving different units are connected to a central condensing unit.
    - Central systems are typically variable refrigerant flow (VRF) systems capable of sharing load between zones in heating mode and those in cooling mode.

Both types of systems should utilize R-410A or 407C as the refrigerant.

Individual Systems D T

Individual systems will typically consist of ducted or ductless evaporators and one outdoor condensing unit per system. They are applicable to all duplex style housing and can be applied in all townhouse style housing as well although larger townhouse style projects, those consisting of 6 to 8 connected units or more can consider central systems as well.

Ductless evaporators will have to be located in each non-contiguous space within each unit to ensure proper space conditioning. Ductless systems must be selected to ensure the evaporator is appropriately sized for the application. The heating and cooling loads in buildings with exceptionally good envelopes are very low.

Manufacturers must be consulted regarding heating capacities at very low outdoor air temperatures. The models noted below are rated to between -13 deg F and -15 deg F ambient, but under certain circumstances may be able to operate at lower temperatures. These circumstances are manufacturer specific; consult the manufacturer when lower ambient temperatures are expected.

- *An example of an acceptable ductless system is:*
    - *Mitsubishi MUZ (outdoor) and MSZ (indoor), 15.5 SEER and 8.5 HSPF*
        - *Available with 2 to 8 zones*

Ducted evaporators can be centralized to distribute conditioned air to multiple spaces, combining them into a single zone.

- *An example of an acceptable ducted system is:*
    - *Mitsubishi MUZ (outdoor) and SEZ (indoor), 15.5 SEER and 8.5 HSPF*
        - *Available with 2 to 8 zones*

Central Systems T DLC

Central systems will typically consist of ducted or ductless evaporators, each controlled by a thermostat and connected to a central condensing unit. Refrigerant piping can be limited in large, DLC style buildings by using two or three central condensing units rather than one.

- *An example of an acceptable ductless system is:*
    - *Mitsubishi CityMulti H2i (outdoor) and PKFY (indoor)*

    - *Available with up to 50 zones*

Ducted evaporators can be centralized to distribute conditioned air to multiple spaces. This does not allow for individual control of each space, but this is often not necessary.

- *An example of an acceptable ducted system is:*
  - *Mitsubishi CityMulti H2i (outdoor) and PEFY (indoor)*
    - *Available with up to 50 zones*

Central Heating Plant

For most buildings, the heating plant will be an integrated system providing heat and domestic hot water. Because of the low heating loads of these buildings, this approach will result in the least energy consumption and the lowest first cost.

Modular Design

Modular system design, with multiple, smaller central plant units, increases efficiency and provides redundancy, particularly when serving buildings with four or more housing units. In the case of equipment with higher part load than full load efficiencies, such as condensing boilers with modulating burners, multiple boilers should be fired in parallel to meet part load demand while optimizing efficiency. In the case of boilers with higher efficiency at full load, the sequences can be configured to operate only one unit until it reaches capacity, at which point another unit can be brought online, again optimizing combustion efficiency, to the extent possible, based upon the specific equipments performance characteristics.

Modeling was done for one, two, three and five boiler systems on buildings with four or more units. Based on the modeling results, the recommendation is to use as many boilers as possible to match the building load, each sized at the appropriate percentage of load, up to three boilers. The benefits of multiple boilers include:

- Increased ability to ride through the loss of a boiler in high load conditions
- Boiler staging to better match part load conditions
- Optimized system efficiency

Modular design enables matching total boiler capacity closely to the building loads and also enables the provisions for contingent supplemental capacity with much less first cost impact than adding a fully redundant boiler.

Oil Boilers D T DLC

Most oil boilers at any size are available with single-stage or two stage burners. When these boilers are required to perform in off-design conditions, conditions that occur between 95% and 99% of the time, they are forced to cycle on & off more frequently. The further actual conditions are from design conditions, the more frequently the boilers will cycle which results in significant degradation of operating efficiency, increases the likelihood or premature failure and causes noise problems for building occupants. This short cycling condition has been observed in recent affordable housing installations and must be avoided through appropriate application of the sizing and equipment selection criteria in this guide. Oil boiler technology has recently advanced to include condensing boilers (modulating and non-modulating). Optimal efficiency equipment will help to keep energy use affordable as fossil fuel prices escalate and should be selected.

- *Two oil boilers are recommended. Both are condensing oil boilers with AFUE ratings above 91%.*
    - *Buderus Logano GB125BE*
    - *Peerless Pinnacle PO-70 or PO-84.*
- *For fuel oil systems, Thermal Energy Storage (TES), described below, will likely be necessary to minimize boiler short cycling whenever non-modulating boilers are specified.*

  - *The manufacturer's offerings should be reviewed regularly for the introduction of additional modulating oil boilers. Currently, the Peerless boiler does not modulate while the Buderus model does.*
  - *As condensing oil boiler technology advances the boilers may perform better at low load conditions and the need for thermal energy storage may be reduced.*
- *Both recommended boilers allow resetting the HW temperature based on outdoor air temperature. This function should be utilized as outlined in the* Hot Water Temperature Control *section.*

Natural Gas Boilers

High efficiency natural gas condensing boilers should be used.

- *Three oil boilers are recommended for consideration. All have AFEU ratings above 95[7]%.*
  - *Buderus Logamax Plus GB142*
  - *W eil-McLain Ultra*
  - *Peerless PureFire*
- *The recommended condensing boilers utilize burner modulation as a means of capacity control. In most cases, TES is not required for these boilers.*
  - *The specific minimum turndown of the boiler should be reviewed specifically for each project. Based on that minimum value, consult the* Thermal Energy Storage *section to determine whether TES should be included.*
- *All recommended boilers allow resetting the HW temperature based on outdoor air temperature. This function should be utilized as outlined in the* Hot Water Temperature Control *section.*

Wood Pellet Fired Boiler

Wood pellet boilers are another viable option for space heating and domestic hot water generation due to fuel availability and cost. Pellets have the highest delivered BTU per fuel dollar of all current fuel options. Pellet boilers are applicable to all building types discussed herein. Unlike other currently available biomass options, such as wood chips, pellet fuel quality is determined by standardized testing, the requirements of which are described by an independent, third party, the PFI. The operation of pellet boilers, however, is very different than gas or oil fired boilers. Pellet boilers should only be cycled (started & stopped) between once and twice per day according to most manufacturers. This means that even at minimum turn down, on most days the boiler will want to cycle many times. In order to avoid this cycling thermal energy storage (TES) must be included in the system design.

- *All pellet boiler systems require TES to function properly and at optimal efficiency.*
- *Two pellet boilers are recommended for consideration. Both have manufacturer's efficiency ratings above 85%.*
  - *TARM Fröling P4*
  - *Ökofen Pellematic*

[7] 10 CFR Part 430

Consideration must be given to fuel storage space as well. Whether biomass systems are wood chip or pellet systems, the same guidelines apply to fuel storage.

- Location, location, location. Ensure the storage location is close enough to a road, driveway, or other area that will allow a delivery truck proper access. Size and weight of the truck as well as length of the delivery hose or pipe must be considered as should the ability of the maintenance staff to maintain access to the delivery location after significant winter storms.
- The designer must contact the expected fuel provider at the beginning of the design process as delivery considerations could likely impact the location of the fuel storage or even the decision to use a biomass system.
- Biomass fuel must be fire separated from the rest of the building. Discuss the proposed installation with the local AHJ to ensure their requirements are met.
- Biomass fuel must be kept dry.
- It is recommended to size the storage capacity to minimize the number of deliveries to one or two per heating season. This is somewhat dependent on the size of the available delivery truck and should be coordinated with the local supplier.
    - Delivery during non-heating season, i.e. for the purpose of indirect DHW, will not generally pose much of a challenge due to clear roads, driveways, etc.
- Visual indication of the fuel level is required.
- All components of outside storage systems should be UV resistant. This is typically not an issue with the silo, tank, etc. but must be considered for the fuel transfer or conveyance equipment.

Wood pellets must be rated Premium[8] by the PFI for nearly all residential pellet boilers. These pellets are required to have a minimum density of 40 pounds per cubic foot. The PFI does not set standards for energy content (BTU/lb) of pellet fuels, but the generally accepted “good but achievable” energy content is roughly 8,000 BTU / lb or 16 Million BTU / US ton.

Example of storage requirement calculation:

> Assume:
>
> Annual energy consumption of 80,000,000 BTU per year to be addressed with pellets.
>
> Pellet boiler efficiency: 85%
>
> (80,000,000 BTU) / [(8,000 BTU/lb)*(0.85)] = 11,765 lbs
>
> (11,765 lbs) / (40 lbs/cuft) = 294 cu ft or a 6’-8” cube.
>
> This assumes one delivery per year. Multiple deliveries will lower the storage capacity requirement.

[8] As of October 25, 2010, the “Super Premium” is no longer used by the PFI.

Thermal Energy Storage D T DLC

The objective of TES is to improve system efficiency by increasing the minimum boiler firing time and minimizing short cycling, especially in low load conditions. TES ensures maximum efficiency in fuel fired equipment that does not modulate and can eliminate or greatly reduce the maintenance associated with burning biomass. A critical step in sizing TES is obtaining the boiler minimum run time from the equipment manufacturer.

Quantifying the benefits of TES is difficult to do accurately. There is industry consensus, supported by the U.S. DOE, that minimizing boiler cycling results in more efficient boiler operation. There does not seem to be much consensus, however, or available data from manufacturers regarding the precise reduction in efficiencies due to cycling. Cycling inefficiencies are attributable to the pre-purge and post-purge cycles of the boiler before and after the burner fires. These purge cycles serve to eliminate combustible gasses that may accumulate in the boiler. The losses occur because the purged air removes heat from the boiler that would otherwise have been used to heat the water.

In its simplest form, TES will consist of a storage, or buffer tank, of water that is heated by the boiler. The thermal mass of the buffer tank allows the boiler ON-OFF cycle to be significantly extended.

- TES should be included in the following systems:
  - Oil systems in which the modulation or turndown ratio is not adequate to allow the boiler to meet the part load condition of the building without short cycling (most oil fired boiler systems)
  - Biomass fired heating systems.
- TES may also be necessary in low energy multifamily buildings where the DHW load drives the size of the boiler. This means that the boiler may be oversized for the heating loads and will, to some degree, short cycle particularly in off-design conditions. The inclusion of TES, if sized properly, will significantly reduce this short cycling and extend the life of the equipment as well as increase its overall operating efficiency.
  - This applies to systems with indirect DHW heaters
  - The necessity for TES should be reviewed with the chosen boiler’s ability to modulate considered.

Two manufactures are listed below. Both of these manufacturers offer small, residential scale buffer tanks as well as larger ones. Both manufacturers also list the insulation of the tank at R-12 or better. It is important to know the insulation value applied to the tank as this will directly impact the standby losses.

- Heat-Flo
- Boiler Buddy
- Lochinvar

Following is the method used to calculate the tank volume.

$V = t*(Q_{b-min} – Q_{l-min}) / (dT \times 500)$

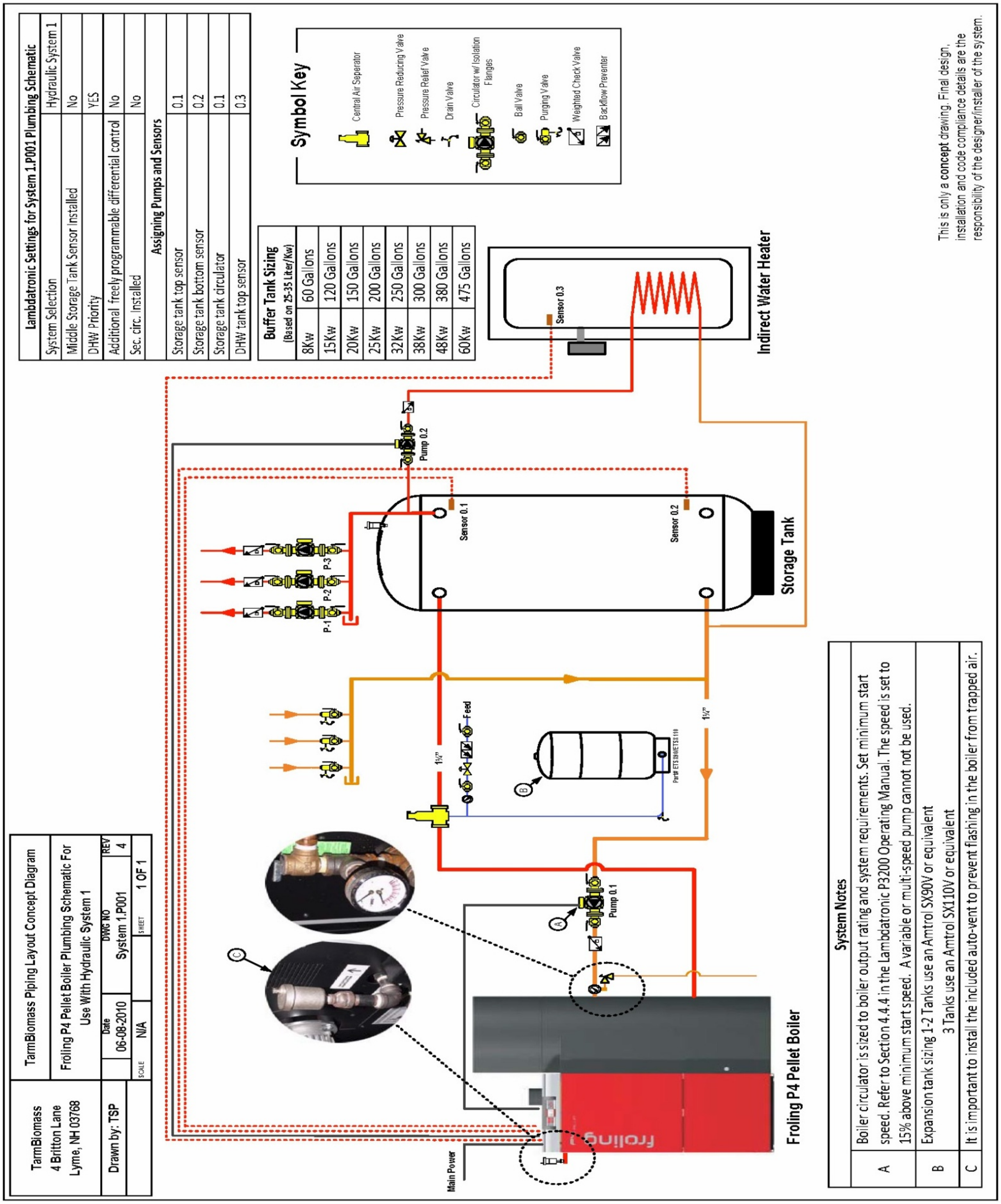
Where:
V = Tank volume in gallons
t = minimum boiler run time in minutes
Q_{b-min} = Boiler minimum heat output in BTU per hour
Q_{l-min} = System minimum rate of heat use in BTU per hour – unless a constant load is present, this can be assumed to be 0 to ensure minimum boiler run time is always achieved.
dT = Tank temperature difference between boiler start and boiler stop calls

Given an oil fired boiler with a **10 minute** desired fire time and a **minimum output of 20,000 BTU / h** and a **10 deg temperature difference**:

V = (10 min)*(20,000 BTU / h – 0 BTU / h) / (10*500) = **40 Gallons of storage**.

TES allows the heating system to operate for a limited time while the boiler is being serviced. See diagram following from TARM, a pellet boiler manufacturer, for an example of a TES piping arrangement. Supplemental information on this diagram is specific to this manufacturer only; the selected manufacturer should be consulted regarding applicability to their boiler.

SEE DIAGRAM ON FOLLOWING PAGE


TarmBiomass
4 Britton Lane
Lyme, NH 03768
Drawn by: TSP
TarmBiomass Piping Layout Concept Diagram
Fröling P4 Pellet Boiler Plumbing Schematic For Use With Hydraulic System 1
Date 06-08-2010
DWG NO System 1.P001
REV 4
SCALE N/A
SHEET 1 OF 1
Lambdatronic Settings for System 1.P001 Plumbing Schematic
System Selection: Hydraulic System 1
Middle Storage Tank Sensor Installed: No
DHW Priority: YES
Additional freely programmable differential control: No
Sec. circ. Installed: No
Assigning Pumps and Sensors
Storage tank top sensor: 0.1
Storage tank bottom sensor: 0.2
Storage tank circulator: 0.1
DHW tank top sensor: 0.3
Buffer Tank Sizing (Based on 25-35 Liter/Kw)
8Kw 60 Gallons
15Kw 120 Gallons
20Kw 150 Gallons
25Kw 200 Gallons
32Kw 250 Gallons
38Kw 300 Gallons
48Kw 380 Gallons
60Kw 475 Gallons
Symbol Key
Central Air Seperator
Pressure Reducing Valve
Pressure Relief Valve
Drain Valve
Circulator w/ Isolation Flanges
Ball Valve
Purging Valve
Weighted Check Valve
Backflow Preventer
Main Power
P-1
P-2
P-3
Pump 0.2
Pump 0.1
Sensor 0.1
Sensor 0.2
Sensor 0.3
1¼"
Feed
Froling P4 Pellet Boiler
Storage Tank
Indirect Water Heater
System Notes
A Boiler circulator is sized to boiler output rating and system requirements. Set minimum start speed. Refer to Section 4.4.4 in the Lambdatronic P3200 Operating Manual. The speed is set to 15% above minimum start speed. A variable or multi-speed pump cannot not be used.
B Expansion tank sizing 1-2 Tanks use an Amtrol SX90V or equivalent
3 Tanks use an Amtrol SX110V or equivalent
C It is important to install the included auto-vent to prevent flashing in the boiler from trapped air.
This is only a concept drawing. Final design, installation and code compliance details are the responsibility of the designer/installer of the system.

Terminal Equipment

D T DLC

Heating Equipment

Terminal equipment delivers heat to the occupied space. By significantly reducing the instantaneous heat loss as well as reducing the overall rate of heat loss, high performance building envelopes allow for relatively lower temperature heating water to be delivered to the terminal devices and provide sufficient heat to maintain occupant comfort. As discussed in the Hot Water Temperature Control section, the design day hot water supply temperature should be 130 deg F where condensing equipment is utilized. A design strategy of utilizing 130F design water temperatures will significantly increase the total footage of finned tube radiation required by a factor of about 2.5. This incremental cost is offset by reduced fuel use through boiler efficiency by always operating in condensing mode. The supply temperature, along with the design dT or temperature difference between supply and return water are the driving factors in the selection of terminal equipment.

The two most common types of heating terminal devices are baseboard radiation (finned tube) and panel radiators, also known by their manufacturer's name, Runtal. More traditional style radiators are also readily available.

- Finned tube, panel style, and traditional radiators are all acceptable terminal devices for low energy buildings.
- Finned tube will result in the lowest first cost when compared to panel type or traditional radiators.
    - Finned tube should be the basis of design for affordable housing.
- Finned tube radiation should be "light commercial" grade for longevity and performance. Standard residential grade radiation lacks durability.
- For an average water temperature of 125 deg F, the expected output of both finned tube and panel style radiators will typically be in the range of 250 BTU/h/LF to 300 BTU/h/LF.
- Finned tube and flat panel devices should be installed at the base of the exterior perimeter wall of the room.
- Flat panel applications should consider the surface temperature of the panel when HWS temperatures above 130F are utilized, to avoid injury to young children.
- Heating hot water design temperature differences of 20F or greater will minimize pump size and annual pump energy use.
- Ceiling mounted radiant panels are not recommended. Due to their purely radiative output, they provide comfort primarily to occupants situated directly beneath them (there is no opportunity for convection) and cannot overcome any downdrafts on perimeter walls (drafts at the perimeter are not an anticipated concern in low energy buildings).
- Radiant floors are typically not cost effective in affordable housing.
- At flow rates below 1.0 GPM, manufacturers of terminal equipment should be consulted regarding the ratings of their devices.

Terminal Device Control - Thermostats

In all cases, terminal heating devices will be controlled by a space thermostat which will call a zone valve to open or close based on the need for heat.

D **T**

In duplex and townhouse style buildings heating zones should be set up as follows:

- One zone per floor per unit

The central heating system should operate directly by a space thermostat. For one or two zones systems the thermostats are wired directly to the boiler control panel. Systems with more than two thermostats will use an end switch on the zone control valve to activate the heating system.

DLC

In DLC style buildings, the zone heating systems should be controlled with a thermostat controlling its respective zone valve with end switches. Closure of the end switch will activate central heating hot water pumps. Controllers (such as Tekmar®) within the central heating plant manage the plant boiler staging, HWS temperature reset, etc. In this case the thermostat will control the local zone valve and the central system will operate to maintain a hot water system temperature and pressure to ensure heating hot water will be delivered to the loads that are calling for heat.

D **T** **DLC**

Thermostats should have the following attributes:

- No batteries required
    - Dead batteries often result in service calls. When a service call costs $50 per hour for the technician, vehicle, etc, this becomes a *very* expensive battery.
- Lockable set point limits
    - This is necessary so occupants do not set their thermostats to 84 degrees for example.
- Clear indication of space temperature and space set point.

Standalone programmable thermostats are not generally recommended due to the requirement of batteries and due to occupant confusion in using these devices. However, significant savings can be seen in incorporating a setback during unoccupied spaces and DDC connected, hardwired thermostats with local override should be considered to take advantage of these potential savings.

Zone Valves

Zone valves should be two position, ON-OFF valves with spring returns. This means that they are either powered open (normally closed – N.C.) or powered closed (normally open – N.O.). “Normal” refers to the position of the valve when no power is applied.

- N.C. zone valves should be used so the valves do not have to be powered closed all summer long. This will extend the life of the valve actuator compared to a N.O. valve that must be powered closed continuously all summer long.

- Zone valves should be full port, sized to match the piping size they are installed in to minimize water friction losses.
- Size zone valve actuators for pump maximum expected operating pressure to ensure full closure under maximum pressure conditions.

Pipe and Duct Sizing D T DLC

Distribution ducts and pipes should be sized to limit pressure losses and noise attributable to fluid flow while maintaining first cost expectations. A 3” pipe requires exponentially less energy be used to pump water than a 1” pipe conveying the same flow rate, but the first cost tradeoff, assuming a 1” pipe would normally be used, is likely not acceptable.

In general, the following guidelines should be followed for duct and pipe sizing:

Ductwork:

CFM equal to or less than 500 cfm: 0.05” of pressure loss or less per 100 ft of duct.

CFM between 500 cfm and 1,500 cfm, 0.08[9]” of pressure loss or less per 100 ft of duct.

CFM greater than 1,500 cfm, 0.10” of pressure loss or less per equivalent 100 ft of duct OR a maximum of 1,000 FPM where ducts are in ceilings or chases immediately adjacent to dwellings OR 1,500 FPM otherwise, whichever method yields the larger duct.

These equate to:

>500 CFM & <1500 CFM at .08’’/100 FT	Minimum (cfm)	Maximum (cfm)
18’’	1281	1750
16’’	901	1280
14’’	600	900
< 500 CFM at .05’’/100 FT	Minimum (cfm)	Maximum (cfm)
12’’	301	500
10’’	161	300
8’’	76	160
6’’	46	75
5’’	26	45
4’’	0	25

Piping:

All GPM: 3’ of pressure loss or less per equivalent 100 ft of pipe.

[9] *Advanced Energy Design Guide for Small Office Buildings*, 2004, ASHRAE

Type L Copper	Velocity (FT/s)	Flow (GPM)
¾''	1.8	2.9
1''	2.2	6.0
1¼''	2.7	10.8
1½''	3.0	17.0
2''	3.5	37.0
Sched. 40 Steel	Velocity (FT/s)	Flow (GPM)
¾''	2.0	3.4
1''	2.3	6.5
1¼''	2.7	13.5
1½''	3.0	20.5
2''	3.6	40.0
3''	4.4	115.0
4''	5.1	235.0

Systems Typically not Suitable for Affordable Housing

In buildings where no cooling is present, any system employing fans for the distribution of heat should be avoided. Fans utilize significantly more energy that pumps per BTU delivered.

- Systems to be avoided include:
    - Fan coils
    - Furnaces
    - Ducted, heating only heat pumps

Domestic Hot Water

Domestic Hot Water Sizing

Sizing methodology of domestic hot water demand for multifamily housing should be based on the methods outlined in the ASHRAE Applications Handbook Chapter 49 Service Water Heating. ***The DHW sizing guidelines in manufacturers' literature has been found to result in significant over sizing.*** The approach recommended in ASHRAE is based on field studies of multi-family housing performed in the 1990s and has been found to provide good estimates for hot water system sizing based on the number and demographic profile of the building occupants.

Different types of occupants consume hot water in fairly predictable patterns, which are classified based on demographic research as high, medium and low usage rates. Rather than assuming a volume of water used per apartment, this approach more accurately reflects the hot water usage rates of the expected building occupants[10].

Table 3 - Guidelines for Multifamily Water Heating

Low use – occupancy mix including:	All occupants work One person works, one stays home Seniors Couples Middle Income Higher population density
Medium use – occupancy mix including:	Families Singles Residents on public assistance Single parent households
High use – occupancy mix including:	Families High percentage of children Low income/public assistance No occupants working Single parent households

The property developer will provide information on the expected population mix for the project. Use that information and the occupancy density along with the table of usage rates below to determine the DHW load profile over a three hour peak period to size the DHW equipment for townhouse style and double loaded corridor occupancies.

[10] Fredric S. Goldner, "*Try These On for Size: New Guidelines for Multifamily Water Heating*", Home Energy Magazine Online July/August 1996

Table 4 - ASHRAE Applications 2007, Chapter 49 "Table 8 Hot-Water Demand and Use Guidelines for Apartment Buildings" (Gallons per Person at 120 Degrees F Delivered to Fixtures

	Peak Minutes						Max Daily	Avg Daily
Guideline	5	15	30	60	120	180		
Low	.4	1.0	1.7	2.8	4.5	6.1	20	14
Medium	.7	1.7	2.9	4.8	8.0	11.0	49	30
High	1.2	3.0	5.1	8.5	14.5	19.0	90	54

Chapter 49 also provides DHW sizing methodology for duplex housing based on number of bedrooms and bathrooms.

Generation and storage systems should be designed both to provide hot water for the average load and to meet the short, sharp peaks. Residential water-heating equipment sizing is frequently driven by amounts of water used over periods of considerably less than 1 h, often as short as 15 minutes. Sizing should be based on the calculation of the flow rates needed to deliver hot water over the various use time period from the table above. Equipment selection should be optimized between generation and storage.

The ASHRAE *2007 HVAC Applications Handbook* recommends domestic hot water storage temperature in the 140°F[11] range to limit the potential for L. pneumophila growth. A mixing valve is required to provide a 120°F delivery temperature. Assume 40° F cold water temperature in sizing calculations.

For indirect fired hot water systems, once the selection has been made for boiler capacity and storage mix, calculate the ratio of building heating load to domestic hot water load to determine the factor to apply to the domestic hot water load. To determine total boiler capacity add the adjusted DHW load and the heating load. Select boilers to meet this load. Once the boiler selection is made, recheck the system against the DHW load profile and increase storage, if needed to ensure the load is met in all conditions.

See example in Appendix L.

Domestic Hot Water Recirculation D T DLC

In order to achieve wait times for domestic hot water that are in accordance with current recommendations, recirculation is necessary in all buildings.

From the time a faucet is turned on until hot water reaches the fixture should range from 0 to 10 seconds for residential buildings.[12] ASPE also recommends 11 to 30 seconds as marginally acceptable for other building types depending on the application. Any wait exceeding 30 seconds is considered to be unacceptable.

Current code, IPC[13] 2009, allows for no recirculation or other temperature maintenance in systems where there is less than 100 feet of piping between the DHW source and the farthest fixture but does

[11] Also referenced in ASHRAE Guideline 12-2000, *Minimizing the Risk of Legionellosis Associated with Building Water Systems*

[12] *ASPE Domestic Hot Water Heating Design Manual (*American Society of Plumbing Engineers)

[13] International Plumbing Code, 2009

not preclude it. As shown below, 100 feet greatly exceeds the acceptable distance to meet the acceptable wait time threshold.

If 100 feet of piping were installed without recirculation and a 0.5 GPM fixture was at the end, it would take roughly 2-1/2 minutes to get hot water to that fixture, wasting 1-1/4 gallons of water, which has been previously heated, in the process.

- The design of DHW distribution systems should be done in a manner that results in a wait time of no more than 10 seconds with a goal of 5 second delivery.

Table 5 - Pipe size and resulting velocity at 1.0 GPM

Pipe size and resulting velocity at 1.0 GPM This table is provided for calculation purposes only and is not intended to recommend specific velocity limitations.		
Type L Pipe Size	Velocity (FPS)	Notes
3/8”	2.15	Per IPC 2009, only allowable for lavatories.
1/2”	1.35	
3/4”	0.65	
1”	0.37	
1-1/4”	0.26	
1-1/2”	0.18	
2”	0.11	

The values above can be used to calculate the time it takes water to get from the source of hot water to the fixture. The source is either the DHW heater or the DHW main. Using 5 seconds as a goal:

For a **0.5 GPM fixture** and **1/2 inch pipe** the maximum piping length is:

(5 SEC * 1.35 FPS)*(0.5 GPM/1.0 GPM) = **3’-4”**

For a **0.5 GPM fixture** and **3/8 inch pipe** the maximum piping length is:

(5 SEC * 2.15 FPS)*(0.5 GPM/1.0 GPM) = **5’-4”**

These distances are indicated as D_1 in the following diagrams.

In practice, the use of 3/8” piping is limited to lavatory supplies only per code. This approach, however, can allow for slightly longer runs of pipe while still achieving acceptable wait times and velocities. As shown above, the use of 3/8” vs 1/2” allows for the DHW main to be 2’-0 farther away from the fixture.

Intermittent DHW Recirculation Control

Domestic hot water recirculation is a source of both energy loss and power consumption within a building due both to the power required to operate the recirculation pump as well as the heat loss attributable to the additional return water piping. These losses and consumption can, however, be limited with an intermittently controlled DHW recirculation system. Intermittent controls can consist of demand based controls, timer based controls or temperature based controls.

Resistance has been given to the intermittent approach in the past due to concerns of non-circulating, warm water in the piping system. If the designer considers that the International Plumbing Code 2009, the current plumbing code in the State of Vermont, does not specify minimum hot water storage temperatures and does not require recirculation in systems where the most remote fixture is up to 100 feet away from the source, this may address this concern

Demand Based Recirculation D

A demand based system is one in which the recirculation pump operates only when hot water is needed at a fixture. This need can be indicated by a water flow sensor in the DHW supply pipe. In this type of system, the recirculation pump flow rate must be based on the velocity required to deliver hot water in the time required.

For example, in the diagram below, D_1 is determined as noted above while D_2 is determined as follows:

Assume:
0.5 GPM,
3/8" Lav piping,
1/2" DHW main supply piping.
Max wait time of 5 seconds.

Divide the wait time between the two distances so each distance is covered in 2.5 seconds.

D_1 = (2.5 SEC * 2.15 FPS)*(0.5 GPM/1.0 GPM) = **2'-8"**

Max velocity in DHW main = 5 FPS

Using readily available pipe sizing tables, this equates to a flow rate of just less than **4 GPM for the recirculation pump**.

D_2 = (2.5 SEC *5 FPS) = **12'-6"**

See following diagram.

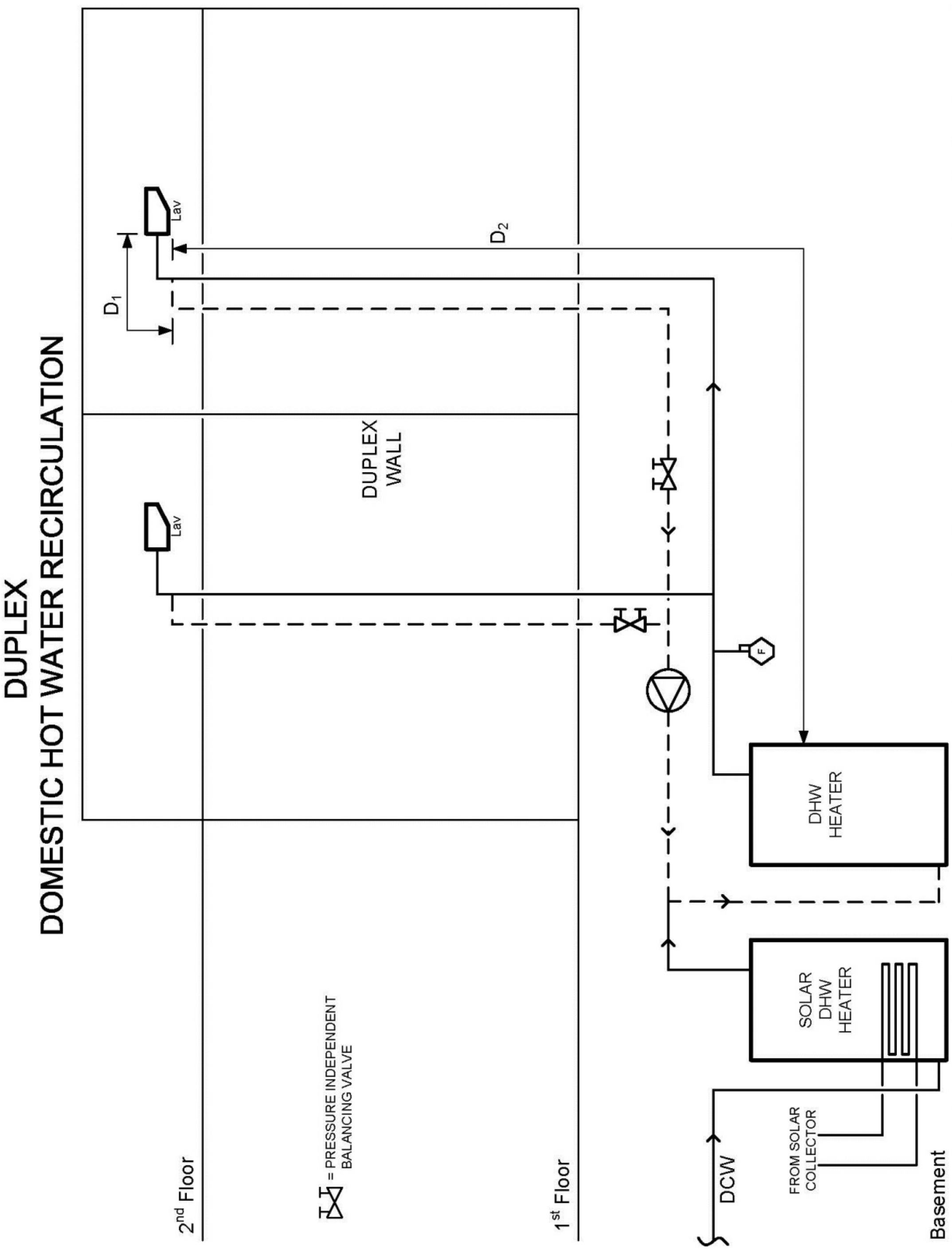
NOTE: When multiple fixtures are calling for DHW at the same time, the wait time will remain nearly the same. The control of the ECM pump (described elsewhere) combined with the pressure independent balancing valves will ensure this.

The copper industry[14] recommends that velocities be limited to 5 FPS in DHW systems to limit the possibility of pipe erosion and minimize noise concerns, though the design community lacks a consensus on maximum velocity.

[14] The Copper Tube Handbook, 2010, Copper Development Association.

- A demand based DHW recirculation system is only applicable in very small, compact installations where D_2 can be achieved.

SEE DIAGRAM ON FOLLOWING PAGE



While this flow rate may seem excessive, the pump only needs to run until the water just beyond the last fixture becomes hot. As shown, the pump will need to run for 2.5 seconds to distribute water to the most remote point of connection to the main. A minimum pump run time of 30 seconds is advisable to prevent pump short-cycling.

- A time delay of at least 15 minutes between successive pump starts will prevent excessive pump cycling without noticeable loss of hot water temperature delivered to the fixtures when systems are insulated in accordance with this guide.
    - To more precisely calculate the acceptable time delay between successive starts, equations 5 thru 8 in the 2007 ASHRAE Handbook HVAC Applications, chapter 49 may be used. A DHW temperature of 105 deg F is generally recognized as the minimum temperature at or above which a user will not feel they have to run the water and let it drain to obtain a useable temperature.

The use of a demand based system will result in the minimum pump run time. It will incur additional first cost due to the flow switch and pump and return pipe in duplex units.

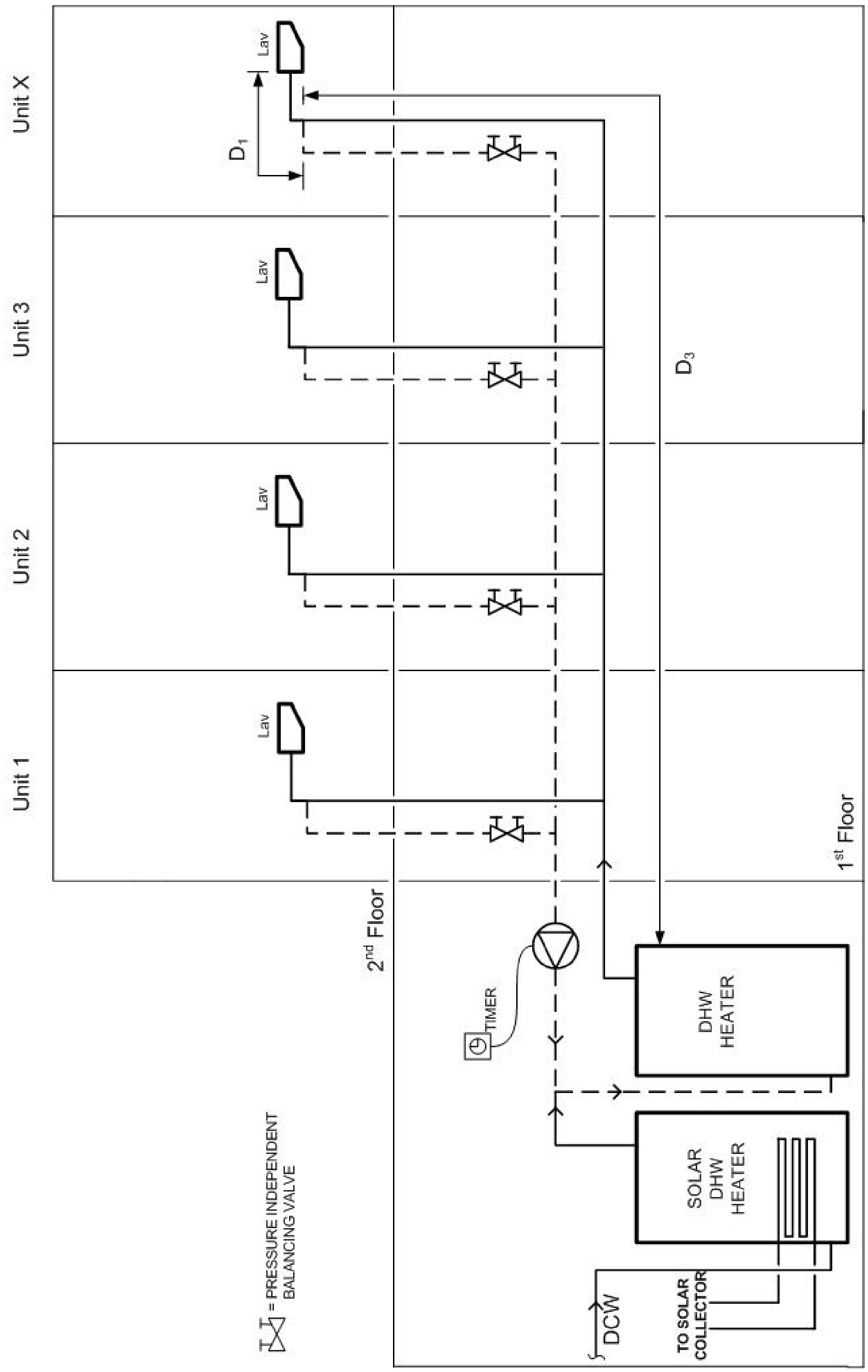
Demand based recirculation requires a truly integrated design process whereby the architecture allows the concentration of DHW fixtures around a central core to minimize the length of piping runs.

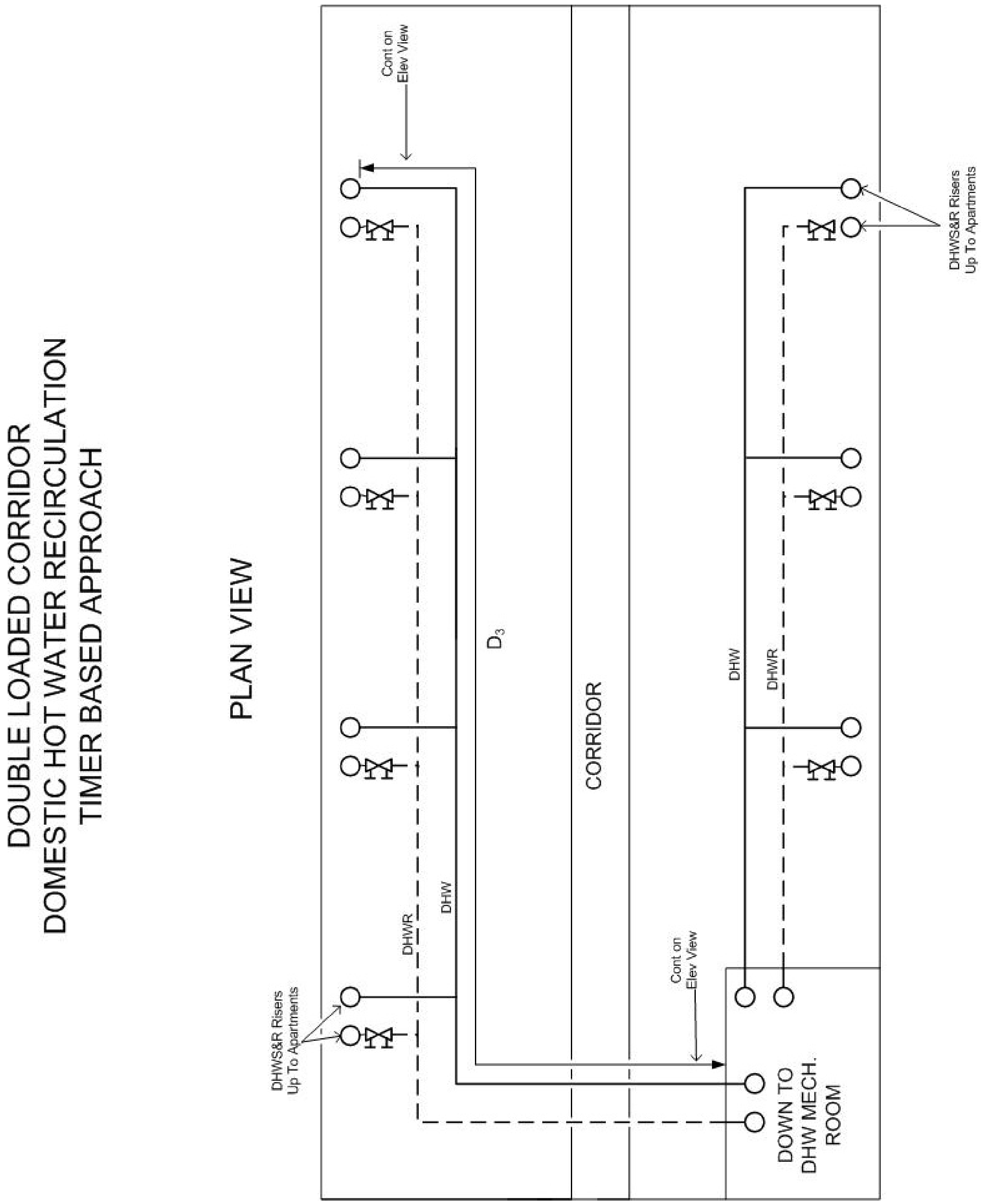
Timer Based Recirculation D T DLC

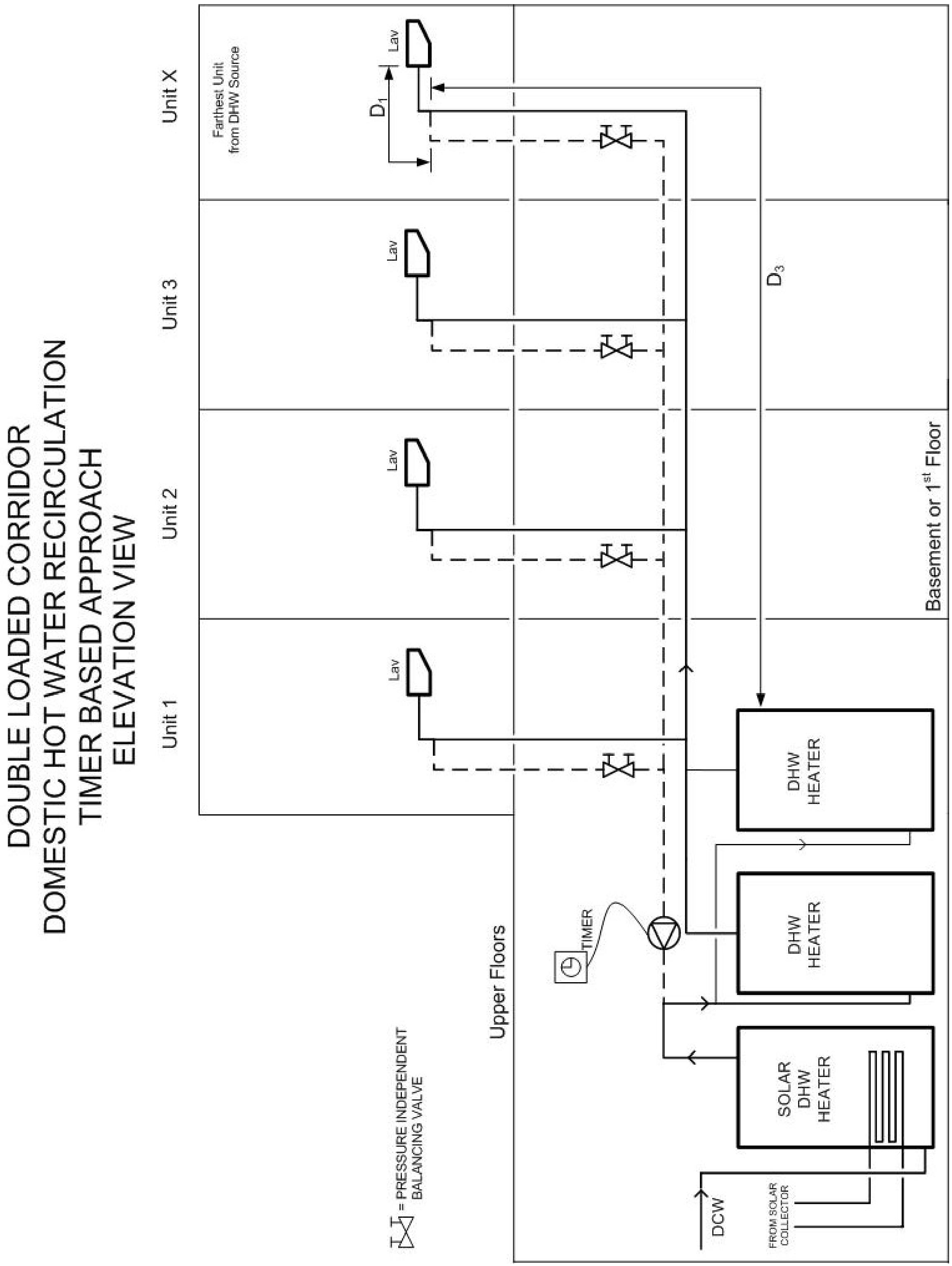
Another approach to intermittent recirculation control is a simpler, timed ON cycle for the recirculation pump. In this case, the pump size may be the same as it would be in a constant recirculation system, but the pump ON cycle operation is based on a calculated time that will deliver DHW to the most remote fixture. The OFF time can be calculated using equations 5 thru 8 in the 2007 ASHRAE Handbook HVAC Applications, chapter 49 although 15 minutes as a guideline will be acceptable in most instances. These calculations will use D_3 in the diagrams following where D_3 is the one-way distance to the most remote fixture.

SEE DIAGRAMS ON FOLLOWING PAGES

TOWN HOME
DOMESTIC HOT WATER RECIRCULATION
TIMER APPROACH

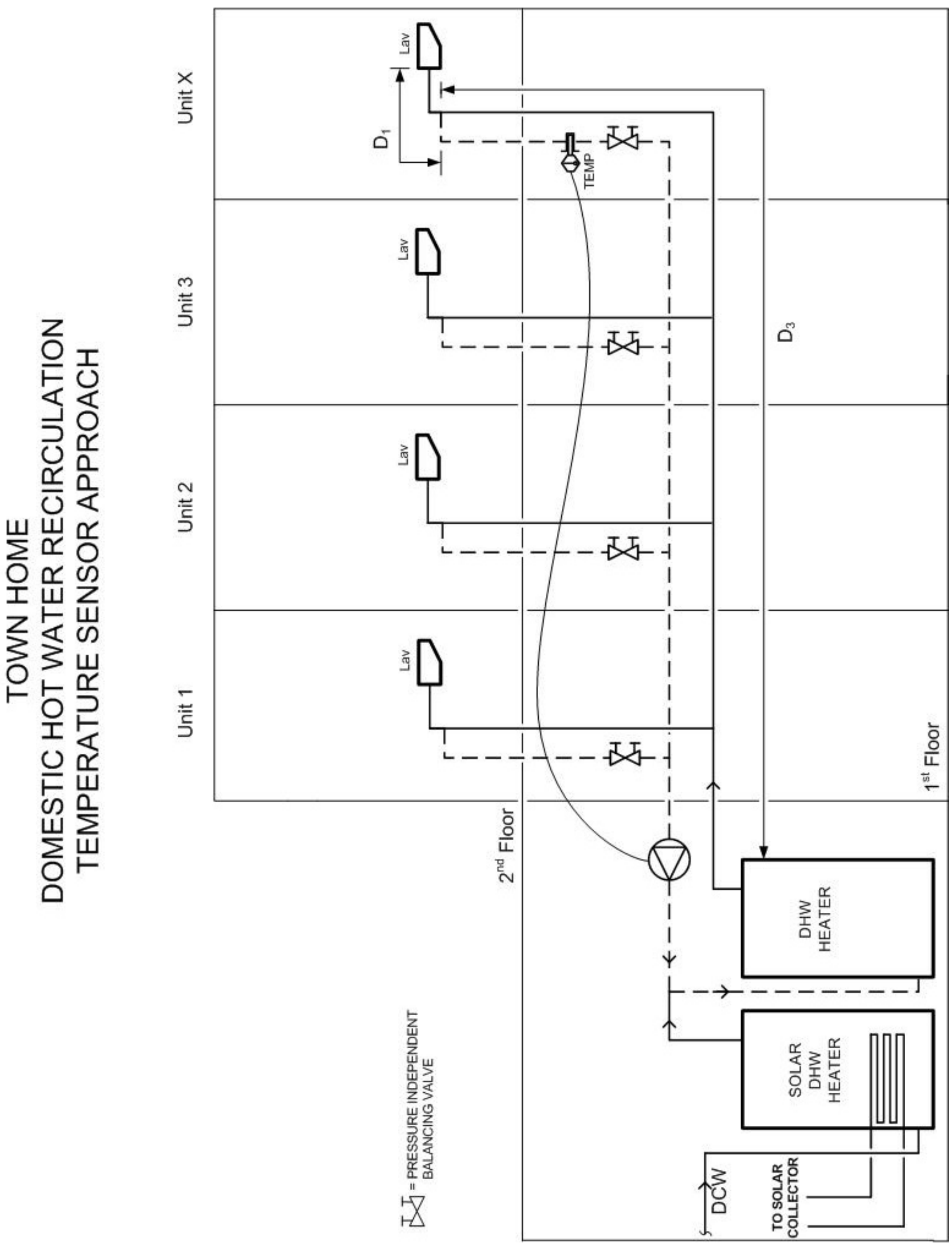



DOUBLE LOADED CORRIDOR
DOMESTIC HOT WATER RECIRCULATION
TIMER BASED APPROACH
PLAN VIEW
Cont on Elev View
DHWS&R Risers Up To Apartments
D3
DHW
DHWR
CORRIDOR
DHWS&R Risers Up To Apartments
Cont on Elev View
DOWN TO DHW MECH. ROOM


DOUBLE LOADED CORRIDOR
DOMESTIC HOT WATER RECIRCULATION
TIMER BASED APPROACH
ELEVATION VIEW
Unit 1
Unit 2
Unit 3
Unit X
Farthest Unit from DHW Source
Lav
Lav
Lav
Lav
D1
D3
Upper Floors
Basement or 1st Floor
TIMER
DHW HEATER
DHW HEATER
SOLAR DHW HEATER
DCW
FROM SOLAR COLLECTOR
= PRESSURE INDEPENDENT BALANCING VALVE

Temperature Based Recirculation D T DLC

The calculation for the timer based recirculation may be avoided by using a temperature sensor in the return line of the system that calls the pump to run until the sensor is satisfied. It is still recommended to maintain a minimum ON time of at least 30 seconds or longer if recommended by the manufacturer.



By utilizing a temperature based system, the temperature in the DHW piping is kept above a prescribed temperature thereby guaranteeing hot water to each fixture.

- Temperature sensor should be located after the fixture that is furthest from the DHW heater.
- Pump minimum run time should be at least 30 seconds.
- Pump is energized on a drop in temperature below the minimum set point.
  - Minimum set point should not be lower than 105 deg F while 115 deg F is recommended.
- Pump is stopped once the temperature sensor has reached the maximum set point and has run for at least 30 seconds.
  - Both Taco & Wilo confirmed that as many as 12 starts per hour (once every 5 minutes) will not compromise the longevity of the pump motor for small, fractional horsepower, wet-rotor circulators.
  - Circulators with non-ECM motors larger than 1/2 horsepower may be more limited regarding allowable number of starts per hour. This is manufacturer specific and can vary widely.

DHW Pump Sizing

The following guidelines[15] may be used to size DHW recirculation pumps in all systems except those utilizing demand based recirculation.

Table 6 - DHW Pump Sizing Guidelines

DHW Riser Size	Recirculation Allowance per Riser (GPM)
1/2" – 1"	0.5
1-1/4" – 1-1/2"	1.0
2" and larger	2.0
Every group of 20 fixtures (not fixture units)	1.0 in addition to riser allowances.

DHW Pipe Insulation D T DLC

A significant contributor to the energy used in recirculating DHW is the heat lost via the supply and recirculation piping. DHW heat loss contributes to the internal building heat gains. Current code requires the DHW distribution and recirculation piping to be insulated with 1" insulation; increasing this to two inches will halve the energy consumed to re-heat the water as it is returned to the DHW heater and reduce the internal heat gains from the DHW system, which contribute to building overheating issues during shoulder and summer months.

[15] ASPE (American Society of Plumbing Engineers) Data Book Vol 2, 2000.

A temperature loss of 5 deg F from the DHW heater outlet to the point of return entering the tank is common for code compliant systems***. If the insulation on both the supply and recirculation piping is increased from 1 to 2 inches, that effectively halves the dT at the same flow rate.***

Based on the need to limit internal heat gains in low energy buildings and the goal of long-term energy affordability in the target housing stock, 2" insulation on all DHW distribution piping should be used in all building types. Additional coordination is required to ensure wall cavities and plumbing chases have adequate space for the larger diameter of fully insulated pipe.

DHW Pump Considerations D T DLC

Small circulators are very inefficient in turning electrical energy into mechanical energy. Many DHW circulators utilize fractional HP motors in the range of 1/40 HP to 1/8 HP. In this HP range the following efficiencies are common:

- Shaded Pole motors – 10%-15%
- PSC motors – 35% - 55%
- EC (electronically commutated) motors – 65% - 75%

A marked improvement in efficiency can be obtained by using pumps with ECMs at minimal additional first cost. However, as of February 2011 no pumps with ECMs are commercially available that meet Vermont's "Lead Free" plumbing rules. This should, however, be reviewed on a regular basis. At this time PSC motors are acceptable for DHW applications and should be specified.

DHW Heat Tracing

Heat trace is not a recommended method for maintaining DHW at or near delivery temperatures due to the lack of access and resulting maintenance problems in the event of failure. Circulation pumps are, by contrast, one isolated piece of equipment typically located in the same area as the boiler making access for repairs or replacement much better.

Domestic Hot Water Equipment

- High performance indirect hot water heaters should be used for fuel oil and biomass systems.
  - Triangle Tube Smart Series
  - 85% usable storage tank capacity
  - Less than 0.5% standby losses
- In natural gas territory use direct fired, condensing domestic water heaters
  - AO Smith Vertex, 96% Thermal Efficiency
- Where piping runs are short and recirculation not necessary, as is possible in Duplex style buildings, instantaneous DHW heaters can be considered
  - Verify that the system flow rates are above the minimum flow rate required by instantaneous heaters in light of very low flow (0.5 GPM) lavatory fixtures
  - Location of instantaneous DHW heaters to ensure delivery of hot water within the 10 second delivery period.
  - Bosch 2400ES, 86% efficient

Indirect DHW heaters require that the boiler direct its heat output to the DHW storage tank (DHW priority) to ensure DHW is production is maintained. Normally, this mode of operation goes unnoticed with little or no discernable change in space temperature. Discussions with maintenance staff, however, indicated that in multi-family installations on particularly cold days at or near the design conditions, prolonged calls for domestic hot water have caused space temperatures to fall enough to cause occupants to notice and, hence, place service calls. This typically occurs in the morning when DHW demand for showering is high.

DHW priority typically results in a reset of the boiler HW supply temperature to its maximum in order to ensure quick DHW recovery. This typically takes the boiler out of its condensing temperature range.

Issues associated with under heating due to DHW priority will be reduced in buildings with high performance envelopes as the time it takes for the temperature to drop to a point that initiates service calls will be greatly extended. For low energy buildings the domestic hot water loads will typically exceed the building heating load. For multiple boiler systems, providing the correct amount of DHW storage will mitigate this issue.

Solar Domestic Hot Water

Overview

Where site conditions are deemed to be appropriate based upon a feasibility study, installing a solar domestic hot water system sized to provide 50% of annual DHW load significantly reduces energy consumption[16] and has a short simple payback period of 4-8 years[17]. Additionally, in buildings where achieving envelope goals are more difficult (such as in retrofit situations), installing a solar domestic hot water system sized for 75% of annual DHW load may be an effective energy cost reduction measure, when evaluated against other envelope improvement options.

Solar domestic hot water should be included early in the project planning process. Building orientation, roof pitch, and roof style affect the cost, ease, and aesthetics of solar installation, necessitating an integrated architectural plan. A feasibility evaluation for the specific building site and DHW loads, as well as the design and installation of the system should be performed by an appropriately certified professional. At present, the North American Board of Certified Energy Practitioners (NABCEP) provides nationally recognized certifications for solar thermal installers and system designers. As with all building trade disciplines, quality and experience can vary greatly even within the pool of qualified installers, and care should be used to select a candidate with relevant experience and proven track record in order to achieve high performance.

In the event that developers/owners decide against the upfront installation of solar domestic hot water, at the very least the following provisions should be made to enable future installation:

- Provide space in the mechanical room for an additional SDHW storage tank
- Size and provide space (chase) for installation of future insulated supply and return piping to the future location of the solar system
- Provide spare conduit between the mechanical room and the future system location

Including these provisions in the initial construction will allow for the cost effective and a less disruptive installation of solar DHW equipment at a future date. Again, qualified professionals should be engaged to detail the initial provisions as well as other contingencies that may reduce cost and difficulty of future solar thermal installation. The National Renewable Energy Laboratory (NREL) produces a Technical Report titled: “Solar Ready Buildings Planning Guide”[18], which provides sound, specific technical advice for planning for future solar installation.

Collector Types

Solar thermal “collectors” are generally divided into two types, evacuated tube and flat-plate. Evacuated tubes are generally more expensive and more efficient than flat plate collectors. Flat plate collections are more common in this region. There is not yet a consensus on flat-plate vs. evacuated collectors. Flat plate collectors are less efficient and less expensive, but as a result of this reduced efficiency can deal with snowmelt better than evacuated tubes. Evacuated tubes can achieve higher water temperatures and may make sense in some applications.

[16] NREL, *Break-even Cost for Residential Solar Water Heating in the United States*, http://www.nrel.gov/docs/fy11osti/48986proof.pdf, 2011
[17] NREL EEREC *Solar Water Heating* http://www.nrel.gov/docs/legosti/fy96/17459.pdf,1996
[18] NREL *Solar Ready Planning Guide* - NREL/TP-7A2-46078 - http://www.nrel.gov/docs/fy10osti/46078.pdf,2009

System Sizing

The design strategy for solar systems should focus on maximizing annual BTUs generated by the solar system, rather than in achieving an optimal water temperature—solar collectors operate at higher efficiencies when the collector loop water temperature is lower.

Solar thermal installations in northern climates, sized to achieve at least 50% of the annual domestic hot water load, typically require the following collector areas and storage volumes:

Table 7 - Solar Sizing Guidelines[19]

Flat Plate Solar Collector Area	Solar Thermal DHW Storage
10-15 Square Feet Per Building Occupant	1.5 gallons per square foot of collector area.

Thermal storage for smaller buildings is readily achievable with standard pressure tanks. As an example, for a duplex building with 8 occupants (4 people per unit) we would estimate:

Collector Area: $20ft^2$ x 2 people + $14ft^2$ x 2 people = $68ft^2$ per unit, or $136ft^2$ for the complete duplex.

Storage Tank: $136ft^2$ x 1.5 gal/ft^2 = 204 gallon storage tank capacity.

However, in larger buildings with higher occupancy, significant storage would be required—for example, a three story double-loaded corridor with 80 occupants, and an average of 2 occupants per unit, would require 1,600 square feet of collector area, and 2,400 gallons of storage capacity. Pressure-rated storage tanks are relatively expensive, and some savings at this scale may be achieved by using alternative bulk storage options. Some manufacturers such as Marathon have product lines specifically designed to provide more easily interconnected thermal storage tanks for solar applications as well.

Structural Loading Issues

Solar panels provide a direct static load to a building roof, and contribute additional surface area for wind loading. System sizing and location must be considered early in design and incorporated into the structural design. The NREL Solar Ready Building Planning Guide, referenced above, provides additional information regarding designing for solar panel loads.

Costs

Solar thermal systems typically cost $90-150/ft^2$ of collector area for flat plate collectors[20]—more for evacuated tube systems. The typical system cost breakdown is typically as follows:

Table 8 - Solar Thermal System Costs

Typical Cost Breakdown[21]	Fraction
Installation	30%
Panels	50%

[19] http://www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=12880
[20] http://www.wbdg.org/resources/swheating.php
[21] http://www.rurdev.usda.gov/or/biz/QuickGuide2SolarThermal.pdf

Storage, piping, controls, etc.	15%
Engineering	5%

Operation and maintenance costs for solar thermal system are low and system lifetime can be expected to be between 20 and 30 years[22].

[22] http://www.rurdev.usda.gov/or/biz/QuickGuide2SolarThermal.pdf

Ventilation

Overview

The 2005 "Residential Building Energy Standards" (RBES), also referred to as the VT Residential Energy Code, applies to all new construction (and major renovations within Burlington) of single family, duplex, and multifamily housing of three stories or less. Mechanical whole-house (building) ventilation is required by this code in order to provide fresh outside air to the occupied space, and to remove indoor contaminants including CO_2 generated by occupants, water vapors from bathing, cooking particulates, volatile organic compounds (VOC's) from off-gassing construction materials, radon, and more. As the housing stock moves towards highly air-sealed, well insulated buildings, issues of indoor air quality and the need for appropriately designed mechanical ventilation systems become more critical.

It should be noted that the VT Residential Energy Code applies to all residential and multifamily buildings 3 stories or less, except if the building is also partly commercial (known as "mixed-use"), in which case commercial code supersedes the residential code. The specifics of this case will not be covered in this material, though the VT Commercial code provides appropriate guidance towards mechanical ventilation in commercial applications.

System Sizing & Code

Whole Building Ventilation

The VT Residential Energy Guideline 2005 (RBES)[23] – recommends 0.05 CFM of ventilation per square foot of building floor space. The code also allows an alternate compliance path to size ventilation rates at 15 cfm per bedroom, but to do so require ventilation system testing as defined by the code after construction.

For a building similar to the Middlebury South double-loaded-corridor[24], as an example, and compared to other ventilation standards from ASHRAE, this would require:

Method	Floor Area (sf)	Bedrooms	No Testing	With Testing
VT Res. Guidelines	32,000	51	2,025 Cfm	810 Cfm
ASHRAE Standard 62.2[25]	32,000	51	723 Cfm	N/A
ASHRAE Standard 62.1[26]	32,000	51	2,730 Cfm	N/A

As can be seen above, flow rates in the Middlebury South building could be more than halved through verification of the ventilation performance. These concur with the recently published ASHRAE residential ventilation Standard 62.2.. ASHRAE Standard 62.1, the commercial ventilation criteria, addresses residential ventilation in a more limited manner. This requires ventilation to be based on square footage (.06 cfm per square foot) and 5 cfm per person, assuming 2 people per studio or one

[23] Vermont is expected to issue an updated Residential Energy Code in 2011
[24] Assumes 30 units, 51 bedrooms; (12) 1-BR units; (15) 2-BR units; (3) 3-BR units
[25] ASHRAE Standard 62.2-2010, *Ventilation for Acceptable Indoor Air Quality for Low Rise Residential Buildings*
[26] ASHRAE Standard 62.1-2007, *Ventilation for Acceptable Indoor Air Quality*; residential dwelling units, Table 6-1.

bedroom apartment. For a multi family building with more than one bedroom per apartment, the ventilation rates noted in the table for Standard 62.1 would be even higher.

The RBES code also requires that for buildings with four bedrooms or more and a ventilation system that is not centrally ducted, there must be a minimum of 2 mechanical ventilation units installed.

Local Ventilation

The 2005 RBES requires that all bathrooms containing a bathing fixture[27] must have an exhaust fan rated at a minimum capacity of 50 cfm for intermittent use (wall switch, timer), or 20 cfm for continuous use. If the whole house ventilation system does not provide this ventilation, a separate fan with the specified capacity is required.

System Types

- Double loaded corridor building should be provided with central heat recovery ventilation systems.
- Townhouse and duplex units are should be provided with in-unit systems, examples include:
  - Fantech SE & SER model of energy recovery ventilators.
  - Venmar HRV-600i model Heat Recovery Ventilator.

There are two major categories of efficient ventilation systems: enthalpy (total energy) and sensible (heat only) recovery systems. The main benefit of enthalpy recovery ventilation (ERV) systems, when compared to heat recovery ventilation systems (HRVs) is that ERVs provide moisture removal from entering outside air during the humid summer months, thereby preventing that latent heat from becoming a load on cooling coils, require additional energy.

- While larger central ventilation and energy recovery systems with ERV energy wheels can often have lower costs by taking advantages of some economies of scale, odor migration issues were identified during the site visits as an area of occupant dissatisfaction—primarily due to the migration of cooking odors. Migration of odors can especially be an issue in wheel type system, where odors may cross over from exhaust to supply side in the wheel material. To mitigate the possibility of odor migration, wheel-type central ERVs should be avoided
- Plate-type HRVs are available that do not allow the migration of odors across the heat exchange medium.

Where cooling is not provided there is minimal energy cost benefit from choosing ERVs over HRVs. Additionally, for the reasons of odor migration identified above, it may be the most practical choice to choose heat recovery ventilation only, with fully separated air streams, such as the configuration found in flat plate cross-flow systems. If plans around cooling change, this recommendation may be revised.

Thermal efficiencies for small single unit HRV's should be specified for a minimum efficiency of 60%. For central HRV's, a minimum efficiency of 50%.

Installation and Ducting

Central ventilation equipment should be isolated from ductwork by flexible connection as specified by RBES 2005 and manufacturers guidelines to prevent issues of duct noise. ASHRAE Standard 62.2 also has

[27] Defined as a bathtub, shower, spa or similar fixture

minimum ventilation/exhaust duct sizing requirements which will mitigate potential noise problems and ensure air friction. Refer to duct sizing discussed elsewhere in this document.

Exhaust air should be removed from each unit from the bathrooms, though not directly above bathing fixtures to avoid drafts and poor exhaust capture when show doors or curtains are closed. Supply air should be supplied at the bedrooms, high on the wall or at the ceiling level to ensure adequate mixing occurs.

For duplex and townhouse style units design should include a single dedicated HRV for each dwelling unit. Include HRV efficiency and equipment type on design drawing equipment schedules. HRVs require quarterly filter changes. Review the access requirements with the building maintenance staff and owner. HRVs should generally be located in easily accessible spaces such as basements.

For DLC a central HRV ventilation air handler with hot water reheat coil should be applied. A supply air temperature setpoint of 65F often works well with some apartments having heavier internal heat gains concurrently with adjoining apartments where minimal internal gains from lighting, televisions, etc. may be far less. The reheat coil should be sized based on the heating hot water supply temperature reset and to reheat the air to the supply air temperature setpoint during HRV defrost mode, when HRV discharge air temperatures are cooler.

DLC ventilation distribution should address common area ventilation, including corridors. Supplying air to corridors (without corridor exhaust registers) so that they are pressurized relative to dwelling areas helps minimize odor migration.

For any tight high performance building, indoor air quality can be improved by minimizing the off-gassing of materials, by specifying low VoC construction materials, such as those typically meeting LEED IEQ credit requirements.

Controls for central HRV units are generally packaged factory installed which work fairly well when field verified and tested. Central HRV's should operate continuously. Where a hot water reheat coil is utilized to temper supply air, a modulating two port, normally closed coil control valve should be utilized.

A good method to operate small individual apartment HRV's is on an intermittent, demand based mode. When a bathroom is occupied, determined either by a built in motion sensor within the HRV, or interfaced with a wall switch, the unit runs at full capacity mode. When demand does not exist, operate continuously at low volume mode.

Directly from VT Code:
"The ventilation system must have an automatic control or be capable of being set remotely for continuous operation. Intermittently operated systems must have an automatic control capable of operating the system without the need for occupant intervention, such as a time switch. Twist or crank-style timers are not acceptable as controls for the whole-house system.

Continuously operated systems must have a remotely mounted (i.e, not in the living space) on/off switch that is appropriately labeled. Continuously operated systems cannot have any local controls unless such controls affect the speed only and cannot turn the system off."

Hot Water Temperature Control

Condensing Boilers with Modulation – Fossil Fuels

For boilers with condensing capability and indirect DHW, the following controls are recommended. In townhouses and DLC style buildings, multiple boilers will be modulated in parallel to achieve peak boiler efficiency. Pump controls will be similar for Duplex & Townhouse style buildings. Pump control for DLC buildings will be as outlined in the Pumps and Pump Control section.

- Supply water temperature reset per the following table.

Outdoor Air Temperature	Hot Water Supply Temperature
0	130
55	100

- When there is a call for heat
  - The zone control valve shall open and remain open until zone is satisfied.
  - Zone pump starts and runs until call for heat is satisfied.
  - The boiler circulation pump shall start and operate as long as there is a call from a zone or the boiler is firing.
  - The boiler shall fire to maintain a target temperature based on the reset schedule. Once met, boiler burner shall stop.
- When there is a call for DHW without a call for heat
  - The DHW circulation pump shall start and operate as long as there is a call from the DHW heater.
    - Zone circulator shall not run
    - Boiler circulator shall not run.
  - The boiler shall reset its target temperature to its max allowable temperature, typically 180 deg F or 190 deg F depending on manufacturer.
  - The boiler shall fire to maintain the DHW priority target temperature.
- When there is a call for DHW during a call for heat (DHW priority)
  - The zone valve(s) remain open – they are controlled by the thermostats
  - The zone circulator stops.
  - The boiler circulator stops unless required to run by the boiler's manufacturer.
  - The DHW circulation pump shall start and operate as long as there is a call from the DHW heater.
  - The boiler shall reset its target temperature to approximately 40 deg F above the DHW set point.

- The boiler shall fire to maintain the DHW priority target temperature.
- Once DHW call is satisfied, system reverts back to heating mode until heating calls are satisfied.

Boilers Requiring TES – Non-modulating Condensing Oil and Pellets

When TES is included in the system, the following controls are recommended.

- Supply water temperature should be reset for oil boilers per the table below and fixed at 160 deg F for pellets.

Outdoor Air Temperature	Hot Water Supply Temperature
0	130
55	100

- When there is a call for heat
    - The zone control valve shall open and remain open until zone is satisfied.
    - The building heating pump shall run as long as any zone calls for heat.
    - The boiler circulation pump shall start and operate as long as there is a call from a zone or the boiler is firing.
    - The boiler shall fire to maintain a target temperature based on the reset schedule. Once met, boiler burner shall stop in the case of oil. Pellet boiler shall modulate down to minimum output.
- When there is a call for DHW with no zones calling for heat
    - The DHW circulation pump shall start and operate as long as there is a call from the DHW heater.
    - Boiler circulator
        - Shall not run on oil boilers.
        - Shall run on pellet boilers to maintain full flow through boiler.
    - The boiler shall reset its target temperature to its max allowable temperature, typically 180 deg F or 190 deg F depending on manufacturer.
    - The boiler shall fire to maintain the DHW priority target temperature.
    - If there is a call for heat from a zone the building heating pump shall start.
        - The boiler circulator shall remain off for oil boilers.
        - The boiler circulator on pellet boilers shall run.
- When there is a call for DHW during a call for heat (DHW priority)
    - The zone valve(s) remain open – they are controlled by the thermostats
    - The building heating pump remains running.

- The boiler circulator shall stop for oil boilers and shall run for pellet boilers
- The DHW circulation pump shall start and operate as long as there is a call from the DHW heater.
- The boiler shall reset its target temperature to its max allowable temperature, typically 180 deg F or 190 deg F depending on manufacturer.
- The boiler shall fire to maintain the DHW priority target temperature.
- Once DHW call is satisfied, system reverts back to heating mode until heating calls are satisfied.

PIPING DIAGRAMS IN DEVELOPMENT

Pumps and Pump Controls

Pumps for Duplex and Townhouse style buildings should utilize EC motors without exception. EC motors are commercially available up to 1HP with some manufacturers offering ECMs up to 2HP. ECMs offer between 50% and 80% energy savings compared to other motor types available at the same HP.

D

Hot water pumping systems in small, duplex style housing should consist of one building heating pump serving all heating zones. Typically, these buildings will utilize the boiler’s on-board controls which do not usually allow for multiple pump control. This limitation precludes the ability to install one run and one standby pump without requiring manual switchover to equalize run time.

- Pumps should be controlled to deliver water only when there is a need for heat as determined by a call from a zone or on a call for indirect DHW.
- Do not install balancing valves to set pump flow. Pumps with ECMs will respond to the zone valves opening and closing by internal pump controls to maintain a constant pressure with variations in flow demand which enables efficient part load operation.

A dedicated boiler circulator is not necessary in these installations; care must be taken to ensure that under minimum loading, when the lowest-flow zone is the only one calling, that minimum flow rates through the boiler are maintained. A small, end of the line bypass can be used for this purpose. The bypass should use a calibrated, pressure independent balance valve to ensure that the minimum flow is returned to the boiler under all possible flow conditions. Circuit Setter® type balance valves should not be used for this purpose as under low load conditions they will allow more water to flow than necessary.

T

Townhouse style buildings will have more than two zones which is the typical limit for inputs directly to a boiler. This necessitates the installation of a 3rd party controller to accept all the zone inputs (thermostats). Commonly available controllers, such as those by Tekmar®, can be configured to automatically swap two operating pumps to equalize run time although they are not capable of recognizing a pump failure.

- Pumps should be controlled to deliver water only where there is a need for heat as determined by a call from a zone or on a call for indirect DHW.

- Controller should be configured to swap lead / lag circulation pumps every 7 days.
- Do not install balancing valves to set pump flow. Pumps with ECMs will respond to the zone valves opening and closing automatically to maintain efficient operation.

DLC

In larger, DLC style buildings where the flow and pressure requirements require system pump motors that are larger than 2HP, they should be controlled with VFDs to maintain a differential pressure in the piping system. It is critical that the control point, the location of the dP sensor, be roughly 2/3 down the index run of the piping system. If the dP sensor is located closer to the pumps, the amount of turndown is unnecessarily limited and approximately 50% of the expected annual pump variable flow energy use savings will fail to be captured.

The differential pressure set point should be estimated by the designer and included in the design documents with the requirement that the balancing contractor refine this value at the time the system is balanced.

The final dP set point should be the *minimum* dP required to maintain satisfactory water supply to all affected load. The test and balance (T&B) procedures to determine appropriate minimum dP pressure setpoint should be implemented by opening no more than 33% of all terminal heating controls valves at a time, verify flow rates to each of those zones and concurrently ensuring the dP setpoint in the lowest possible value which will meet the terminal flow requirements. A T&B procedure where by all terminal units control valves are opened concurrently should not be used to determine dP setpoint because it may result in inadequate flow rates to some zones under certain conditions.

- As a guideline, for systems typical of a DLC building, the high end of expected dP set points should be +/- 8.0 PSID. If the engineer's estimated setpoint is higher than this value, then the system piping layout, sizing and terminal selection should be reviewed.
- All pumps, including standby, should be included in a lead-lag strategy whereby run time for each pump is equalized.
- Balance valves for terminal unit flow control in variable flow systems should be pressure independent (automatic) style. A variable flow hydronic system using manual balance valves (circuit setters) cannot be adjusted to provide repeatable results when the hydronic system operates in either part load or full load mode.
- Avoid installation of balancing valves (triple duty valves) at pump discharge to set pump flow. Pumps with VFDs, even when operating in parallel, will respond to meet the system dP set point. Manual balance valves at pump discharge or in piping submains impose an unnecessary permanent pressure loss corresponding to unnecessary energy expenditure. Pump systems should be configured to use two or three running pumps, to allow for sufficient turndown in off-peak conditions.