U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Hydronic Heating Retrofits for Low-Rise Multifamily Buildings

Phase 1: Boiler Control Replacement and Monitoring

Jordan Dentz and Hugh Henderson
ARIES Collaborative

April 2012

Building America
U.S. Department of Energy

This report received minimal editorial review at NREL

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Hydronic Heating Retrofits for Low-Rise Multifamily Buildings

Phase 1: Boiler Control Replacement and Monitoring

Prepared for:

Building America

Building Technologies Program

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

Prepared by:

Jordan Dentz and Hugh Henderson

ARIES Collaborative

The Levy Partnership, Inc., 1776 Broadway, Suite 2205

New York, NY 10019

NREL Technical Monitor: Michael Gestwick

Prepared Under Subcontract No. KNDJ-0-40347-00

April 2012

Acknowledgments

The Advanced Residential Integrated Energy Solutions (ARIES) Collaborative would like to recognize the support of the U.S. Department of Energy's Building America Program and Michael Gestwick of the National Renewable Energy Laboratory for technical guidance. This project would not have been possible without the support and participation on Jane Carbone and Beverly Craig of Homeowners' Rehab Inc., Cambridge, Massachusetts; Martha Abrams and Ivan Leslie of Abrams Management, Boston, Massachusetts; and Kevin Reid of Boston Cooling and Heating, Norwood, Massachusetts. Thanks are also due to Victor Zelmanovich, Intech 21, Port Washington, New York, and Michael Keber, tekmar Controls, Vernon, British Columbia.

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Contents

List of Figures

Unless otherwise indicated, all figures were created by ARIES.

List of Tables

Unless otherwise indicated, all tables were created by ARIES.

Definitions

ARIES	Advanced Residential Integrated Energy Solutions
CAST	Cambridge Alliance for Spanish Tenants
DHW	Domestic hot water
TRV	Thermostatic radiator valve

Executive Summary

The ARIES Collaborative, a U.S. Department of Energy Building America research team, partnered with NeighborWorks America affiliate Homeowners' Rehab Inc. of Cambridge, Massachusetts, to implement and study improvements to the heating system in one of the nonprofit's housing developments. The heating control systems in the three-building, 42-unit Columbia Cambridge Alliance for Spanish Tenants (CAST) housing development were upgraded in an effort projected to reduce heating costs 15%–25%.

Homeowners' Rehab Inc. recognized that heating fuel use per square foot per heating degree day in the development was excessive compared to its other properties of similar construction. Although a poorly insulated thermal envelope contributes to high energy bills, adding insulation to the exterior walls is not a cost-effective or practical option for Columbia CAST, given the desire to maintain the building's historic exterior finish; insulating the interior walls was also impractical, as it would disrupt the residents. The more cost-effective and readily available option was improving heating system performance.

Efficient operation of the heating system faces several obstacles, including inflexible boiler controls, failed thermostatic radiator valves, and disregard by residents of recommended thermostat set points. In Phase 1 of the project, the boiler controls in three buildings were replaced with alternative systems, including those with more aggressive setbacks and a system that supplies heat based on apartment temperatures and outdoor temperatures. In one building, real-time apartment temperature data are available to building staff via the Internet, as is an interface allowing remote control of the heating system. Although similar multifamily energy management systems have been available for a number of years, a rigorous study quantifying the effectiveness of these features was not found.

Phase 2 of the project (planned for 2012) will integrate direct control of individual radiator zones into the system. A wireless communications network will enable the central control strategy to operate the heating system efficiently by tailoring heat distribution based on space temperatures in individual zones.

As of the writing of this report, the heating system retrofits have been completed and data collection has commenced. This report summarizes the research progress to date on Phase 1 and provides a preliminary economic analysis based on projected energy savings.

1 Introduction and Background

1.1 Introduction

There is a large stock of multifamily buildings in the Northeast and Midwest with space heating provided by centralized hot water or steam. According to the 2005 American Housing Survey, there are about 3.2 million occupied hydronically heated, low-rise multifamily housing units in the United States. Nearly 90% of these homes are in the Northeast or Midwest; with a large portion being rental units (40%) or occupied by the elderly (24%). Most hydronically heated homes are older, with only 1% being classified as new construction (built within the past four years) in the 2005 American Housing Survey data (U.S. Census Bureau 2006). Many of these housing units are candidates for improved boiler controls as described in this project. Regional firms using established technologies are currently well suited to offer these systems on a more widespread basis, should they prove to be cost effective and easily implemented.

Typically, residents of these buildings do not pay for heat directly (heat is not submetered). Losses from these systems are often higher than would be expected for buildings with centralized heat provided by a boiler serving multiple units (a significant number of apartments are overheated much of the time).

Upgrades to these heating systems often include the installation of new, higher performance boilers, yet heating costs sometimes remain high because space temperatures are too warm and the thermal distribution systems are inefficient. The major underlying problems are: (1) outmoded and inefficient boiler control strategies, and (2) the inability to regulate the amount of heat provided at the point of use (the radiator).

Heating cost reductions can be achieved in several ways, including improving the boiler control strategy, giving the resident or building manager the ability to more precisely modulate the temperature according to need (instead of opening a window), and altering the distribution of heat in the building in ways that better reflect demand.

The objective of this project is to evaluate the relative effectiveness of various control and distribution strategies to improve hydronic space heating performance in existing low-rise multifamily buildings.

1.2 Background

A number of older studies exist, documenting the benefits of outdoor reset control in multifamily buildings compared to the aquastat-controlled constant water temperatures (sometimes with controls that turn off the boiler when outdoor temperatures exceed a certain threshold) that typified the previous generation of multifamily heating systems (Hewett and Peterson 1984; Peterson 1986). Outdoor reset controls alone can improve the overall performance of the heating system, but they are very sensitive to commissioning. If the compensation curve is not adjusted properly, the overall performance can be worse than that of a boiler controlled at a constant water temperature. Adding thermostatic radiator valves (TRVs) to radiators has been shown to reduce the system's dependence on commissioning, but under- or overheating at low loads can easily occur as TRVs age. Additionally, correct use of TRVs depends on proper use by the tenants. One study found that more than 65% of tenants had their TRVs set higher than required (Liao and Dexter 2004). It has been shown that the overall performance of a heating system is highly dependent on the algorithm for determining the boiler temperature set point. Inferential models that, in the absence of real-time data, predict the average indoor temperature based on a simplified physical model, have been shown to be effective at increasing heating system efficiency (Liao and Dexter 2005; Liao et al. 2005). Now another shift in control strategies is underway, to one based on measured real-time average indoor temperatures in combination with outdoor temperatures (Center for Energy and the Environment 2006; CNT Energy, 2010; Gifford 2004).

New wireless technologies are available to cost-effectively monitor indoor space temperatures, centralize and automate thermostat set points, and, with the requisite level of control points in place, dynamically adjust heat distribution patterns. Control system manufacturers have produced case studies claiming benefits from indoor space temperature-based reset boiler control retrofits of 25%–40% of heating fuel use. However, existing conditions and control algorithms are typically not well documented in these case studies. No known third-party, independent studies exist quantifying the effects of these improvements.

Research is needed to establish optimum boiler control selection and operating strategies for older, multifamily buildings, verify the estimated savings associated with this technology, and characterize the factors that impact potential energy savings.

The results of this work could be included in a future Building America Measures Guideline about hydronic heating system retrofits for multifamily buildings. No Building America guidelines address this topic. Three planned, but not started, guideline documents to which this research might contribute are Centralized Heating Systems in Multi-Family Buildings (for new homes); HVAC Controls (for existing homes); and Hydronic Space Heating Improvements (for existing homes).

2 Research Methods

2.1 Research Questions

The first phase of the research addresses the following questions:

- How can a central boiler control strategy using apartment temperature data be cost-effectively retrofit into existing hydronically heated multifamily buildings?
- What are the associated energy savings and comfort benefits?
- How does a control system incorporating apartment temperature data compare in cost and performance with well-tuned outdoor reset strategies, including those that incorporate more limited indoor temperature input?

The conclusions of this research will be extended to other climate regions by varying load and temperature data in the models developed for the case study buildings.

A subsequent planned phase of the research will address the question: How can individual zone valve controls be cost-effectively integrated into a building-wide wireless hydronic heating control system and what are the associated energy savings and comfort benefits? As an end-of year report in a multiyear project, this report does not answer these questions, but summarizes the research progress to date.

2.2 Technical Approach

The project includes two phases to be conducted over three years. In Phase 1 boiler controls were replaced in each of three buildings with three slightly different control approaches. These are more fully described in Section 3. Each system will be operated using a variety of strategy permutations over the course of the heating system. The impacts on overall heating energy and comfort will be assessed.

During Phase 2, researchers will assess the added benefit of central control of individual radiator risers in one of the buildings. New valves installed in the basement risers will be networked to the central control system. This will enable a central control strategy to operate the heating system efficiently by distributing only the amount of heat needed at each riser to maintain the minimum heat needed in the apartment(s) served by that riser. Existing local radiator valves would be disabled or removed to avoid conflicts with the control system.

2.3 Test Site

The test site is the Columbia CAST housing development, a 42-unit complex of three, three-story masonry buildings in Cambridge, Massachusetts, owned by nonprofit Homeowners' Rehab Inc. (Figure 1). Each building is referred to by its address number (3, 4 or 55). Gas use in the buildings is higher than other similar buildings in the area. Gas use for space heating alone is more than 0.6 therms/ft^2/yr (over 0.8 therms/ft^2/yr overall).[1] Although a poorly insulated thermal envelope contributes to the problem, insulating the masonry walls from the exterior is not an option because of cost and historic preservation restrictions. Insulating the walls on the interior is

[1] Analysis of the buildings by Wegowise.com indicates that their heating consumption is 11–12 Btu/ft^2/heating degree day, rating as poor, with 4–5 considered "great" and 8 considered "good."

also not an option because of the cost and disruption created by interior construction work. Other envelope efficiency measures may be considered in the future, but are unlikely to solve the heating distribution problem.

The buildings are currently heated with either two or three boilers each. Prior to the retrofit, the boilers were operated by controllers that reset the supply water temperature based on outdoor temperature (Figure 2). The building operators are obligated under local ordinance to maintain a minimum space temperature in each apartment of 68°F during the day and 64°F at night during the heating season. Each apartment has one or two nonelectric actuator zone valve controllers to regulate water flow through the baseboard heaters (Figure 2 right). These valves, when functional, allow the resident some control over heating and are marked with temperatures, although their calibration is unknown. Efficient operation of the heating system faces several obstacles, including inflexible boiler controls and disregard by residents of recommended thermostat set points. In addition, many of the radiator valve actuators have failed and run wide open, resulting in space temperatures that are higher than required.

Figure 1. Exterior view of Building 3 and typical basement boiler room

Figure 2. Existing boiler controllers (left and center) and local radiator controller (right)

Figure 3 shows the boiler reset schedules previously used in two of the buildings. Building 4, which had a more modern tekmar controller, was set more aggressively to reduce the hot water supply temperature. The 1990s vintage Weil McLain controller was set on a less aggressive slope. As a result, on April 7, 2011 when outdoor temperatures were 45°–50°F, the supply temperature was about 30°F higher in Building 3. This is consistent with the finding (based on utility bill analysis) that Building 3 consumed 17% more space heating fuel per square foot than did Building 4. The large data points in Figure 3 represent the settings on that day. The other points define the schedules for the respective controllers.

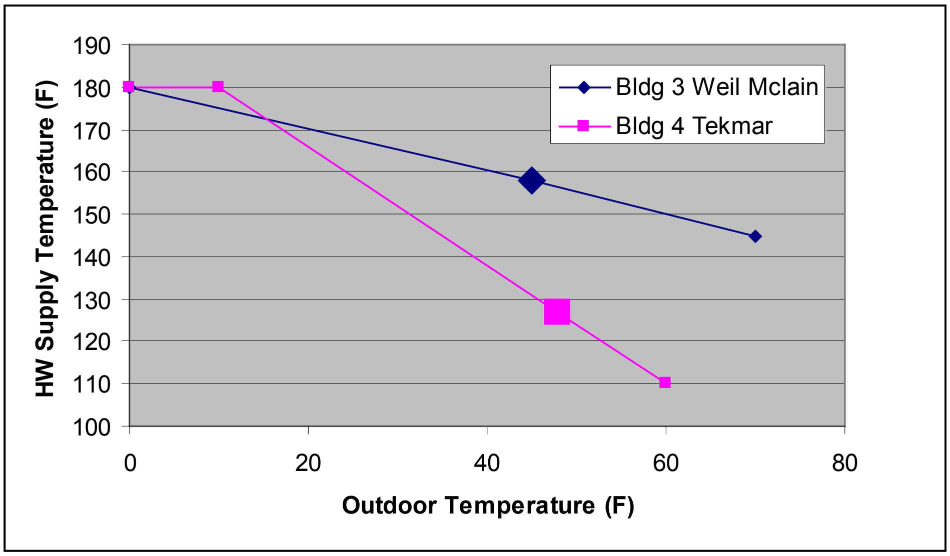


Figure 3. Existing boiler reset schedules

An aerial view of the property indicating divisions between buildings is shown in Figure 4. Each building comprises three attached sections, each with its own address number. Each section contains one or two apartments on each of three floors. Heating system risers are located under each line of radiators in the front and back sides of the buildings with one riser serving each radiator in the first-floor apartment and a second riser serving radiators on both the second and third floors.

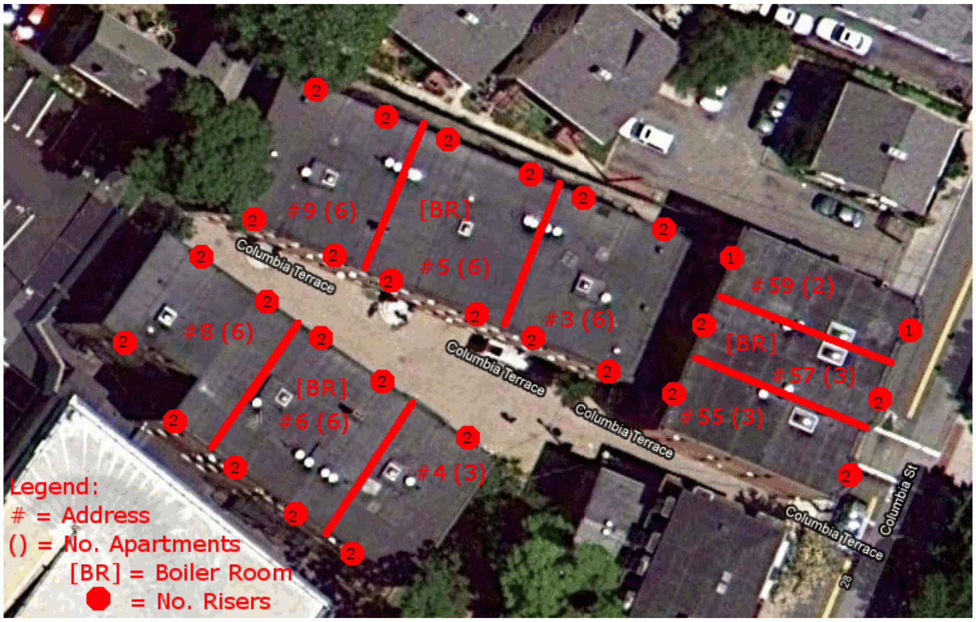


Figure 4. Aerial photo showing divisions of buildings and number of units[2]

Each building has a boiler room in the central portion of the basement. Buildings 3 and 4 (each row of building sections is referred to by its lowest address number) both have three 87% annual fuel utilization efficiency boilers supplying space heating. Building 55 has two 87% annual fuel utilization efficiency space heating boilers. Each building also has one boiler dedicated to supplying domestic hot water (DHW). Figure 5 shows a system diagram typical of the three buildings.

[2] Note that each building is actually composed of three attached sections, each with its own address; the buildings are referred to by the owner and in this report using one of these addresses (3, 4 or 55).

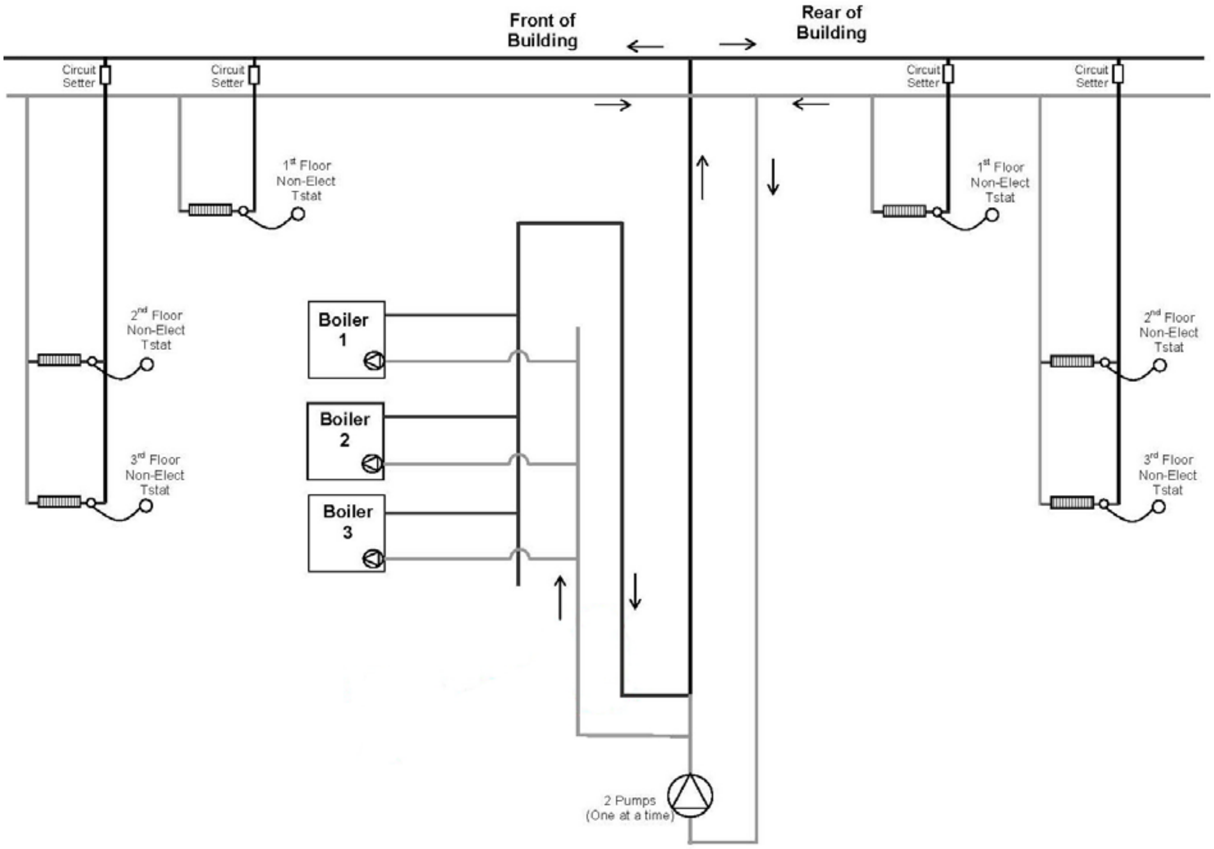


Figure 5. Typical space heating system diagram

3 Retrofit Strategies

Boiler controls were replaced in all three Columbia CAST buildings as part of the retrofit. Table 1 describes the pre-existing control systems and retrofit measures.

Table 1. Existing and Planned Retrofit Controllers

	55 Columbia Street (9 apartments)	4 Columbia Terrace (15 apartments)	3 Columbia Terrace (18 apartments)
Boiler Quantity and Age	(2) – 1.5 years	(3) – 3 years	(3) – 8 years
Pre-Existing Boiler Controller	Weil-McLain System 1	tekmar 264	Weil-McLain System 1
Boiler Return Water Temperature	Boilers have a built-in capability to operate at a return water temperature as low as 60°F.	Boilers should operate with a return water temperature ≥ 140°F.[3] This limits the efficiency of the controller's outdoor temperature reset function.[4]	Boilers should operate at a return water temperature ≥ 140°F. This limits the efficiency of the controller's outdoor temperature reset function.
Retrofit Measures	Replace controller with new outdoor reset controller (tekmar 274) capable of nighttime setbacks.	Add new mixing valve, mixing valve controller (tekmar 362) and boiler controller (tekmar 274) to fully utilize the ability to use the outdoor temperature reset control strategy. Incorporate limited indoor temperature data into control algorithm (future year).	Add new mixing valve, mixing valve controller (Intech 21 HWHC 2100), boiler controller (Intech 21 HWHC 2100BPT), and apartment temperature sensors in every apartment to provide input to controllers to meet the apartment temperature set point.

3.1 Building 3

In Building 3, the new boiler control system allows for remote tracking and control of all parameters, as well as nighttime setbacks. It also incorporates wireless temperature sensors in all apartments that provide input into the control algorithm. When the average of the indoor sensor readings exceeds the indoor set point by the dead band (set to 2.5°F), the controller reduces heat delivered to the building by up to 100%. The system utilizes available hardware from Intech 21, a company that specializes in self-healing wireless networks and heating system controls. The central controller communicates with an offsite server that stores logged temperature and boiler operation readings and makes these historic data available on a website. The Web-based system allows remote operation and modification of the control parameters and provides real time access

[3] The 140° limit comes from the Weil-McLain user manual

[4] Boilers were previously operating without temperature controls in place in Buildings 3 and 4.

to apartment temperature data so that building operators can ensure the legally required minimum heating temperature is provided to each apartment, without requiring an excessively large safety factor. Access to these data will also assist in diagnosing heating system problems and addressing tenant complaints. Figure 6 shows the controller web interface; Figure 7 shows the boiler and mixing valve control modes, set points, and temperatures; and Figure 8 shows sample apartment temperature data.

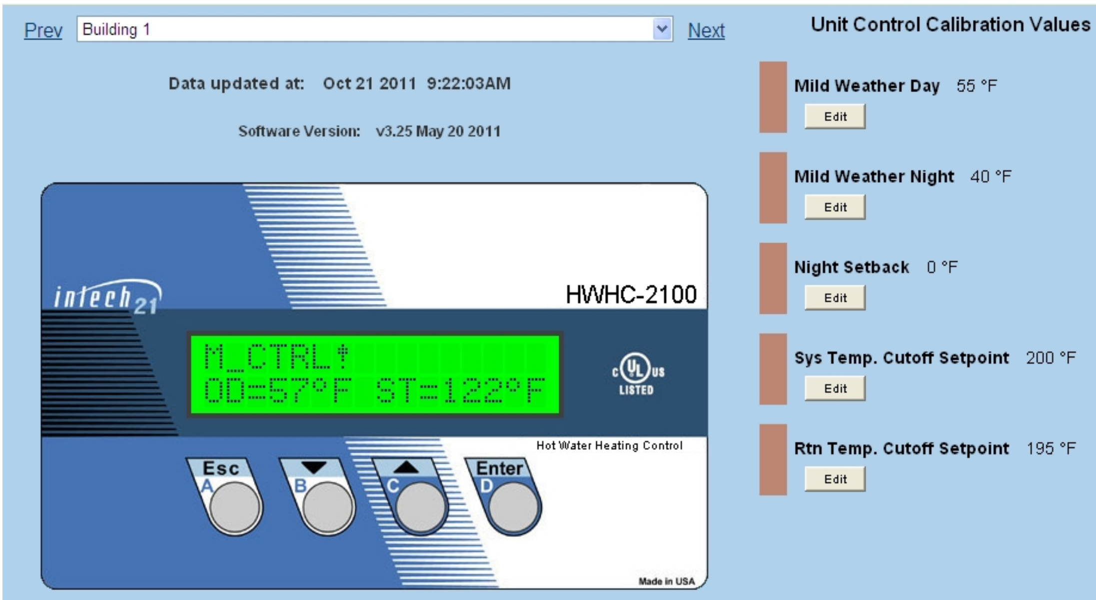
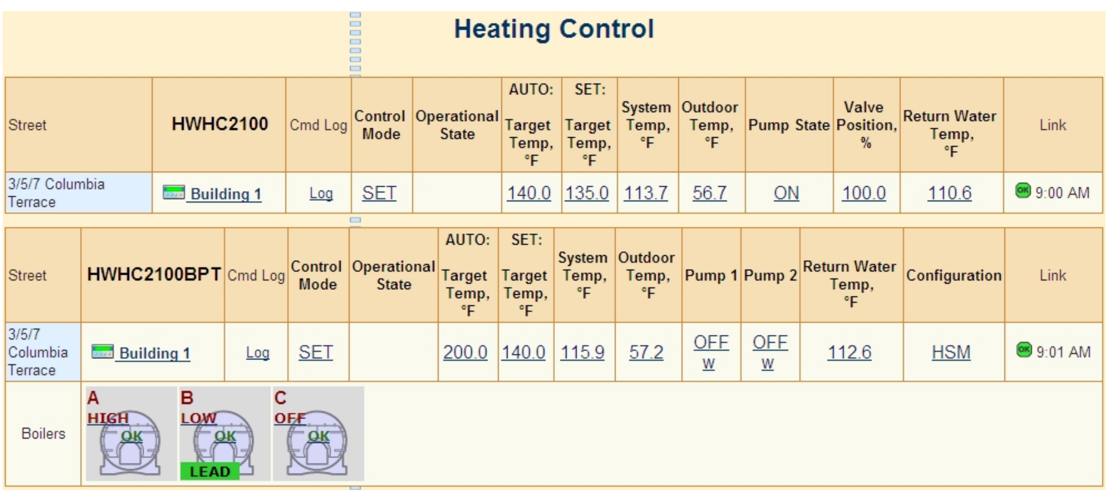


Figure 6. Controller Web interface



Heating Control

Street	HWHC2100	Cmd Log	Control Mode	Operational State	AUTO: Target Temp, °F	SET: Target Temp, °F	System Temp, °F	Outdoor Temp, °F	Pump State	Valve Position, %	Return Water Temp, °F	Link
3/5/7 Columbia Terrace	Building 1	Log	SET		140.0	135.0	113.7	56.7	ON	100.0	110.6	9:00 AM

Street	HWHC2100BPT	Cmd Log	Control Mode	Operational State	AUTO: Target Temp, °F	SET: Target Temp, °F	System Temp, °F	Outdoor Temp, °F	Pump 1	Pump 2	Return Water Temp, °F	Configuration	Link
3/5/7 Columbia Terrace	Building 1	Log	SET		200.0	140.0	115.9	57.2	OFF W	OFF W	112.6	HSM	9:01 AM
Boilers	A HIGH OK	B LOW OK LEAD	C OFF OK										

Figure 7. Mixing valve controller (top) and boiler controller (bottom) set points and system temperatures

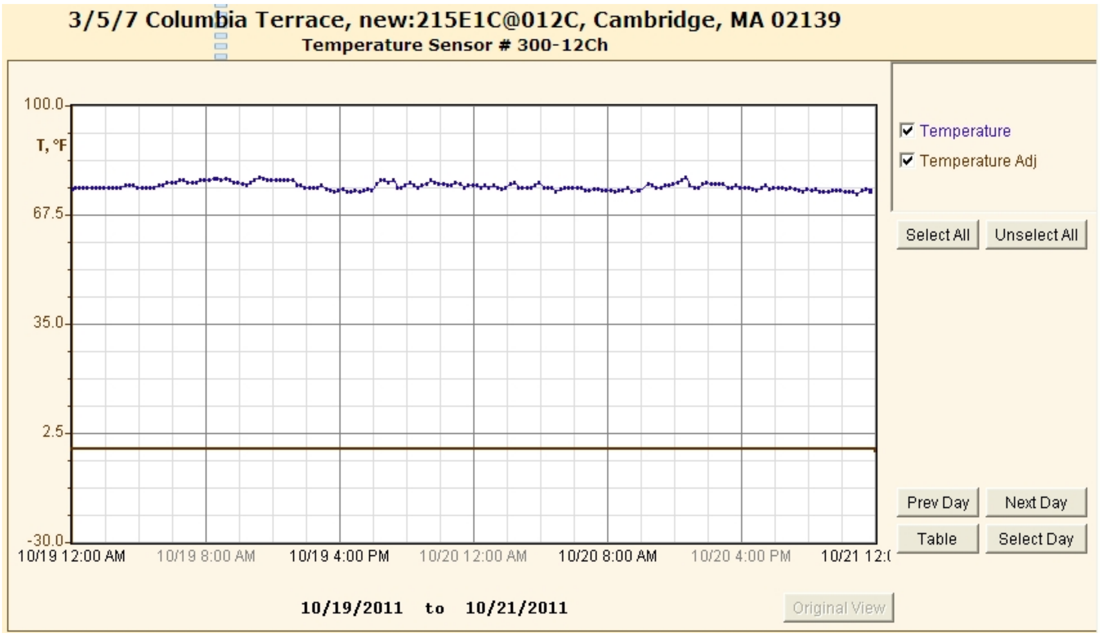


Figure 8. Sample apartment temperature sensor data

A three-way mixing valve was added to the heating system piping (Figure 9) to maintain return water temperatures above the levels that could damage the existing noncondensing boilers (140°F).

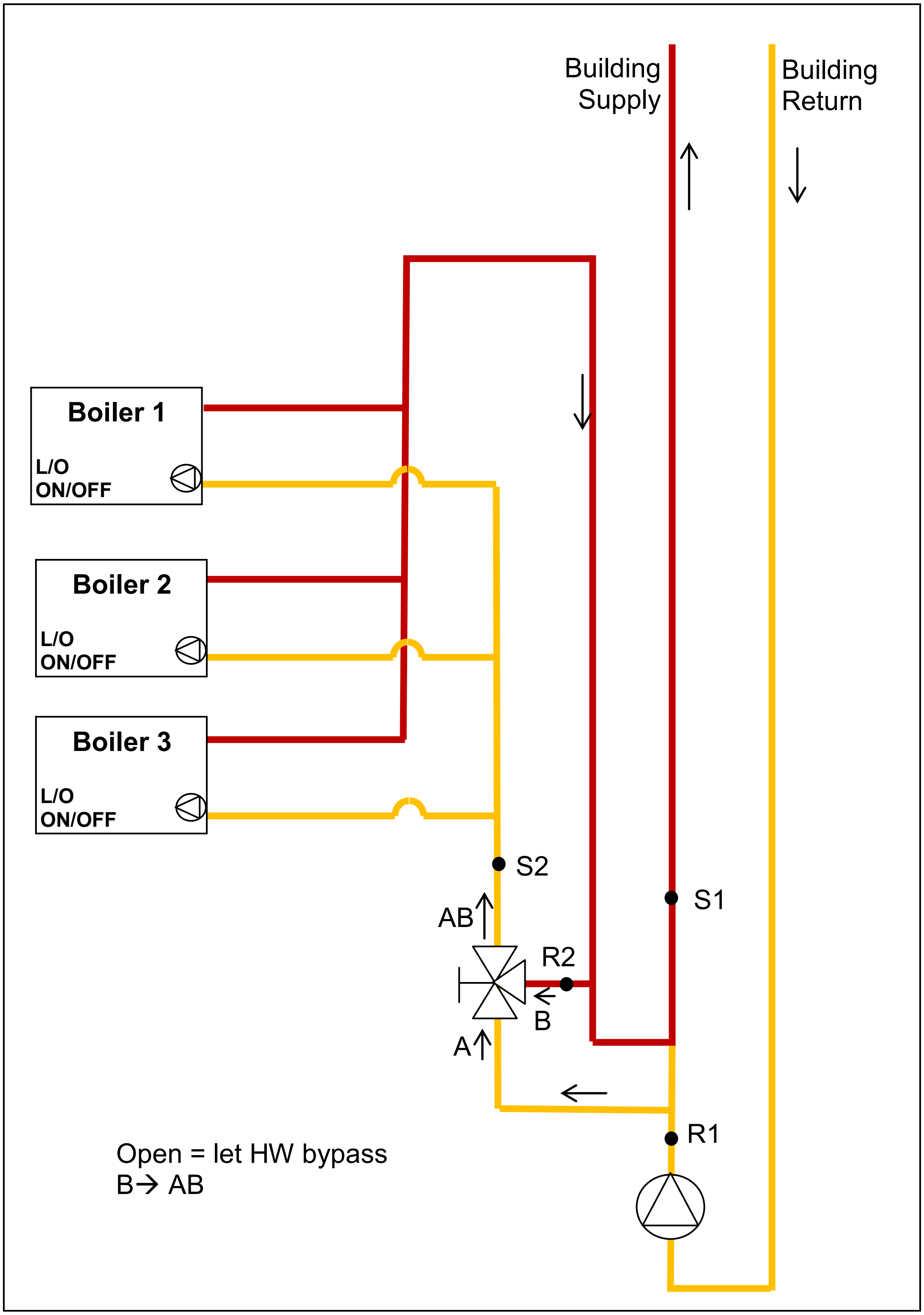


Figure 9. Building 3 system configuration

3.2 Building 4

In Building 4, new boiler controls allow for remote monitoring of all parameters. In the following heating season it will incorporate a degree of indoor temperature input from three additional sensors. The controls permit nighttime setbacks and outdoor reset. A three-way mixing valve was added to the heating system piping (Figure 10) to maintain return water temperatures above the levels that could damage the existing noncondensing boilers (140°F).

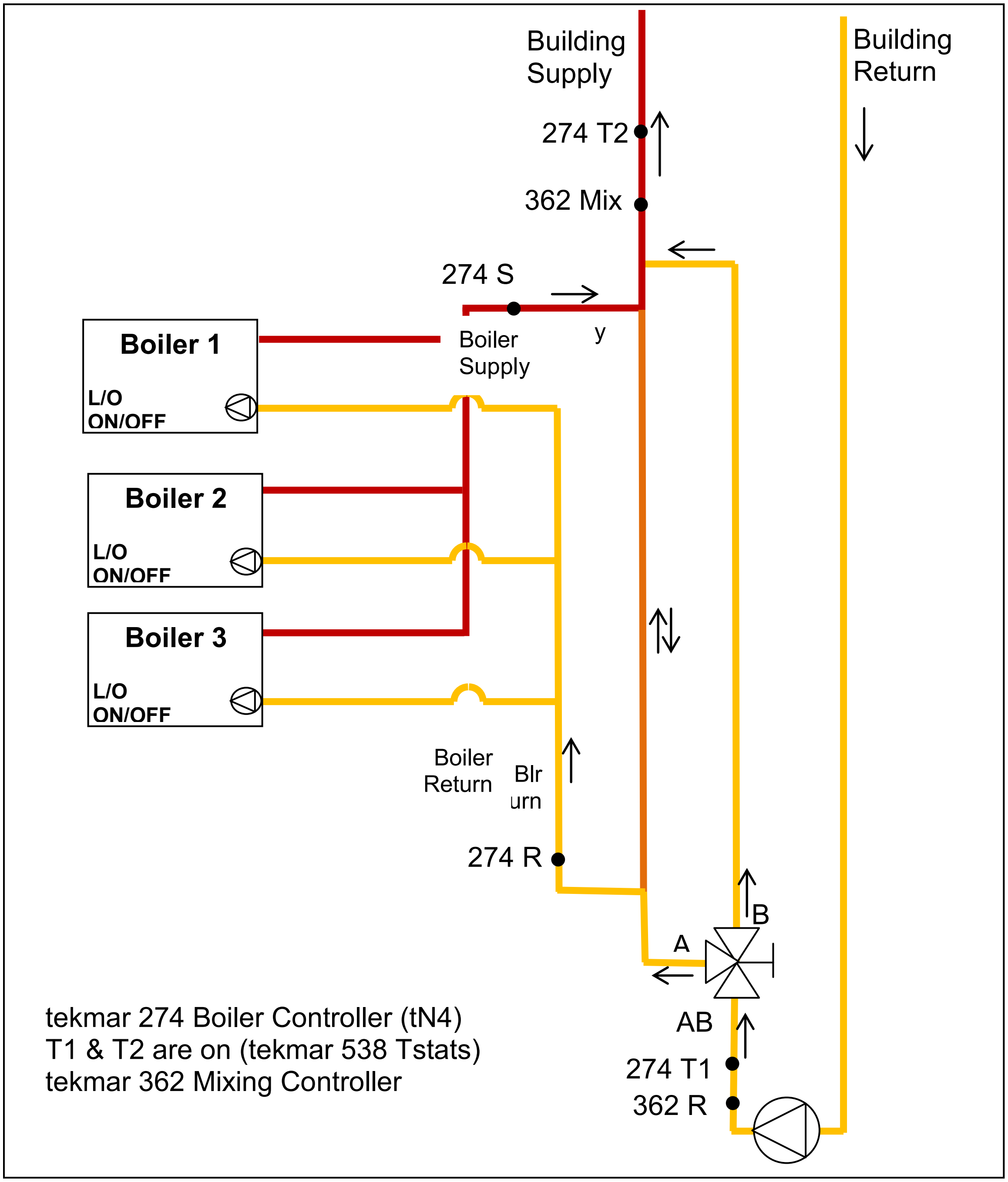


Figure 10. Building 4 system configuration

3.3 Building 55

The new controller in Building 55 is capable of nighttime setbacks. The boilers in Building 55 have a built-in bypass valve to mix hot water from the boiler outlet with colder return water (as low as 60°F) from the system prior to entry to the boiler sections when needed to prevent thermal shock and condensation of flue gases in the boiler. Therefore the addition of a new three-way mixing valve is unnecessary (Figure 11).

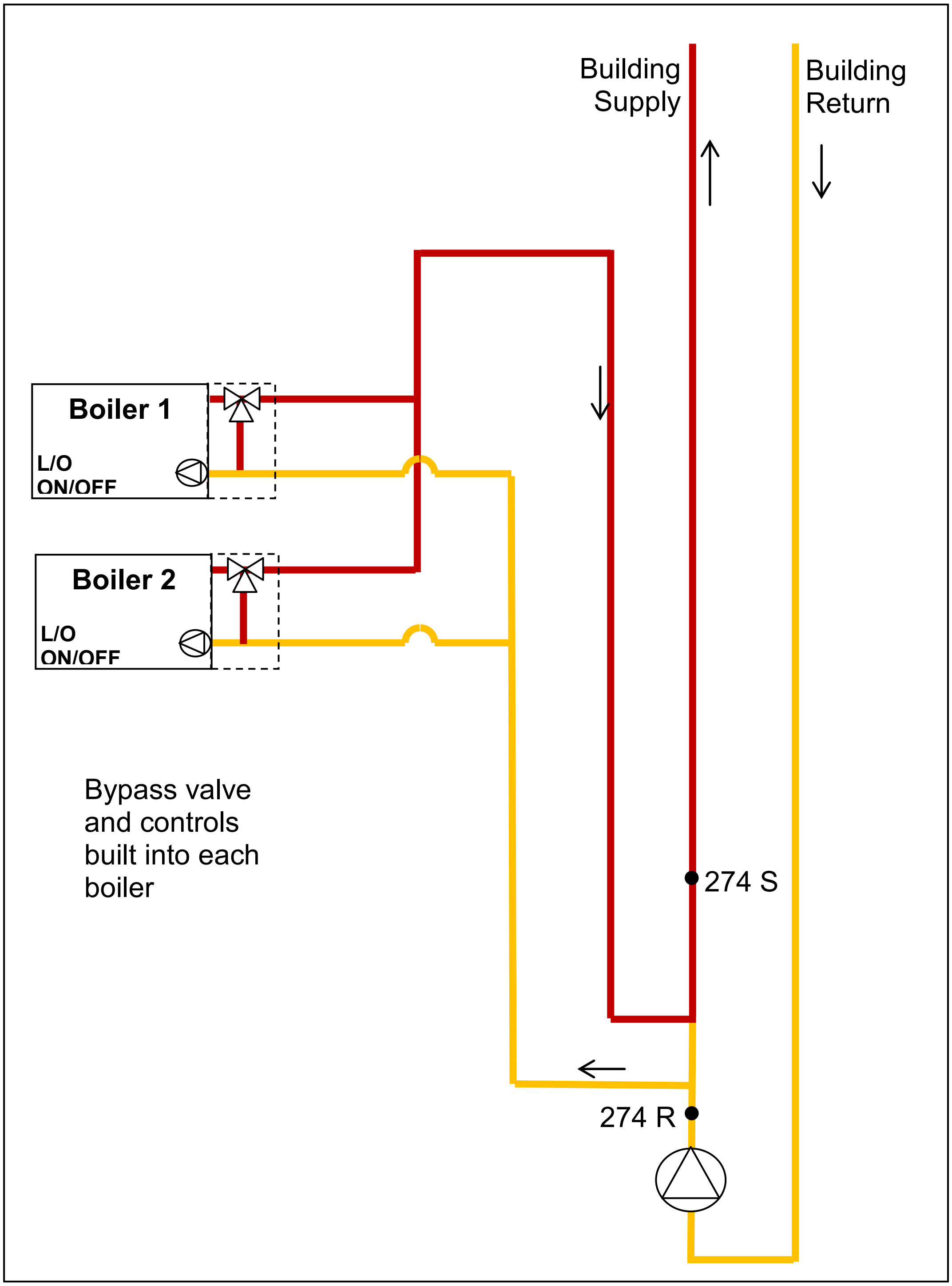


Figure 11. Building 55 system configuration

3.4 Data Collection

Data to evaluate energy savings and comfort impacts will be collected under a number of control scenarios for each building (Table 2). The critical data collection periods are the shoulder seasons when most of the potential energy savings are expected.

Table 2. Data Collection Periods

Time Period	Building 3	Building 4	Building 55
October 2011 – January 15, 2012	Default Outdoor Reset With Indoor Temperature Input	Default Outdoor Reset	Default Outdoor Reset
January 16 – February 15, 2012	Default Outdoor Reset Without Indoor Temperature Input	Default Outdoor Reset With Nighttime Setback	Default Outdoor Reset With Nighttime Setback
February 16 – March 15, 2012	Default Outdoor Reset With Indoor Temperature Input	Default Outdoor Reset With Nighttime Setback	Default Outdoor Reset With Nighttime Setback
March 16 – April 15, 2012	Default Outdoor Reset Without Indoor Temperature Input	Default Outdoor Reset With Nighttime Setback	Default Outdoor Reset With Nighttime Setback
April 16 – End of Heating Season 2012	Default Outdoor Reset With Indoor Temperature Input	Default Outdoor Reset With Nighttime Setback	Default Outdoor Reset With Nighttime Setback

Table 3 summarizes the data collection in Building 3. Unless otherwise noted, these data will be logged approximately every 15 minutes. Location codes in the table refer to Figure 9.

Table 3. Summary of Monitoring Data Points in Building 3

Data Point Name	Description	Location	Engineering Units
TZi	Temperature in Apartment Using Networked Sensors	All 18 Apartments	°F
TZd	Temperature in Sample of Apartments Using Non-Networked Sensors To Record Distribution	Two Locations in Apartments 3-6, 5-4, and 9-6	°F
TAO	Temperature Outdoor Air (used by controller)	Outside	°F
TWS	Temperature of Hot Water Supplied to Building	2100 S1	°F
TWR	Temperature of Hot Water Returned From Building	2100 R1	°F
TBR	Temperature of Hot Water Entering the Boilers	2100 S2	°F
R1-3	Cumulative Run Time on Boilers	Each of 3 boilers	hours
VLV	Mixing valve position	HWHC 2100	%
PMP	Cumulative Runtime on Building Hot Water Pump	HWHC 2100BPT	hours
NG	Natural Gas Usage From Monthly Utility Billing	Wegowise	therms

The tekmar systems have been configured to collect one-minute data using a Mac Mini data server. The sensors are read every few seconds and averaged into one-minute intervals. Table 4 and Table 5 summarize the data collection in Building 4 and Building 55, respectively. Location codes in the tables refer to Figure 10 and Figure 11, respectively.

Table 4. Summary of Monitoring Data Points in Building 4

Data Point Name	Description	Location	Engineering Units
TBS4	Boiler Supply Temperature	274 S	°F
TBR4	Boiler Return Temperature	274 R	°F
TAO4	Temperature Outdoor Air (used by controller)	Outside Building	°F
TWS4	Supply Temperature to Building	274 T2	°F
TWR4	Return Temperature from Building	274 T1	°F
TBT4	Target Supply Temperature for Boilers	274 Set pt	°F
SB4	Boiler Plant Operation Percentage	0, 33, 66, 100	%
TZ1	Temperature in 1st Floor Apt	1st Floor	°F
TZ2	Temperature in 2nd Floor Apt	2nd Floor	°F
TZ3	Temperature in 3rd Floor Apt	3rd Floor	°F
TZd	Temperature in Sample of Apartments Using Non-Networked Sensors to Record Distribution	Apartment 4-3	°F
NG	Natural Gas Usage From Monthly Utility Billing	Wegowise	therms

Table 5. Summary of Monitoring Data Points in Building 55

Data Point Name	Description	Location	Engineering Units
TBS55	Boiler/System Supply Temperature	274 S	°F
TBR55	Boiler/System Return Temperature	274 R	°F
TAO55	Temperature Outdoor Air (used by controller)	Outside Building	°F
TBT55	Target Supply Temperature for Boilers	Set Point	°F
SB55	Boiler Plant Operation Percentage	0, 50, 100	%
TZd	Temperature in Sample of Apartments Using Non-Networked Sensors to Record Distribution	Apartments 55-2	°F
NG	Natural Gas Usage From Monthly Utility Billing	Wegowise	therms

Additional notes about selected data points follow:

- TZi: One networked temperature sensor is installed in a central location on an interior wall in each apartment in Building 3. These sensors provide input about comfort levels and evenness of heat distribution throughout the building from apartment to apartment. Accuracy was checked by a handheld temperature sensor at three locations in each apartment during November 2011 and the system was calibrated accordingly. Temperatures will be checked periodically throughout the project.

- TZd: Data about temperature distribution within apartments are sampled in five apartments among the three buildings using two remote data loggers per apartment placed at either end of the apartment.

- TZ1, TZ2, TZ3: Three wired indoor temperature sensors will provide input to the boiler controls in Building 4 (future year).

- R1-3: Firing or runtime for each of the eight single-stage boilers is totaled for each 15-minute period. This will be compared to monthly gas use to corroborate the boiler input rates. This knowledge will be used to predict gas use for more finely resolved time intervals (daily, hourly, 15-minute) that are available from the utility bills.

- TBR55: Temperature sensors log the temperature in individual boiler returns in Building 55, where the two boilers have built-in bypass valves to mix hot water from the boiler outlet with colder return water from the system prior to entry to the boiler sections when needed to prevent condensation of flue gases in the boiler. When this return temperature is higher than the main building return temperature, it indicates that the valve is open.

- NG: The Columbia CAST buildings are enrolled in Wegowise.com, a system that automatically tracks monthly utility use and costs and uploads the data to a website that permits analysis and comparison with other buildings. This system is used to access monthly gas consumption.

Comfort will be gauged by heat complaint reports, surveys of residents, and periodic observations of open windows on site (frequency and location compared to outdoor temperature and heating system activity). It is acknowledged that complaints and surveys are subjective and an imperfect means of data collection and will limit the accuracy of the comfort assessment.

4 Analysis

4.1 Pre-Retrofit Utility Bill Analysis

Monthly gas bills were used to calculate gas use load lines for the three buildings for 2005 through 2011 (pre-retrofit) (Figure 12 through Figure 14). Gas use becomes constant at about 60°–65°F outdoor temperature. This use represents DHW, cooking, and laundry. Because DHW is provided by separate dedicated systems in each building, all boiler runtimes associated with the space heating boilers are attributable to space heating.

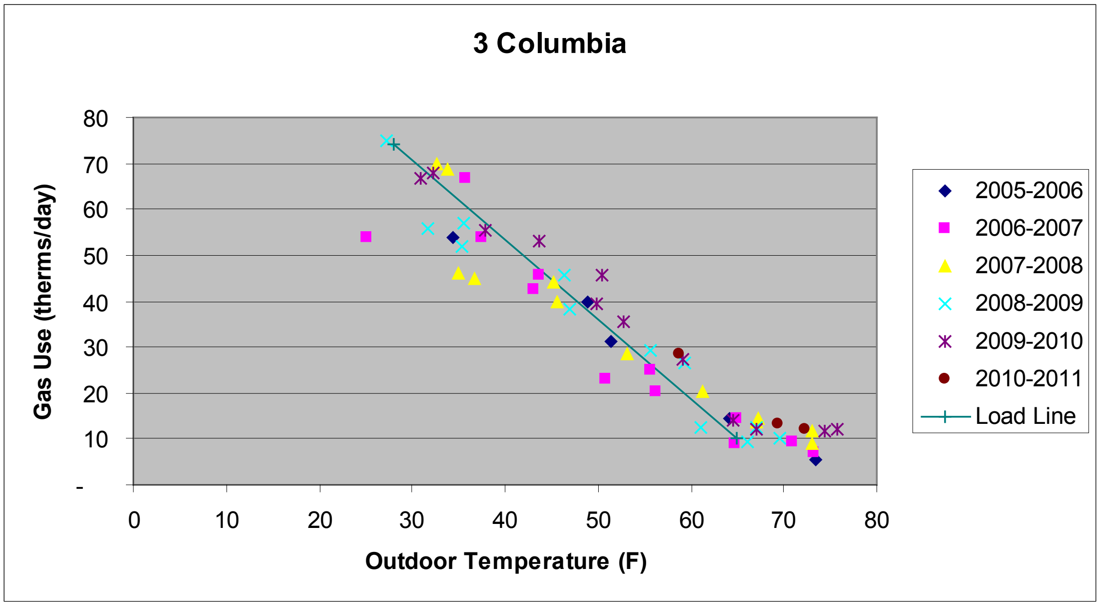


Figure 12. Gas load line for Building 3

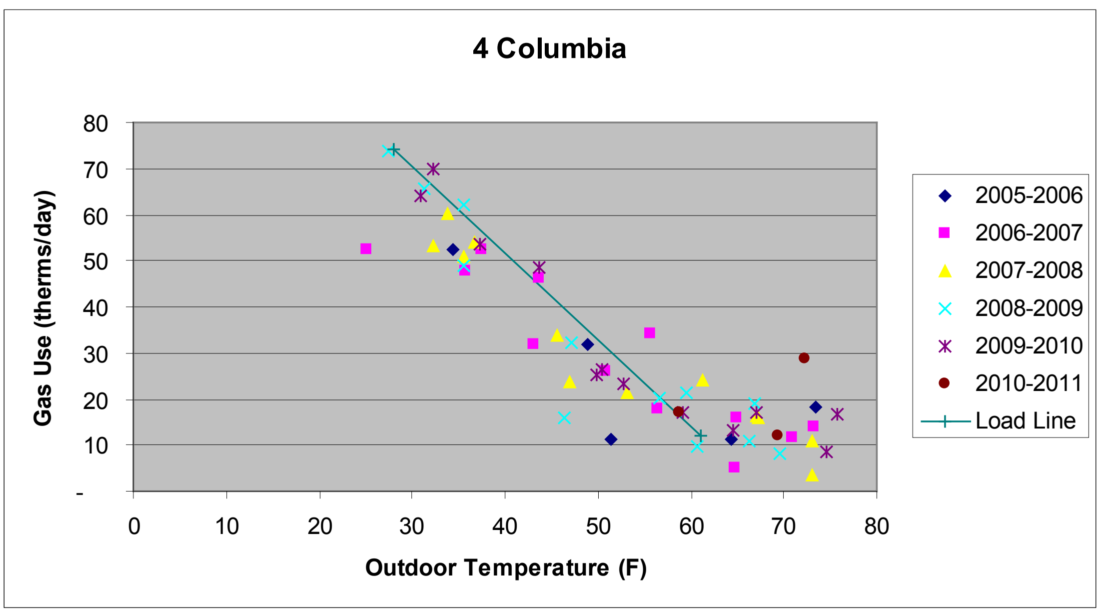


Figure 13. Gas load line for Building 4

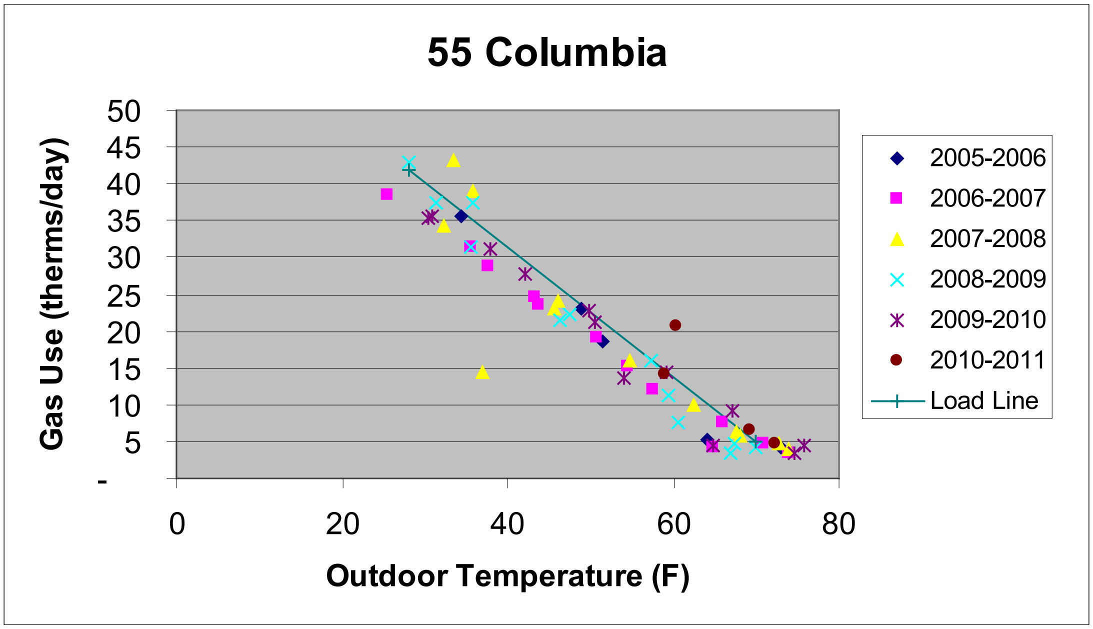


Figure 14. Gas load line for Building 55

A similar analysis (using daily rather than monthly data) will be calculated for the 2011–2012 heating season with the retrofit heating system installed. It will relate total boiler runtime to outdoor temperature for each day. The resulting linear trends for different performance periods or control modes can be directly compared to discern the impacts of the retrofits. A multilinear regression analysis with one or more dummy variables will be used to determine if the difference between the various control modes is statistically significant at the desired confidence level of 95%.

4.2 Preliminary Economic Analysis

The projected cost effectiveness was analyzed for the test site. The control system at the test site is projected to save on average about 16% of the space heating gas use, or 3,631 therms/yr (or $4,357 at $1.2/therm) for all three buildings. The cost to install the wireless sensors, boiler controls, and a Web-based system was $25,296 for all three buildings. The simple payback is projected to be approximately six years. (See Table 6 for calculation details.) Figures were taken from four years of actual gas bills for each of the three buildings. The baseload, representing DHW, cooking, and laundry (dryer) use, was determined from summertime gas use and deducted from heating season use to calculate heating fuel.

Table 6. Preliminary Energy Calculations (projected)

	3 Columbia	4 Columbia	55 Columbia	Total
Building				
Number of Apartments Served	18	15	8	41
Number of Bedrooms	45	40	28	113
Floor Area (ft^2)	15,524	13,672	9,955	39,151
Gas Use				
2009–2010 Season (therms)	13,475	11,798	6,823	32,096
2008–2009 Season (therms)	12,719	11,637	7,272	31,628
2007–2008 Season (therms)	12,330	11,140	6,873	30,343
2006–2007 Season (therms)	11,189	10,733	6,478	28,400
Estimated DHW (therms/day)	10	12	5	27
Estimated DHW (therms/yr)	3,650	4,380	1,825	9,855
Estimated Space Heating (therms)	9,825	7,418	4,998	22,241
Peak (therms/day) @ 28°F	74.9	73.9	42.9	192
Economics				
Savings From Phase I	18%	15%	15%	16%
Savings (therms)	1,769	1,113	750	3,631
Gas Savings	$2,122	$1,335	$900	$4,357
Installed Costs	$9,540	$8,700	$7,020	$25,260
Payback	4.5	6.5	7.8	5.8
Capital Costs				
Number of Apartments Served	18	15	8	41
Equipment Costs	$10,610	$2,470	$1,457	$14,537
Labor Costs	$6,750	$2,809	$1,200	$10,759
Total Costs	$17,360	$5,279	$2,657	$25,296
Cost per Apartment	$964	$352	$332	$617
Statistics				
Total (therms/ft^2-yr)	0.87	0.86	0.69	0.82
Space Heating (therms/ft^2-yr)	0.63	0.54	0.50	0.57
Base/DHW (therms/ft^2-yr)	0.24	0.32	0.18	0.25
Base/DHW (therms/day-bed)	0.22	0.30	0.18	0.24

Gas accounts about 80% of the annual property energy expenditures. Each apartment is metered for electricity directly by the utility, so individual apartment electricity use is not available. Common area electricity use for the most recent complete year available was 22,013 kWh

($3,182) for Building 3, 23,281 kWh ($3,363) for Building 4, and 16,360 kWh ($2,388) for Building 55.

5 Results

5.1 Sample Data

Figure 16 through Figure 19 display some of the initial data gathered from Building 4 and Building 55 for a few days. The control system in Building 3 was commissioned later, so data were not yet available for that building as of this report writing. The runtime of the boilers during the first few weeks of operation are summarized in Figure 15 along with the number of off-cycles that occurred over the day.

		Bldg 4		Bldg 55	
	Outdoor Temp (F)	Runtime (Blr-hrs/day)	Cycle Rate (cyc/day)	Runtime (Blr-hrs/day)	Cycle Rate (cyc/day)
10/1/2011	66.7	-	0	-	0
10/2/2011	63.9	-	0	-	0
10/3/2011	63.0	-	0	-	0
10/4/2011	60.3	0.74	1	0.42	1
10/5/2011	59.1	1.16	2	0.80	2
10/6/2011	53.7	1.38	37	1.13	21
10/7/2011	54.6	0.11	87	0.15	61
10/8/2011	64.6	0.05	35	0.06	27
10/9/2011	69.7	-	0	-	0
10/10/2011	70.8	-	0	-	0
10/11/2011	62.7	-	0	-	0
10/12/2011	59.9	-	0	0.01	2
10/13/2011	60.9	-	0	0.06	26
10/14/2011	64.2	-	0	-	0
10/15/2011	60.8	0.06	42	0.05	16
10/16/2011	60.6	0.07	47	0.07	25
10/17/2011	60.7	0.06	22	0.05	15
10/18/2011	59.8	0.07	56	0.08	29
10/19/2011	57.7	0.08	51	0.14	58
10/20/2011	60.4	0.52	67	0.12	48
10/21/2011	58.1	1.05	42	0.13	53
10/22/2011	56.0	1.16	39	0.14	60
10/23/2011	51.4	1.68	27	0.19	80
10/24/2011	54.1	1.56	28	0.19	80
10/25/2011	54.8	1.38	34	0.18	75
10/26/2011	48.8	2.26	6	0.23	97
10/27/2011	43.9	2.05	3	0.33	197
10/28/2011	41.3	0.53	138	0.43	298
10/29/2011	39.2	0.51	139	0.46	316
10/30/2011	38.8	0.50	139	0.49	323
10/31/2011	43.4	0.50	149	0.44	302
11/1/2011	45.2	0.49	147	0.43	291
11/2/2011	-	-	0	-	0
11/3/2011	51.9	0.73	145	0.32	200

Figure 15. Buildings 4 and 55 boiler runtimes

The plots below show the performance of the two systems over three different days. Those for Building 55 (Figure 16 through Figure 18) show the system supply and return temperature. The target temperature (set point) is also shown as a green line on the plot. Supply temperature tracks the target temperature closely and the boilers are cycling at regular intervals as intended. The boilers cease firing when outdoor temperature increases; when the outdoor temperature falls, both boilers in Building 55 can be seen to fire simultaneously to boost system supply temperature. Figure 18 depicts a cooler day when the boilers are firing regularly throughout the day.

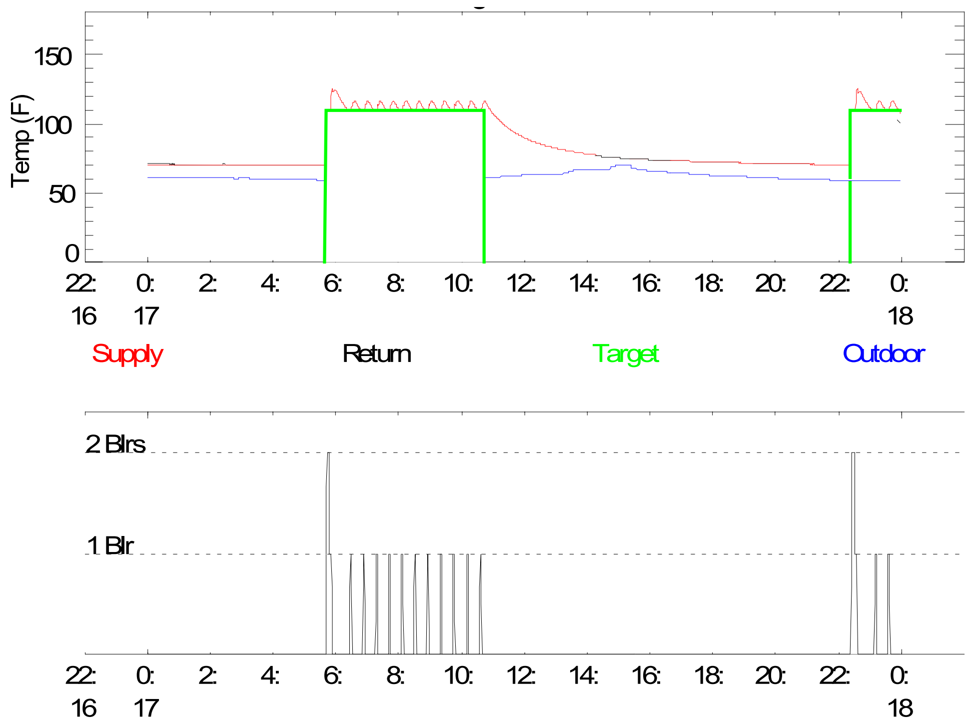


Figure 16. Building 55 boiler performance October 17, 2011

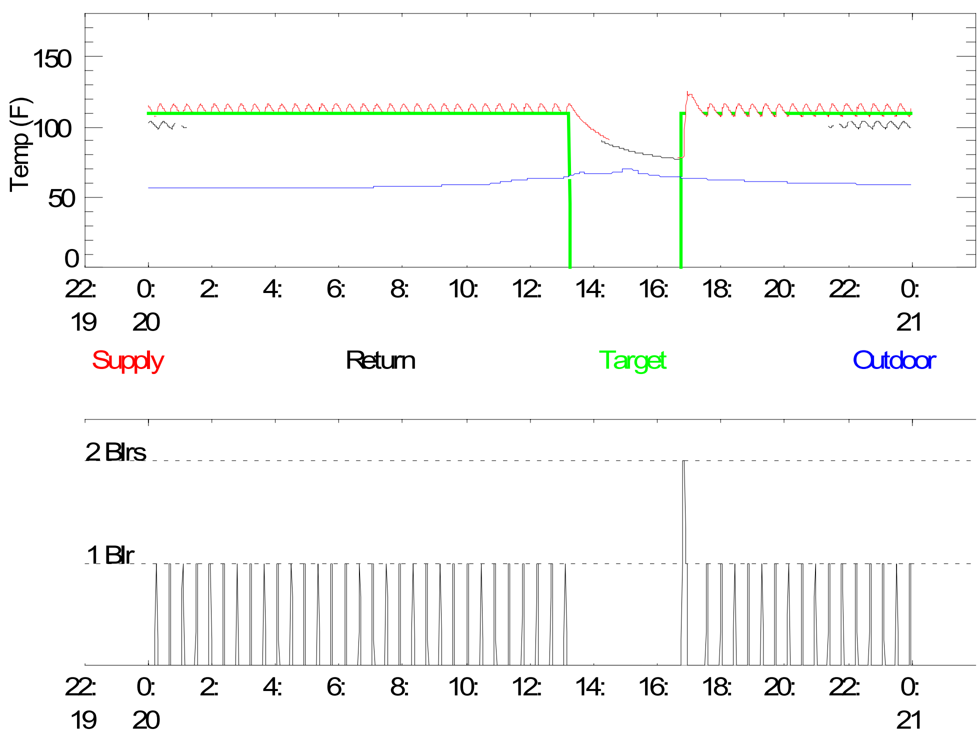


Figure 17. Building 55 boiler performance October 20, 2011

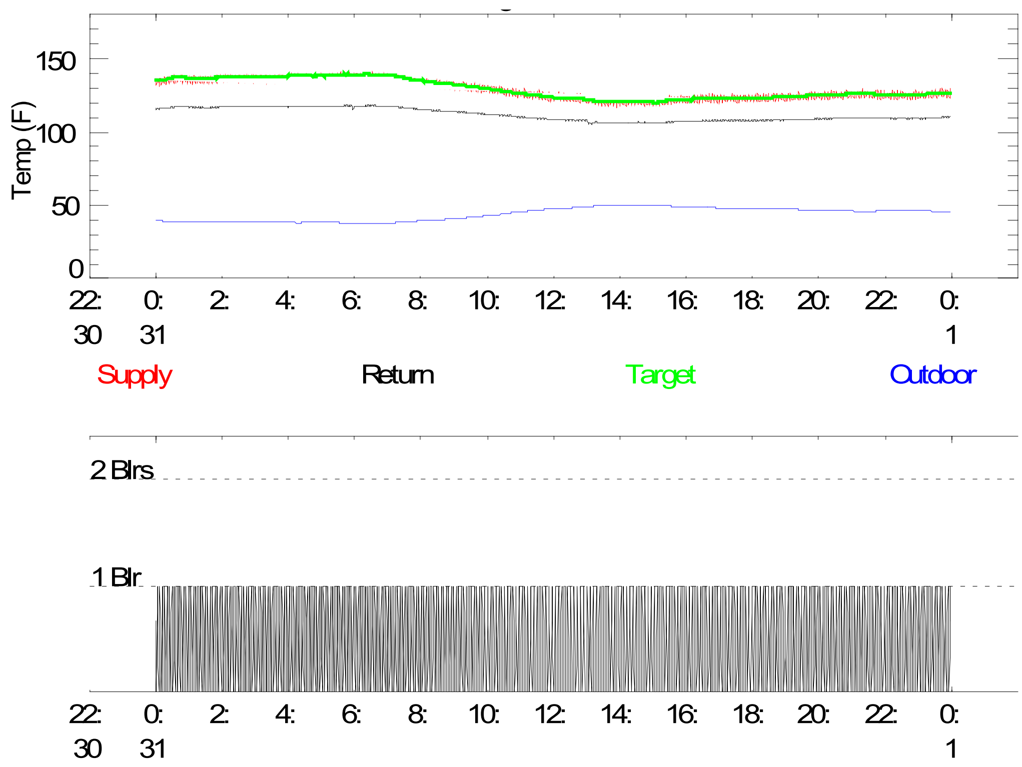


Figure 18. Building 55 boiler performance October 31, 2011

The plot of daily boiler runtime (boiler-hours) versus outdoor temperature (Figure 19) shows the expected linear trend. The daily runtime will be used with the nominal fuel input for each boiler-determined gas use.

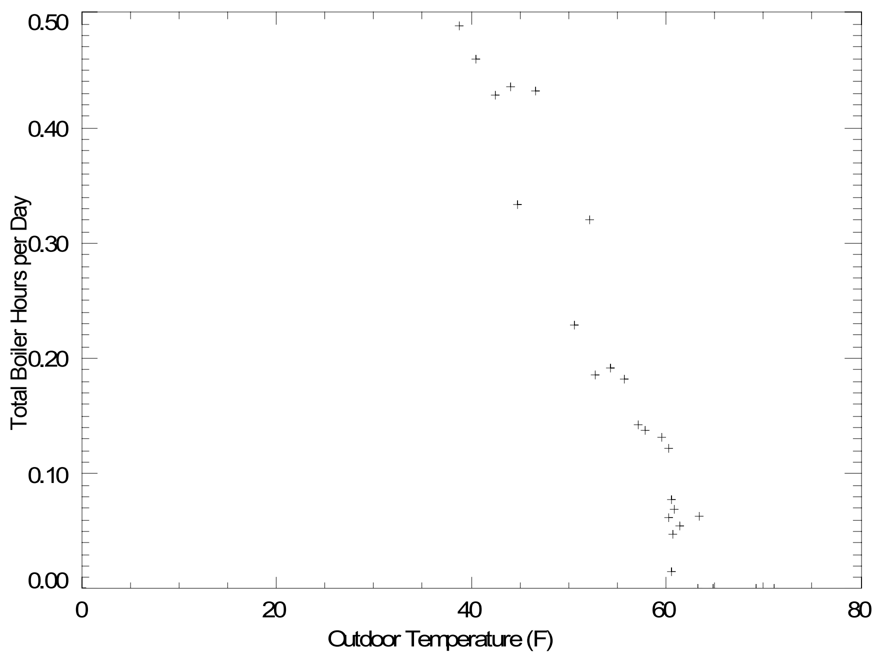


Figure 19. Boiler runtime and outdoor temperature in Building 55

The plot of the supply temperature and outdoor temperature (Figure 20) confirm the specified reset schedule (note that the schedule was altered during the data collection period resulting in a second shorter line to the left of the primary line).

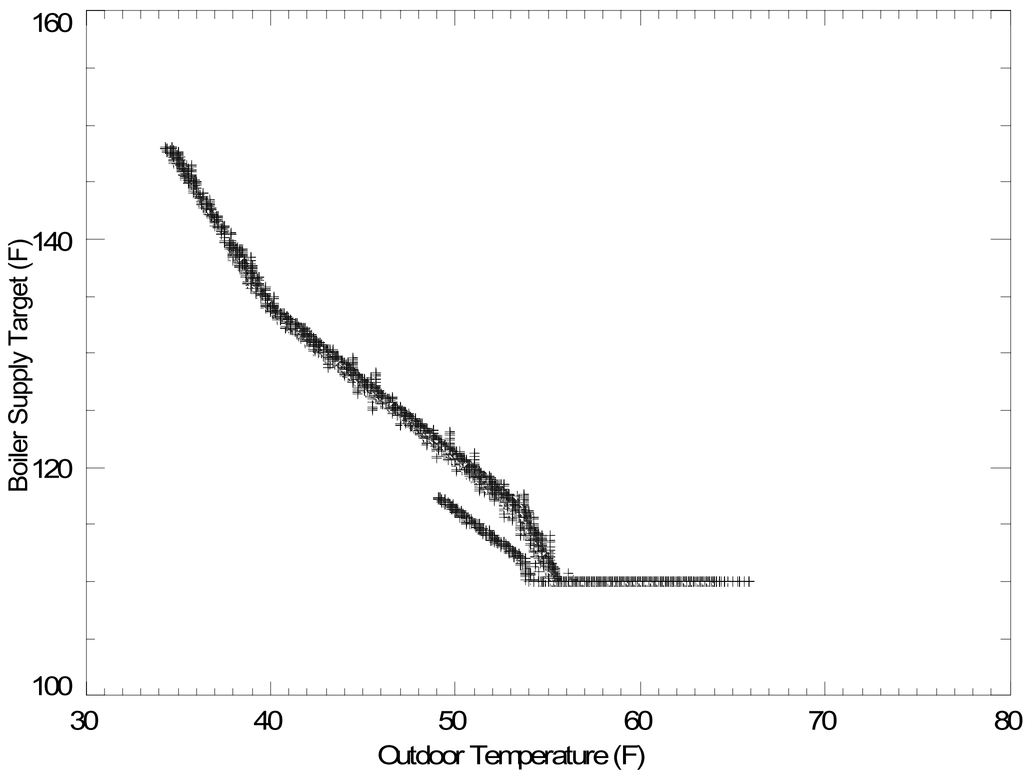


Figure 20. Boiler supply target and outdoor temperature in Building 55

The Building 4 data (Figure 21 through Figure 23) shows the boiler supply and return temperatures, which are set to a higher temperature because the mixing valve controls the system temperature. Note that the 140 minimum is not always achieved and the boiler firing pattern is irregular compared to Building 55. The cause of this is being investigated, but is likely a conflict between the boiler controller and the mixing valve controller (which Building 55 does not have).

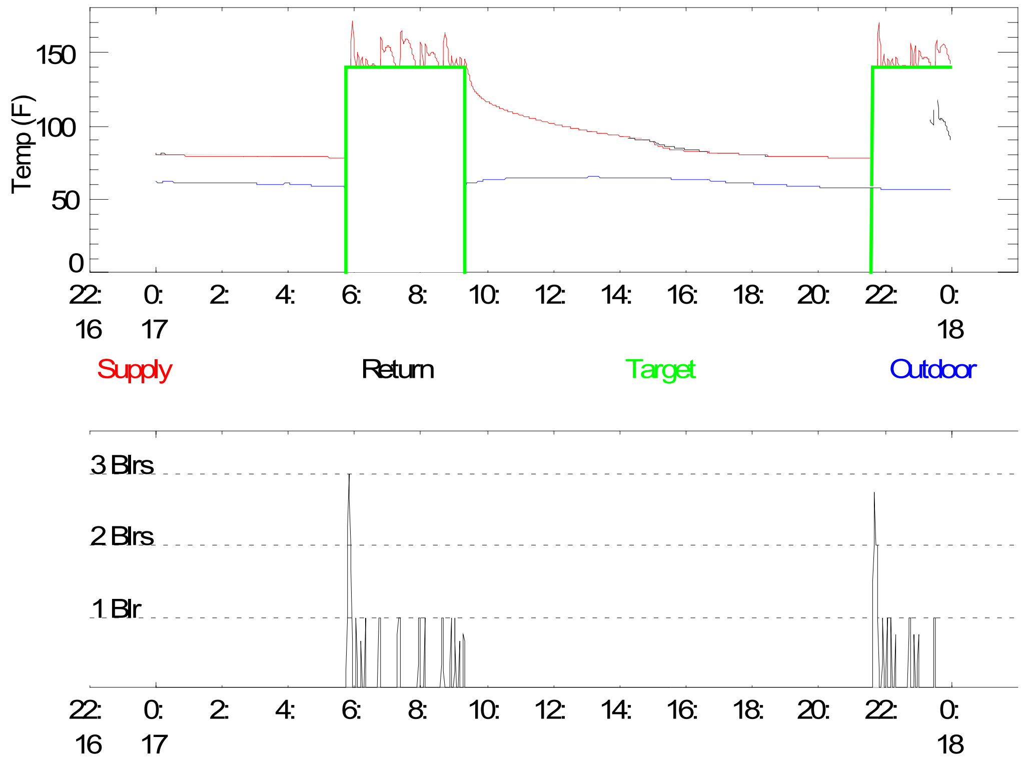


Figure 21. Building 4 boiler performance October 17, 2011

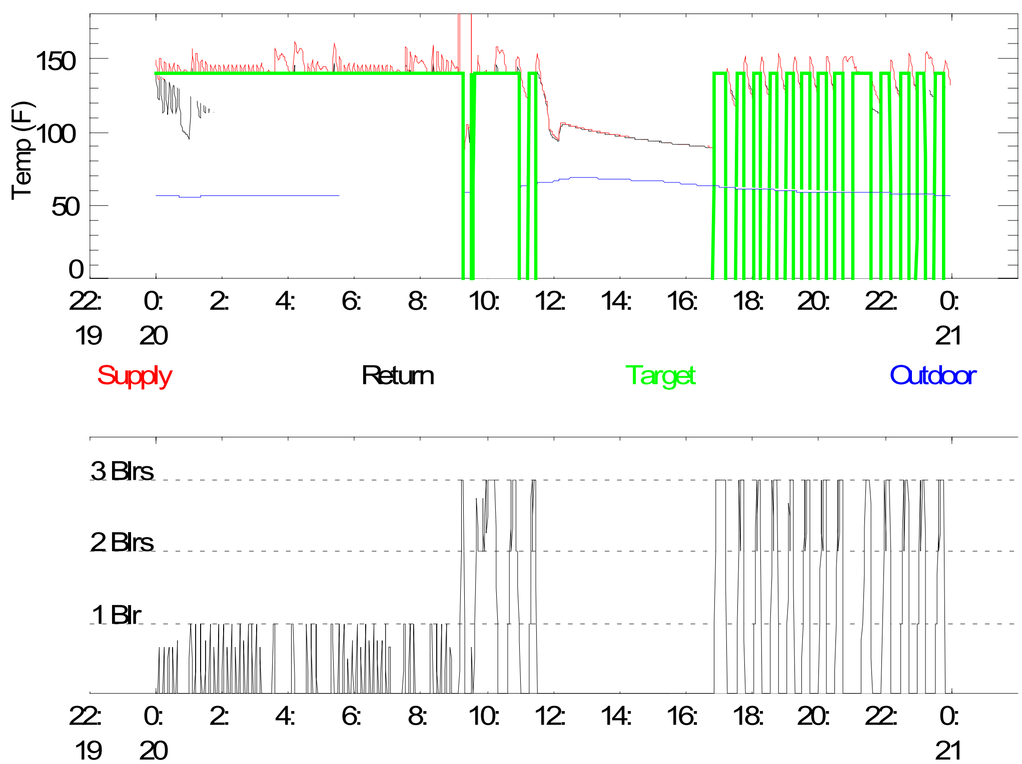


Figure 22. Building 4 boiler performance October 20, 2011

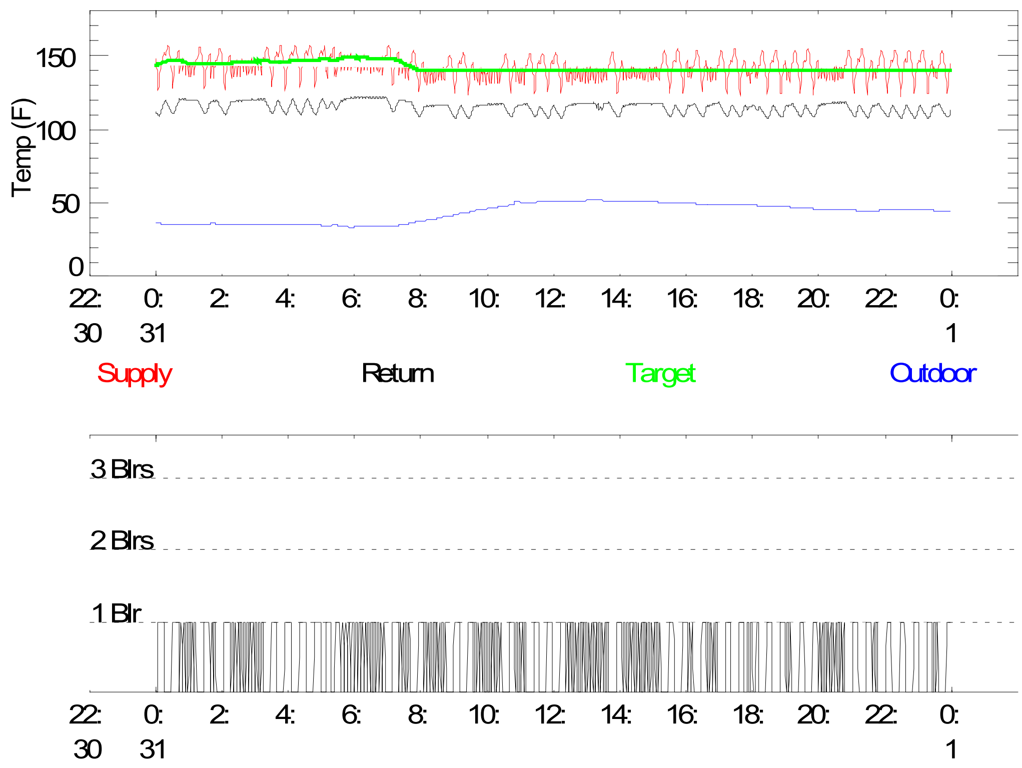


Figure 23. Building 4 boiler performance October 31, 2011

The plot of daily boiler runtime (boiler-hours) versus outdoor temperature for Building 4 (Figure 24) is somewhat more scattered because adjustments were being made to the controller during the data collection period.

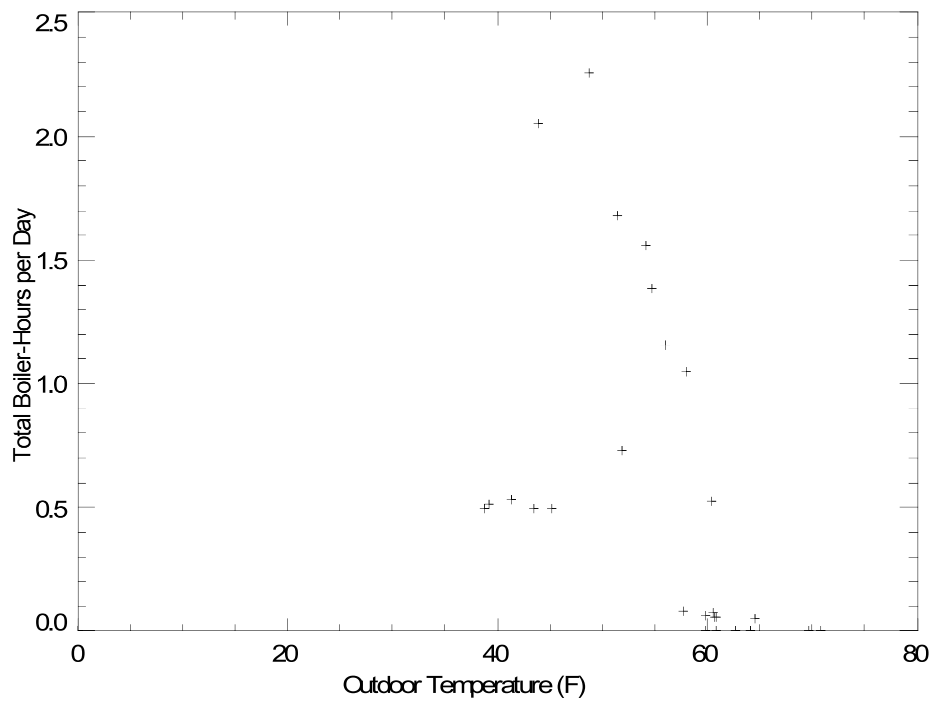


Figure 24. Boiler runtime and outdoor temperature in Building 4

The plot of the supply temperature and outdoor temperature (Figure 25) confirms the specified reset schedule for Building 4.

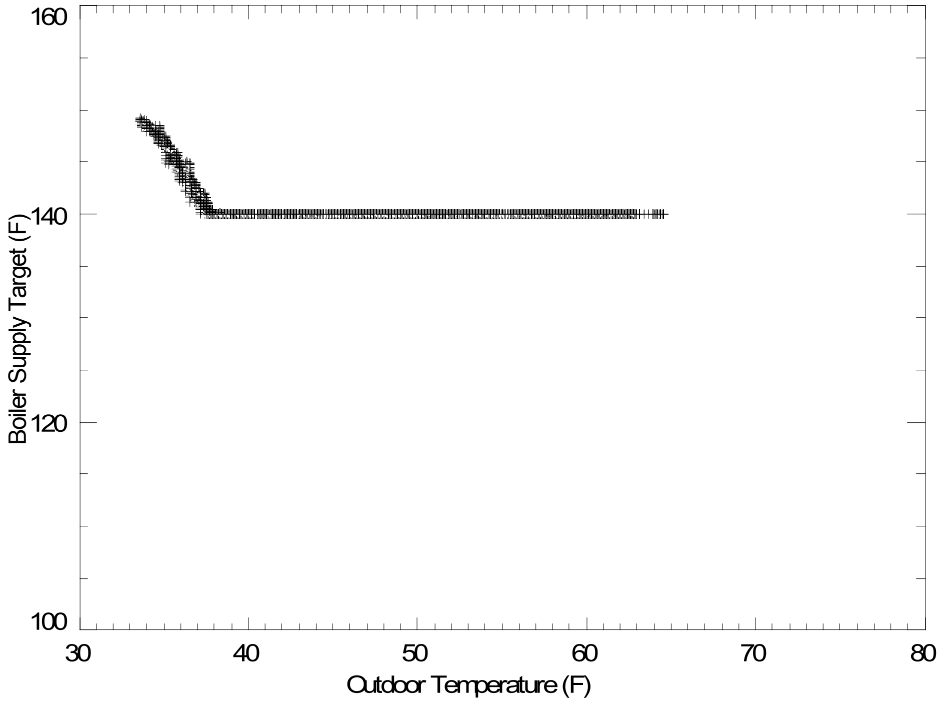


Figure 25. Boiler supply target and outdoor temperature in Building 4

6 Discussion

6.1 Other Impacts

The retrofit control systems are expected to provide other nonenergy benefits to building residents and management, including:

- Occupant comfort: The heating control system should improve comfort by ensuring adequate heat and reducing overheating of apartments. Achieving optimum savings may result in some apartments being cooler than occupants have become accustomed to, but still within the legal limits (Gifford 2004). A survey is planned to gauge occupant satisfaction with the new heating control system.

- Occupant health and safety: Reducing overheating reduces drying of indoor air and limits the need to open windows to allow excess heat to escape in winter, which causes cold drafts.

- Building and equipment durability: The effect on boiler cycling, which could impact durability, will be evaluated. Controls will cycle boilers such that operational time is divided equally among them.

- System reliability: The reliability of new control system will be evaluated compared to the existing system. Eventual elimination of nonelectric radiator valve controllers will remove an unreliable component of the existing system (Gifford 2004). Apartment temperature sensors in Building 3 have an excellent reliability track record.

- Code compliance: The system employed in Building 3 will enable the property manager to more precisely and reliably comply with minimum/maximum heat laws for rental apartments[5] through on-line monitoring and logging of apartment temperatures.

- Building and equipment maintainability: Web-enabled visibility of apartment temperatures (Building 3) and boiler/valve status will permit maintenance personnel to more rapidly detect and react to maintenance issues and complaints.

[5] http://www.bostonapartments.com/tenant.htm

7 Interim Conclusions

This report serves primarily as a status report on the progress of the research and confirms that systems are in place to collect baseline data about the controllers, boiler operation, and indoor and outdoor temperatures. Data are being collected to develop an understanding of the system performance and data collection protocols and systems are being put in place to ensure data quality. The research is on track ensuring that sufficient data will be collected to answer the primary research questions presented by this work.

References

Center for Energy and the Environment. (2006). *Outdoor Reset and Cutout Control.* Center for Energy and Environment: www.mncee.org/pdf/multifamily/outdrreset_coutoutcon.pdf.

CNT Energy. (2010). *Boiler Controls and Sensors.* Retrieved April 2011, from Energy Savers « CNT Energy: http://www.cntenergy.org/media/Boiler-Controls-Sensors.pdf.

Gifford, H. (2004). *Choosing Thermostatic Radiator Valves.* American Boiler Manufacturer's Association.

Hewett, M.J.; Peterson, G.A. (1984). "Measured Energy Savings From Outdoor Resets in Modern, Hydronically Heated Apartment Buildings." *Proceedings of the American Council for an Energy Efficient Economy 1984 Summer Study* (vol. C. pp. 135–152). Washington. D.C.: ACEEE.

Liao, Z.; Dexter, A. (2004). "The Potential for Energy Saving in Heating Systems Through Improving Boiler Controls." *Energy and Buildings* 261–271.

Liao, Z.; Dexter, A. (2005). "An Experimental Study on an Inferential Control Scheme for Optimising the Control of Boilers in Multi-Zone Heating System." *Energy and Buildings* 55–63.

Liao, Z.; Swainsona, M.; Dexter, A. (2005). "On the Control Of Heating Systems in the UK." *Building and Environment* 343–351.

Peterson, G. (1986). "Multifamily Pilot Project Single Pipe Steam Balancing Hot Water Outdoor Reset." *Proceedings of the American Council for an Energy Efficient Economy 1986 Summer Study* (vol. 1, pp. 140–154). Washington, D.C.: ACEEE.

U.S. Census Bureau. (2006). *American Housing Survey for the United States: 2005.* Washington D.C.: U.S. Government Printing Office.

buildingamerica.gov

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE/GO-102012-3502 ▪ April 2012

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.