REHAU MONTANA ECOSMART HOUSE PROJECT
Bozeman, MT
RMEH 02 Test Report

Impact of Room Setpoint Temperatures on Energy Usage


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Executive Summary

An experiment was carried out at the REHAU Montana Ecosmart House (RMEH) in Bozeman to determine the additional energy necessary to maintain higher thermostat setpoints in radiant heating with boiler as heat source. Data analysis showed that 54% more energy was used to maintain the house at 74°F than at 65°F. A modified Heating Degree Day concept was used to account for outside temperature variations.

Experiment Description

The purpose of this experiment was to evaluate the impact of room setpoint temperatures versus energy usage, utilizing a gas-fired boiler as the only heat source and a radiant heating distribution system to determine the additional energy usage for maintaining higher setpoint temperatures. Buffer tank reset control logic was configured within the building management system, REHAU Smart Controls (RSC), to adjust the radiant zone supply temperatures based on space temperature setpoints and outdoor temperature measurements. Each room setpoint temperature scenario was run for a 3-day period at the REHAU Montana Ecosmart House (RMEH).

Results

As outlined in the test schedule document located in Appendix A, the heating degree-day (HDD) method was used for comparing room setpoint temperatures to energy usage. The HDD method accounts for the variability in outdoor air temperatures during the different zone setpoint temperature scenarios. However, this method does not adequately account for variations in solar radiation or prevailing winds over a short period of time. Typically this method is used as a rough estimate for seasonal heating requirements. The HDD values were calculated based on a balance point temperature of 65°F per ASHRAE recommendations. Outside air (OA) temperatures were recorded every 30-seconds and an average OA temperature was calculated for each 30-minute interval. The HDD total for each 3-day test was the summation of the difference between the balance point temperature and the 30-minute OA average temperatures. The HDD and gas consumption per HDD calculations can be found in Appendix D. The data and calculated results for this analysis are summarized in Table 1.

Table 1. Energy Usage and Heating Degree-Days

Test Scenario	Setpoint (°F)	RMEH Temperature Average (°F)	Outside Air Temperature Average (°F)	Net gas consumption (SCF)	°F - HHD 3-day period	Gas usage per HDD (SCF/HDD)
Scenario 1	65	65.5	41.7	1272	74	17.1
Scenario 2	68	68.3	34.4	1456	92	15.8
Scenario 3	72	72.1	40.5	1778	74	24.0
Scenario 4	75	73.9	36.6	2253	86	26.3

The first two attempts (RMEH 02-001, RMEH 02-002) at performing this experiment resulted in some of the radiant zones failing to achieve setpoint temperatures. The control logic within the RSC system was reconfigured resulting in all of the zones reaching setpoint except for the 75°F test. The RMEH temperature averages were calculated using a weighted zone temperature average based on square footage. The 75°F setpoint test failed to achieve setpoint resulting in a RMEH temperature average of 73.9°F. Gas consumption per HDD between 65°F and 75°F zone setpoints resulted in a relative increase of 54%. The analysis also shows there was an unexpected decrease in gas consumption per HDD between the 65°F and 68°F zone setpoints. This measured decrease could be attributed to variations of environmental and physical factors such as prevailing winds, solar radiation, and the large thermal mass of the RMEH. The 3-day testing period for each setpoint was also determined to be a limiting factor. *It is recommended that each test be performed with a longer duration to minimize the effects of weather variations.*

Figure 1 provides a visual representation of the gas consumption versus the average temperatures achieved in the RMEH for each 3-day test scenario. A second order polynomial fit is expected when comparing gas consumption to building temperature. However, over the relatively small temperature range (65-75°F), it is expected to resemble more of a linear fit than that of a polynomial. Figure 2 provides a similar comparison to Figure 1 while representing the gas consumption per HDD versus the average temperatures achieved in the RMEH. Second order polynomial trendlines are shown in each figure.

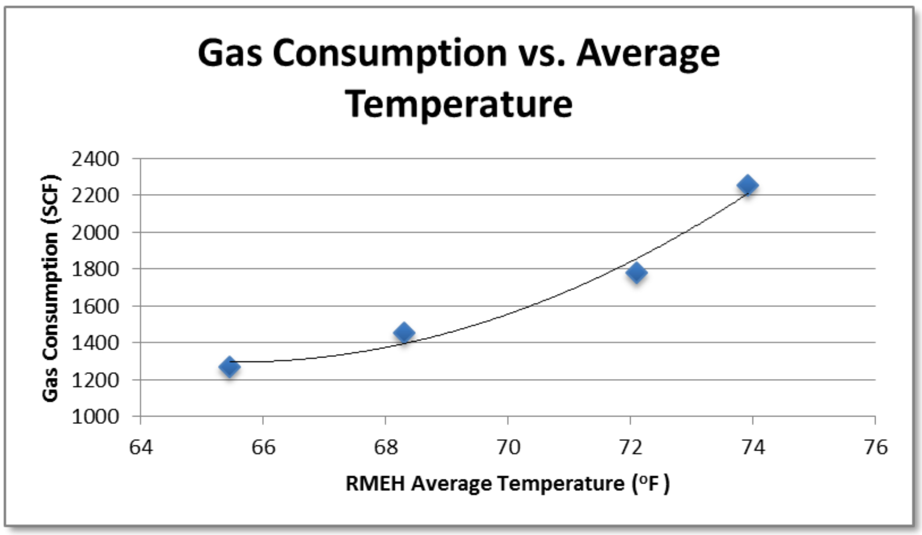

Figure 1. Gas Consumption versus RMEH Average Temperature

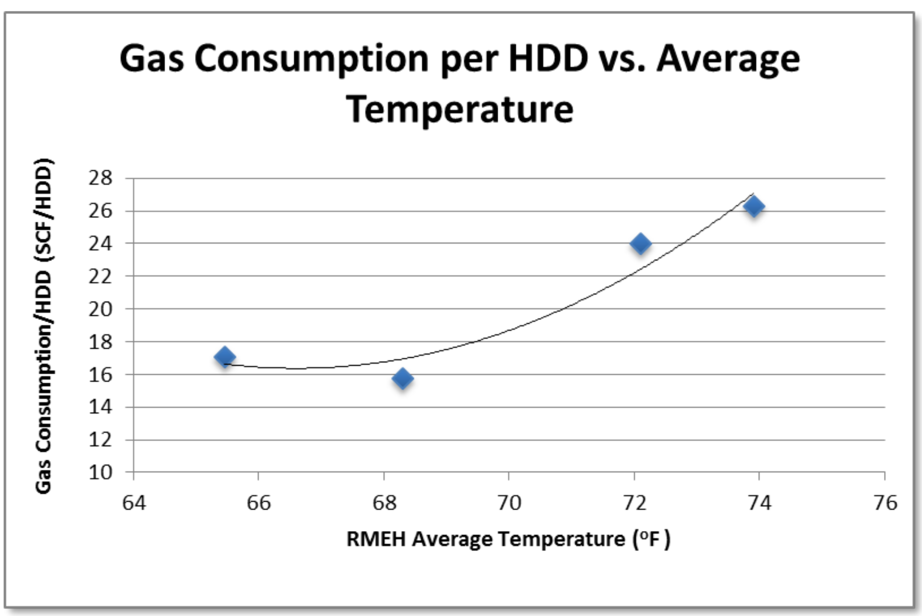

Figure 2. Gas Consumption per HDD versus RMEH Average Temperature

Buffer Tank and Supply Temperature Control

Buildings with radiant heating and cooling systems often utilize an outdoor temperature reset to control the temperature of a given fluid circulated within each zone. The RSC temperature reset control logic was verified by plotting the buffer tank and radiant supply temperatures in conjunction with their respective reset control setpoints. Figure 3 displays the relationship between the actual temperatures and the calculated temperature reset values. In order to maintain adequate radiant zone supply temperatures the primary reset temperature was used to control the mixing valve. The buffer tank control logic utilized a 10°F offset to account for potential heat losses between the buffer tank and mixing valve locations.

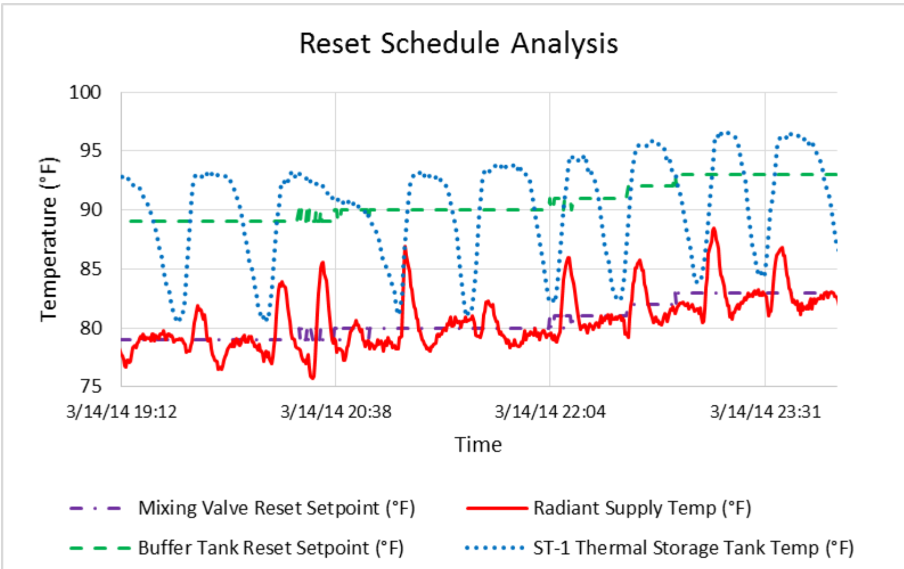

Figure 3. Partial Data Sample of Radiant System Temperatures and Setpoints for Buffer Tank and Hot Water Supply. NOTE: A higher temperature oscillation was observed for the buffer tank control (8°F dead band) when compared to the mixing valve (PID control).

Further analysis of the buffer tank reset control revealed that the buffer tank temperature did not exceed values recorded during the 72°F test. This was determined to be the cause of zone temperatures failing to reach setpoint during the 75°F test. Table 2 shows the monitored buffer tank temperatures for each test. *It is recommended that the buffer tank reset control be reconfigured to allow for higher buffer tank temperatures if a 75°F zone setpoint temperature is needed at the RMEH in the future.*

Table 2. Buffer Tank Temperatures Based on Outdoor Reset Control

Test Scenario	Setpoint (°F)	RMEH Temperature Average (°F)	Outside Air Temperature Average (°F)	Buffer Tank Temperatures (°F)		
				Min.	Max.	Avg.
Scenario 1	65	65.5	41.7	75.8	104.3	90.8
Scenario 2	68	68.3	34.4	81.8	110.4	95.6
Scenario 3	72	72.1	40.5	86.3	112.2	101.7
Scenario 4	75	73.9	36.6	86.0	113.5	101.7

Appendix A. Test Schedule Sheet

Test Number:	RMEH 02-001		
Description:	Evaluate the impact of room set-point temperatures versus energy usage utilizing the gas-fired boiler as the heat source and radiant heating distribution to determine the additional energy usage for maintaining higher setpoint temperatures.		
Objectives:			
	1 Determine energy usage at 65F setpoint versus HDD.		
	2 Determine energy usage at 68F setpoint versus HDD.		
	3 Determine energy usage at 72F setpoint versus HDD.		
	4 Determine energy usage at 75F setpoint versus HDD		
	5 Provide comparision of set point to energy usage		
Data Collection Parameters:		**Description**	**Source**
	1	OA Temp	RSC
	2	Zone Set Point Temp	RSC
	3	Zone Actual Temp	RSC
	4	Slab Sensor Temp	RSC
	5	Buffer Tank Temp	RSC
	6	HDD	MSU
	7	Boiler Gas Usage	MSU
	8		
	9		
	10		
	11		
	12		
	13		
	14		
	15		
	16		
	17		
	18		
Test Duration:			
	Length	3 day test at each setpoint temp	
	Start Date		
	End Date		
Deliverables:			
	1 Analyze energy usage in relation to set point temperature		
	2		
	3		
	4		
	5		
Notes:			
MSU Notes:			

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Appendix B. Experiment Notes

Buffer Tank Reset Temperature Control was debugged and is working as intended by REHAU

Date of experiment: RMEH 02-001 and 02-002 experiments took place between December 2013 and March 2014. The data included in report RMEH 02-003 was collected between 3/13/14 - 4/5/14.

Data for experiment RMEH 02-003 was collected during the following dates:

- Scenario 1 – 65°F Setpoint: 13/Mar/2014 – 16/Mar/2014
- Scenario 2 – 68°F Setpoint: 17/Mar/2015 – 20/Mar/2014
- Scenario 3 – 72°F Setpoint: 02/Apr/2014 – 05/Apr/2014
- Scenario 4 – 75°F Setpoint: 29/Mar/2014 – 01/Apr/2014

Appendix C. Data Collection Parameters

RSC and National Instruments (NI) data acquisition systems were used to collect data for this experiment. Data was collected for the following points:

RSC Data Points

- Outdoor Air Temperature
- Zone Setpoint Temperature
- Zone Actual Temperature
- Slab Sensor Temperature
- Buffer Tank Temperature
- Buffer Tank Reset Setpoint Temperature
- Mixing Valve Reset Setpoint Temperature

NI Data Points

- Gas Consumption from Boiler

Appendix D. Calculations

***Original data sets will be provided upon request.

Heating Degree-Days

Heating Degree Days were calculated using the following equation [1]:

$HDD = T_{base} - T_{ave}$

Where

T_{base} = Selected base temperature, in this case 65°F
T_{ave} = Daily average temperature (°F), the arithmetic mean between the high and low temperature for a 24-hour period. For this instance the average temperature was found for each 30-minute interval and used to calculate the HDD. The summation of each of these 30-minute intervals over the 3-day test period resulted in the total HDD values published in Table 1.

Sample Calculation

Table 3. Sample Calculation of HDD (T_{base} = 65°F)

Date	RSC Outdoor Temperature (°F)	Observations
3/13/2014 17:30:00	48.00	This section is a sample of the outside air sensor values acquired by RSC.
3/13/2014 17:30:30	47.99	
3/13/2014 17:31:00	47.96	
3/13/2014 17:31:30	47.88	
$HDD_{65°F}$	74.46 (≈ 74)	Cumulative HDD for 65°F Test
$HDD_{68°F}$	92.42 (≈ 92)	Cumulative HDD for 68°F Test
$HDD_{72°F}$	74.06 (≈ 74)	Cumulative HDD for 72°F Test
$HDD_{75°F}$	85.82 (≈ 86)	Cumulative HDD for 75°F Test

Gas Consumption per HDD

Table 1 gas consumption values were calculated using the following methodology:

For each setpoint temperature the gas flowmeter totalized reading was taken at the beginning and end of the 3-day test period. The difference between these two readings produced the net gas consumption in standard cubic feet (SCF).

$$Net\ Gas\ Consumption\ (SCF) = Gas_{\mathrm{final}} - Gas_{\mathrm{initial}}$$

Gas consumption per HDD was calculated by dividing the net gas consumption by the total HDD for each 3-day test at each setpoint.

$$Gas\ Consumption\ Rate = \frac{Net\ Gas\ Consumption}{HDD}$$

Appendix E. References

1. ASHRAE (2009). *2009 ASHRAE Handbook. Fundamentals*. Chapter 14, p. 6-7. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.