REHAU MONTANA ECOSMART HOUSE PROJECT
Bozeman, MT
RMEH 05 Test Report

Evaluation of Temperature Stratification in Room with Cathedral Ceiling: Radiant Floor Heating vs. Forced Air

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Executive Summary

Due to gravity and the buoyancy effect caused by changes in air density when it is heated, it is normal for warm air to rise and cold air to fall within a heated space. Typically, the higher the air temperature being supplied to heat a room, the greater the buoyancy effect. This effect is sometimes called temperature stratification, and it can reduce the efficiency and comfort of heating systems, since warm air rising to the ceiling of a space can waste energy through conductive and infiltration losses, while the cooler air is surrounding the occupants near the floor. A worst-case situation for creating stratification is when very hot air is used to heat a space with tall ceilings.

Hydronic radiant floor heating (RFH) systems work by circulating warm fluid through a network of pipes embedded in the floor. Heat is gently radiated from the floor, warming the surfaces, objects and air in the room to create a comfortable environment. Even in cold climates, heated floors rarely exceed 85°F in temperature while meeting the heat loss of the space. With RFH there is some warm air in lower portion of the room, but because of the low floor surface temperature and resulting low air temperature, there is less hot air at the ceiling and less stratification. Both comfort and efficiency are improved.

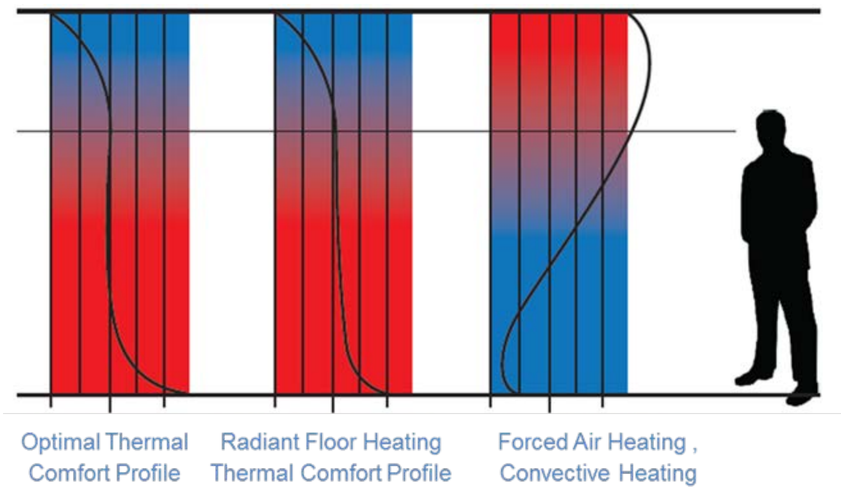

Figure 1. Theoretical comparison of temperature stratification from various heating systems

Experiment RME05 at the REHAU Montana Ecosmart House (RMEH) in Bozeman, MT measured the effects of stratification by heating the same space using radiant floor heating and then warm air heating, and comparing the results. RMEH is a LEED®-certified efficient house with high levels of insulation and low heat loss, resulting in a certified HERS score of just 32. The subject space had an 18-ft tall ceiling, and multiple temperature sensors were mounted on towers throughout the space.

The collected data demonstrates that stratification is a concern with warm-air heating, even when meeting the heat load with a relatively low air supply temperature of just 100°F, whereas using radiant floor heating resulted in far less temperature stratification.

Experiment Description

The purpose of this experiment was to evaluate the temperature stratification from floor to ceiling comparing radiant floor heating with forced air based system in room with cathedral ceiling. Dry bulb temperatures were measured every 2-feet in six different towers, four of which were 18-ft tall and two were 8-feet tall. The towers were located in the Living/Dining Room area on the main floor of the Ecosmart House (see Figure 2 and Figure 3). Two different scenarios were tested: radiant floor heating and traditional forced air heating. Thermostat setpoints were 68°F and 72°F respectively for each scenario. Outdoor reset schedules were in use to determine the temperature of the supply water to the radiant system, which remained within the range of 85°F to 95°F (Figure 18). Supply air temperature was set to constant 100°F (Figure 19), which is conservative compared to traditional furnace systems. Each test scenario was run from a cold start and measurements were processed over the last 36 hours, when stable temperatures were achieved in the room.

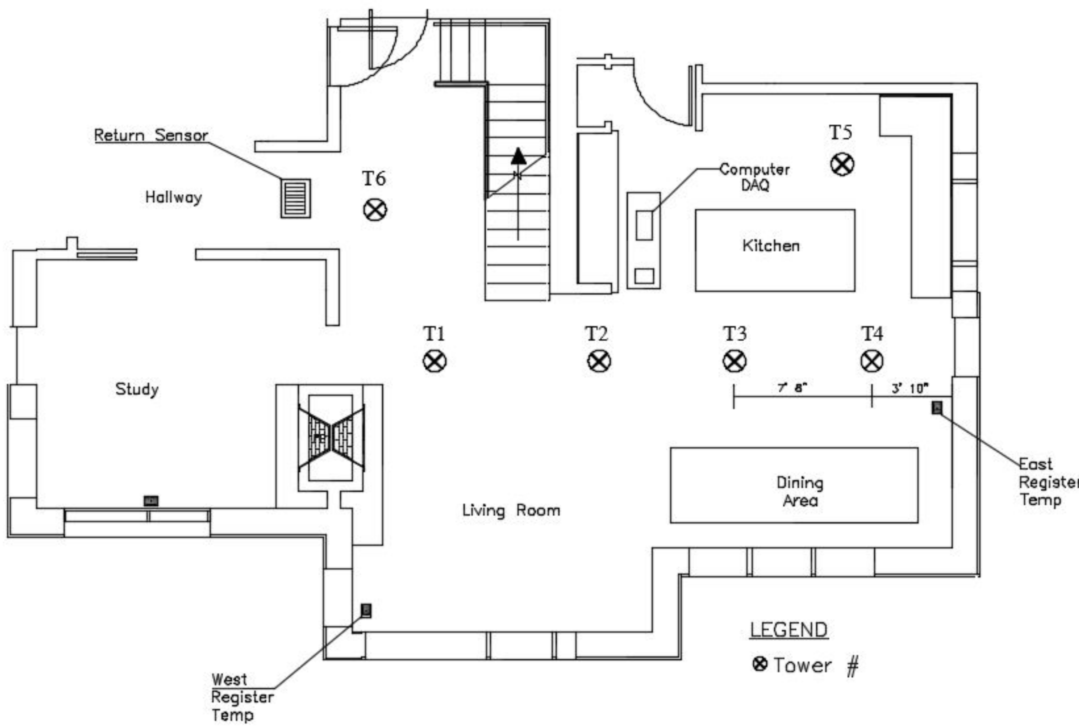

Figure 2. Test Configuration (plan view)

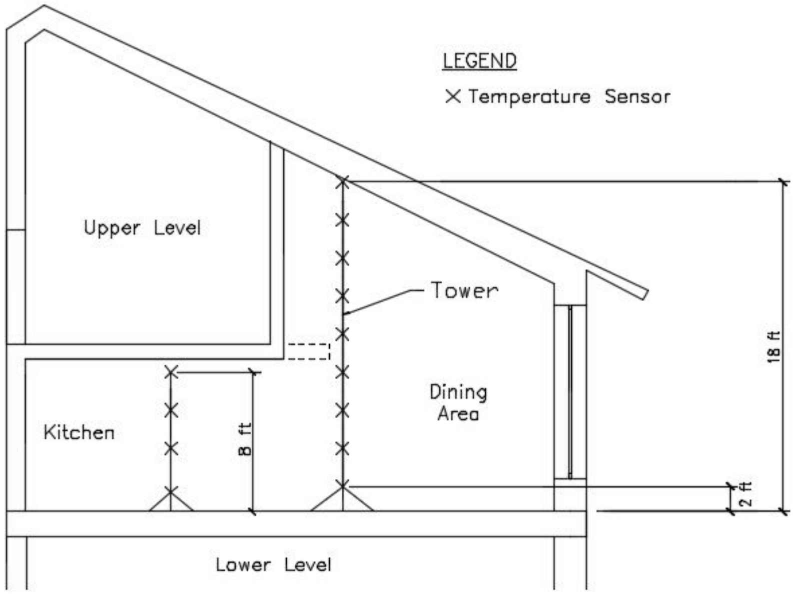

Figure 3. Test Configuration (elevation view)

The floor is a 12” Expanded Polystyrene (EPS) blocks deck on 1-5/8”x10” metal joist 16” OC with an over poured 3” reinforced concrete topping slab, finished with a hardwood panel. The hydronic radiant floor is embedded in the concrete and is made of 1/2” Crossed-linked Polyethylene (PEXa) pipe (see Figure 16 and Figure 17).

Results

During the radiant floor portion of the test, no significant vertical stratification was observed. Temperature difference between sensors at 2-feet and 18-feet height was never greater than 0.5°F in tower 1, whereas in towers 3 and 4, the temperature difference was practically nonexistent (see Figure 4, Figure 5, Figure 6 and Figure 7). This is interesting since the natural tendency of warm air is to rise. However, the warm slab is continuously providing heat from the floor thus counteracting that natural tendency all across the vertical section of the room.

On the other hand, during the forced air portion of the test, stratification was more apparent. Overall, the temperature difference between sensors at 2-feet and 18-feet height ranged between 0.8°F and 1.1°F during the test. It is also interesting to observe that there was a decrease in temperature from 16-feet to 18-feet height, probably because of the inner surface of the exposed roof being cooler due to the cold outside conditions. Stratification on tower 4 was the most noticeable (Figure 7), and it make sense since it was the tower having the closest floor register of the 4 tall ones (see Figure 2).

Another interesting observation was the anomaly occurred near the 8 to 10-feet height sensors on towers 1 and 2. It appears that the temperature was approximately 1°F less than what would have been expected from the natural trending of the other sensors. One possible explanation could be that fact that towers 1 and 2 were placed near by the upstairs hallway (see Figure 12), and this could have affected the temperature of the sensors close to the upstairs floor, which was not being heated during the course of the experiment.

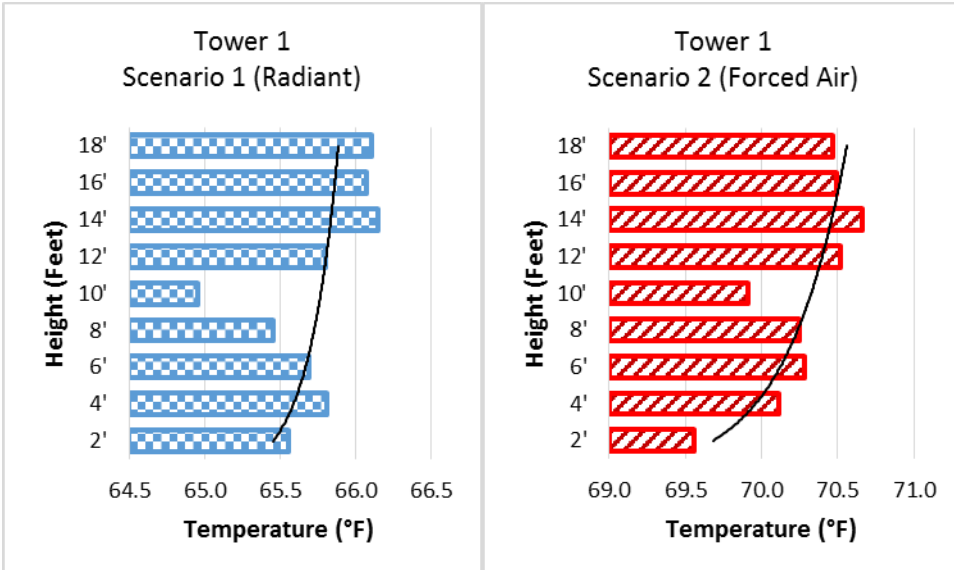

Figure 4. Stratification Study of Tower 1. Temperatures were averaged over the last 36 hours of the experiment. A logarithmic trend line is shown in the graph.

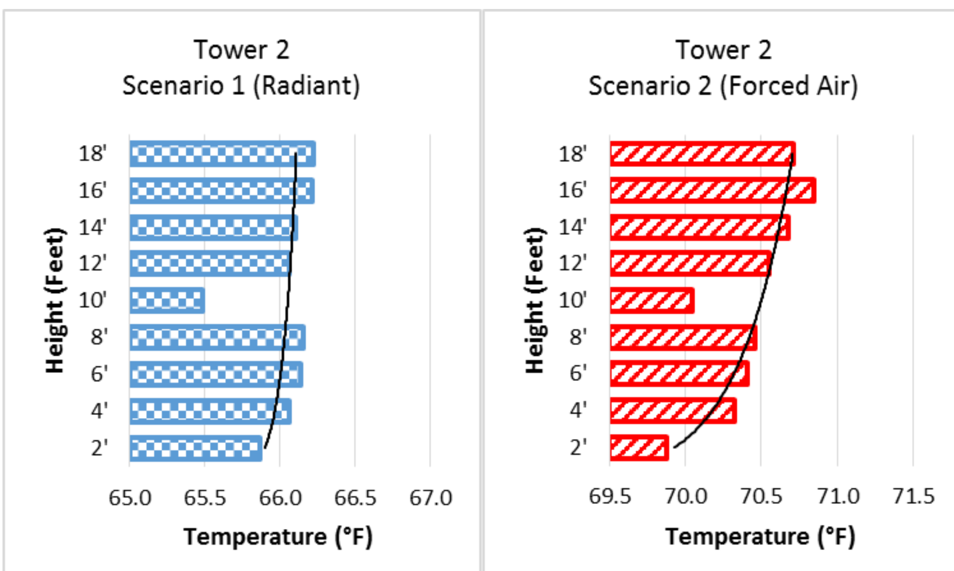

Figure 5. Stratification Study of Tower 2. Temperatures were averaged over the last 36 hours of the experiment. A logarithmic trend line is shown in the graph.

It is important to point out that the temperature of the air supplied to the registers during the forced air scenario was around 100°F or less (Figure 19). If the test had been run with the traditional 120°F supply air temperature used in many furnace systems, the stratification during the forced air scenario would have been most likely even more pronounced.

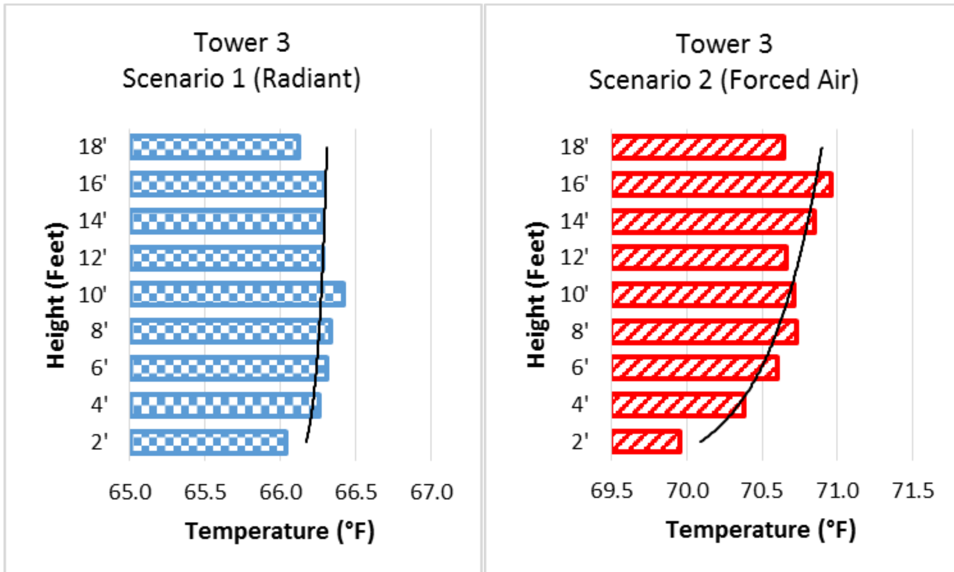

Figure 6. Stratification Study of Tower 3. Temperatures were averaged over the last 36 hours of the experiment. A logarithmic trend line is shown in the graph.

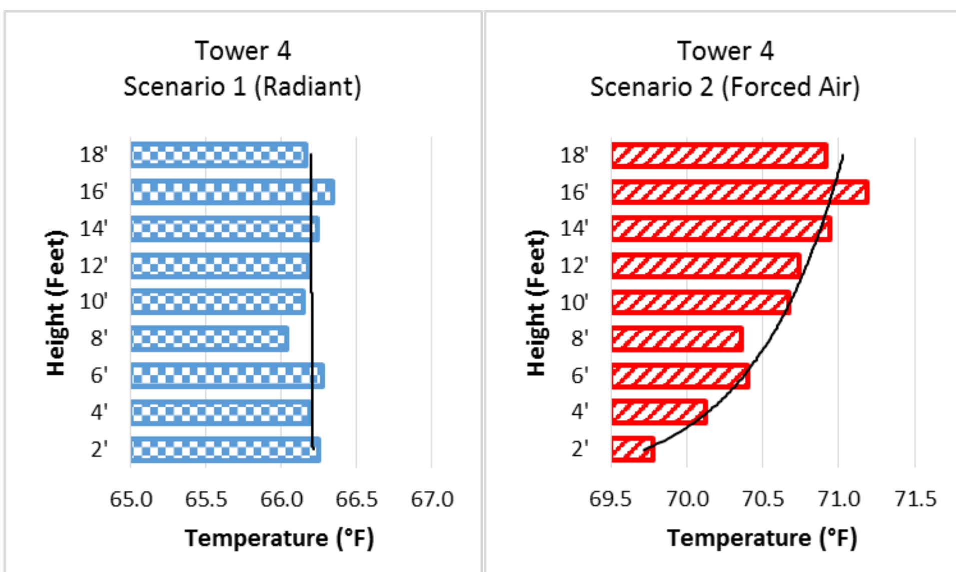

Figure 7. Stratification Study of Tower 4. Temperatures were averaged over the last 36 hours of the experiment. A logarithmic trend line is shown in the graph.

The two short towers showed no relevant vertical stratification occurring during the experiment. Tower 5 was placed in the kitchen (Figure 2), and the average temperature over the last 36 hours showed no significant difference between the radiant floor and forced air scenarios (see Figure 8). Tower 6 was placed on a transition space between the end of the front entry hallway and the stairway (Figure 2). It could be noticed from the data that the floor on that area did not heat up during the radiant floor scenario, thus that tower cannot be considered for this experiment since it was placed on an unheated spot. However, it is interesting to see how the temperature indeed stratified when the slab was not active (see Figure 9), supporting the observation made before of the warm slab counteracting the natural stratification.

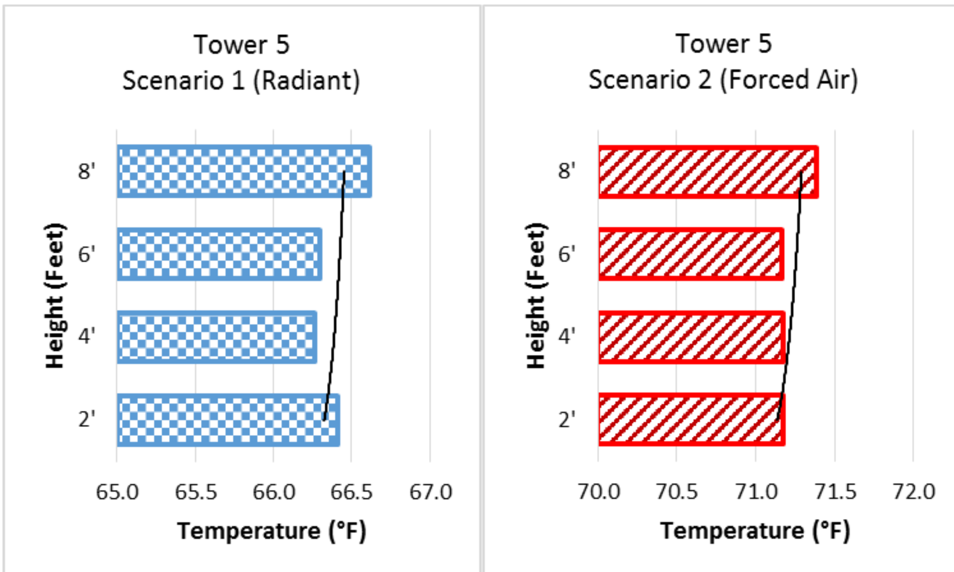

Figure 8. Stratification Study of Tower 5. Temperatures were averaged over the last 36 hours of the experiment. A logarithmic trend line is shown in the graph.

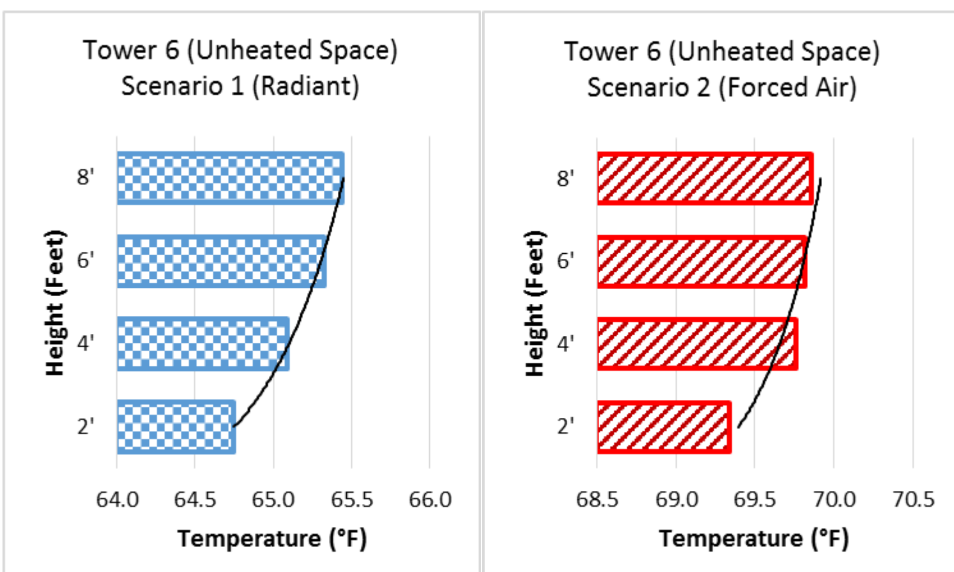

Figure 9. Stratification Study of Tower 6. Temperatures were averaged over the last 36 hours of the experiment. A logarithmic trend line is shown in the graph.

Cycle Times

Temperature profile plots over time showed that the heating cycles (on/off) on the radiant floor panel actuators (Figure 10) are many hours longer than those during the forced air scenario (Figure 11). In the latter, air temperature dropped down sharply as soon as the zone air damper closed, whereas the radiant heating showed a much smoother temperature profile over time. Moreover, the radiant system was able to keep the average thermostat temperature higher than the setpoint, while the forced air system just topped on the setpoint temperature. This supports the finding that even a setpoint temperature difference of 4°F between scenarios lead to a fairly equivalent effective temperature as felt by the occupants in the room. For this analysis, temperature across the four tall towers was averaged by height, representing an "average" tower.

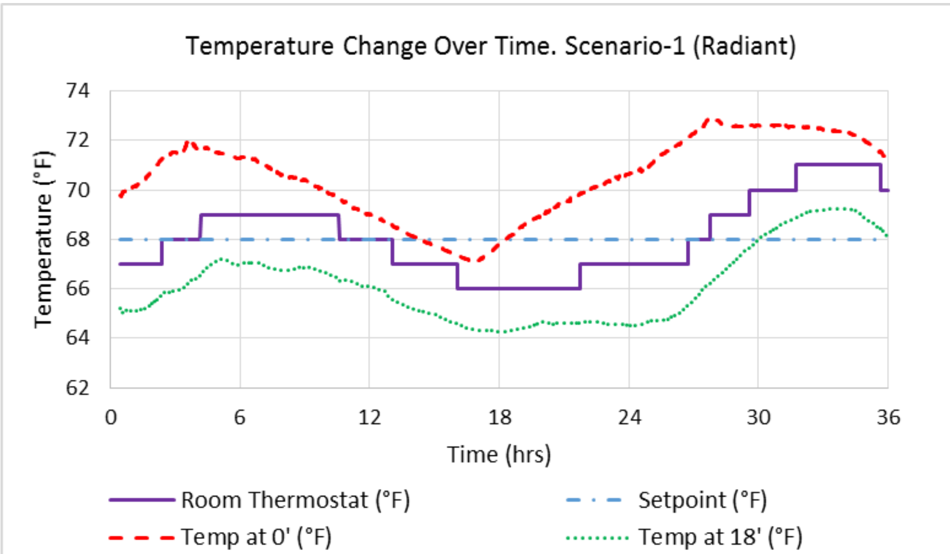

Figure 10. Temp. Change Over Time Study during Scenario 1 – Radiant Floor.

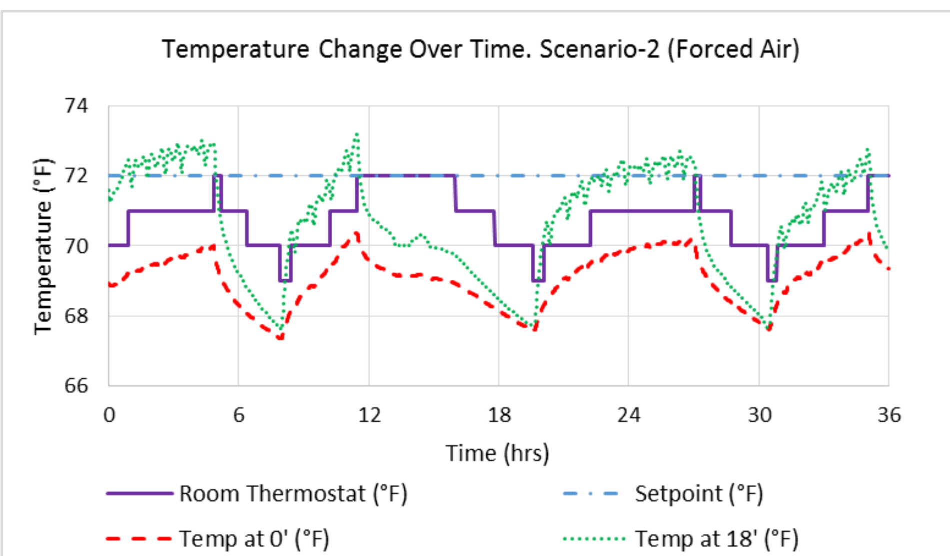

Figure 11. Temp. Change Over Time Study during Scenario 2 – Forced Air.

Appendix A. Test Schedule Sheet

System Performance
Data Collection

REHAU ECOSMART HOUSE
Bozeman, MT

lee2289

Test Number: RMEH 05-003

Description: Evaluate temperature stratification from floor to ceiling comparing RFH system to air-based system in room with cathedral ceiling.

Objectives:

1 Evaluate air temperatures at 2ft intervals from floor to ceiling using RFH
2 Use radiant room set-point at 68F
3 Evaluate air temperatures at 2ft intervals from floor to ceiling using forced air
4 Use forced-air room set-point at 72F
5

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	Slab Set Point Temp	RSC
6	HDD	MSU
7	Air Sensors	MSU
8	Boiler HWS Temp	RSC
9	Boiler HWR Temp	RSC
10	RFH HWS Temp	RSC
11	RFH HWR Temp	RSC
12		
13		
14		
15		
16		
17		
18		

Test Duration:

Length 1 day test for RFH and 1 day test for Air
Start Date ______
End Date ______

Deliverables:

1 Measure temperature stratification at 1 hr intervals over 24 hours
2 Compare RFH system to Air-based system for heating
3
4
5

Notes:

MSU Notes: Testing in February 2015
Used "Reset Schedule 68" for Buffer Tank and Mixing Valve

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Appendix B. Experiment Notes

Data for experiment RMEH 07 was collected during the following dates:

- Scenario 1 – Radiant Floor: 15-Feb-2015 – 17-Feb-2015
- Scenario 2 – Forced Air: 19-Feb-2015 – 21-Feb-2015

The average outdoor temperature was 32.7°F during scenario 1 and 35.4°F during scenario 2

Appendix C. Data Collection Parameters

REHAU Smart Controls (RSC), National Instruments (NI), Agilent Benchlink and eGauge data acquisition systems were used to collect data for this experiment. The most important data points collected were the following (some of them provided redundancy and/or additional information):

RSC Data Points

- Outdoor Air Temperature
- Zone Setpoint Temperature
- Zone Temperature
- Slab Temperature
- Slab Setpoint Temperature
- Buffer Tank Temperature
- Boiler HWS/HWR Temperature
- Radiant Loop HWS/HWR Temperature

Agilent Benchlink Data Points

- Air (space) Temperature at different heights
- Floor Surface Temperature
- Air Features Temperature

NI Data Points

- Various Temperature Sensors across the House

eGauge Data Points

- Power Usage

The sensors used to collect the air temperature at various heights were 10kΩ thermistors with an accuracy of ±0.1°C (0.2°F). Time interval for data collection was 30 seconds.

Appendix D. Experiment Setup

Figure 12. 18-feet tall towers on living/dining area

Figure 13. 8-feet tall towers on hallway and kitchen

Figure 14. Temperature sensors in floor register and return grille

Figure 15. Agilent Benchmark Data Acquisition System

Figure 16. Different phases of the floor construction

Figure 17. Over poured concrete slab with embedded 1/2" PEXa pipe

Appendix E. Additional Figures

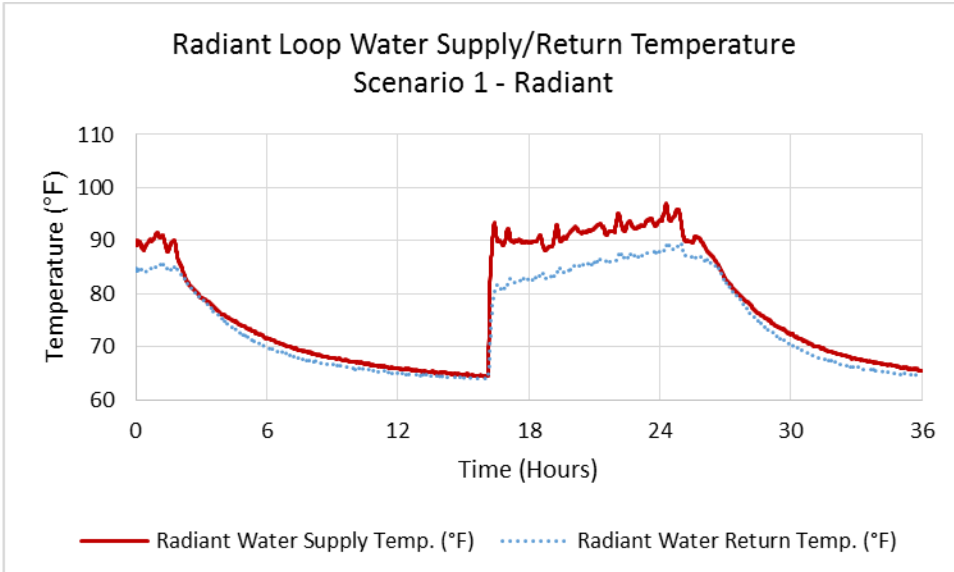

Figure 18. Radiant Loop Water Supply/Return Temperature Profile during Scenario 1 (Radiant)

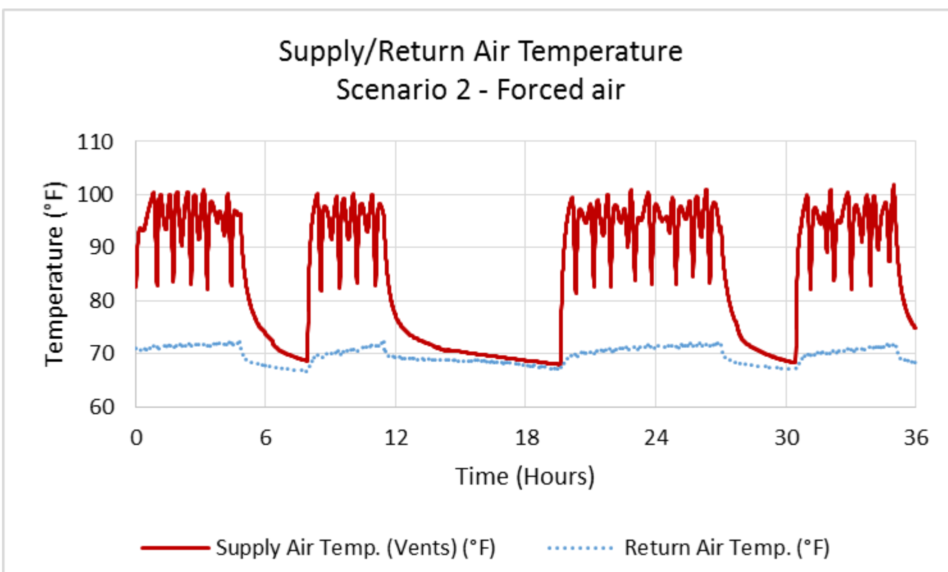

Figure 19. Supply/Return Air Temperature Profile during Scenario 2 (Forced Air)

Appendix F. References

1. REHAU United Polymer Solutions (2013, May). *REHAU Radiant Heating Systems. Design Guide*. Retrieved from http://www.rehau.com/download/869560/radiant-heating-systems-design-guide.pdf

2. REHAU United Polymer Solutions (2013, January). *Sustainable Building Technology. Indoor Comfort Solutions for High-Performance Buildings*. Retrieved from http://www.rehau.com/download/1271132/sustainable-building-technology-brochure.pdf

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