Long-Term Commercial GSHP Performance

Part 5: Comfort and Satisfaction

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This article is the fifth in a series summarizing a data collection and analysis project to identify common characteristics of successful ground source heat pump (GSHP) systems.[1] This article presents results from occupant satisfaction surveys.

GSHP building occupants were provided forms shown in *Figure 1* that allowed them to rate their level of satisfaction. Five check boxes from "Very Dissatisfied" (= 1) to "Very Satisfied" (= 5) are selected, and results were used to achieve a numerical rating for seven areas of satisfaction. The wording for the check boxes attempts to be consistent with the terminology of ASHRAE Standards 55-2010 (…80% occupant acceptability… based on…dissatisfaction criteria…) and 62.1-2010 (…80% or more of people exposed do not express dissatisfaction.). A figure of merit of 2.8 is used to approximate 80% occupant acceptability, and 20% dissatisfaction (since "acceptable" responses are assigned a value of 3.0).

As shown in the figure, the satisfaction topics included room cooling comfort, heating temperature, indoor air quality (IAQ), lighting, acoustics, maintenance responsiveness, and ability to control temperature. Responses from 24 of the sites that had more than five responses and ENERGY STAR rating information were considered. The average number of respondents per site was 19, and they provided many insightful comments that mentioned specific reasons for dissatisfaction. A number of positive comments were also given. Sidebars to this article list comments from three buildings that received the highest overall satisfaction ratings and three buildings that received the lowest ratings.

Average occupant ratings in all areas except the ability to control were between acceptable and satisfied. Satisfaction level improved with increasing ENERGY STAR rating except in the areas of acoustics and lighting. There was a trend toward lower satisfaction, in some cases a marked decline, in all areas with newer GSHP systems. There was a higher level of satisfaction with occupant adjustable thermostats compared to GSHPs controlled by energy management systems that were often perceived to be non-occupant adjustable.

Occupant Satisfaction Results

Figure 2 plots occupant satisfaction level by comparing summer and winter indoor air comfort conditions to the ENERGY STAR rating. There is a

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slight upward trend with higher ENERGY STAR ratings, but the average ratings are only slightly above acceptable. There is much less scatter for sites with lower ratings and a sizeable amount of variation of satisfaction for sites with ENERGY STAR ratings above 80.

Four sites with high ENERGY STAR ratings had satisfaction levels below 2.8 for both heating and cooling comfort. Three of these four sites had ventilation air equipment capacities of 76, 66, and 41 cfm/person (36, 31, and 19 L/s per person) and all were controlled by energy management systems (EMSs). The fourth low rated site used a dual capacity heat pump with a damper system to serve two classrooms. The site also was served by an EMS.

Another low satisfaction site, controlled by an EMS, had a low cooling mode rating, but occupants commented the room temperatures were too cold rather than too warm. A low satisfaction site controlled by thermostats had a low heating mode comfort rating. Occupant comments indicated that the lights were turned off so students could see classroom "smart boards," which disabled the heat pumps.

Building_____ **Location**_____ **Your Name (optional)** _____

☑ Select box that reflects your level of satisfaction with the **cooling season** indoor temperature and humidity:
☐ Very Dissatisfied ☐ Dissatisfied
☐ Acceptable ☐ Satisfied ☐ Very Satisfied
Comments: _____

☑ Select box that reflects your level of satisfaction with the **heating season** indoor temperature:
☐ Very Dissatisfied ☐ Dissatisfied
☐ Acceptable ☐ Satisfied ☐ Very Satisfied
Comments: _____

☑ Select box that reflects level of satisfaction with the **air quality** (odors, stuffiness, air freshness):
☐ Very Dissatisfied ☐ Dissatisfied
☐ Acceptable ☐ Satisfied ☐ Very Satisfied
Comments: _____

☑ Select the box that reflects your level of satisfaction with the **lighting** level:
☐ Very Dissatisfied ☐ Dissatisfied
☐ Acceptable ☐ Satisfied ☐ Very Satisfied

If "Dissatisfied" or "Very Dissatisfied," was the level lighting ☐ Too Low or ☐ Too High
Comments: _____

☑ Select box that reflects level of satisfaction with the **acoustics** (Heat/Cool equipment noise):
☐ Very Dissatisfied ☐ Dissatisfied
☐ Acceptable ☐ Satisfied ☐ Very Satisfied
Comments: _____

☑ Select box that reflects level of satisfaction with the **reporting and responsiveness to building maintenance problems:**
☐ Very Dissatisfied ☐ Dissatisfied
☐ Acceptable ☐ Satisfied ☐ Very Satisfied
Comments: _____

☑ Select box that reflects your ability to adjust the **thermostat settings** in your space:
☐ Very Dissatisfied ☐ Dissatisfied
☐ Acceptable ☐ Satisfied ☐ Very Satisfied
Comments: _____

Other Comments:_____

Figure 1: Building occupant comfort and satisfaction survey.

Figure 3 is a plot of the occupant satisfaction level with IAQ, lighting, and acoustics relative to ENERGY STAR rating. The average satisfaction ratings for IAQ are only slightly above acceptable, but the trend line shows a slight improvement with a higher ENERGY STAR rating. Four sites received a rating less than 2.8 and all were controlled by an EMS. The EMS at the one site that also had a low ENERGY STAR rating was programmed to disable the ventilation air system when the outdoor temperature was above 85°F (29°C) or below 40°F (4°C). This was related to a GSHP performance deficiency because the ground loop was installed at 113 ft/ton (10 m/kW). The sites with ventilation air equipment capacities of 76, 66, 56, 53, and 41 cfm/person (36, 31, 26, 25 and 19 L/s per person) had IAQ satisfaction levels of 3.3, 3.3, 3.5, 2.6 and 2.7 for an average of 3.1. This is slightly lower than the average IAQ satisfaction level for the other sites that had much lower ventilation air equipment capacities.

The average satisfaction rating for lighting was near 4.0 (satisfied) with a slight downward trend with higher ENERGY STAR rating. This trend is likely a result of lower Standard 90.1-2010 mandated lighting power densities for newer installations. Only two sites received ratings below 3.0. Both were

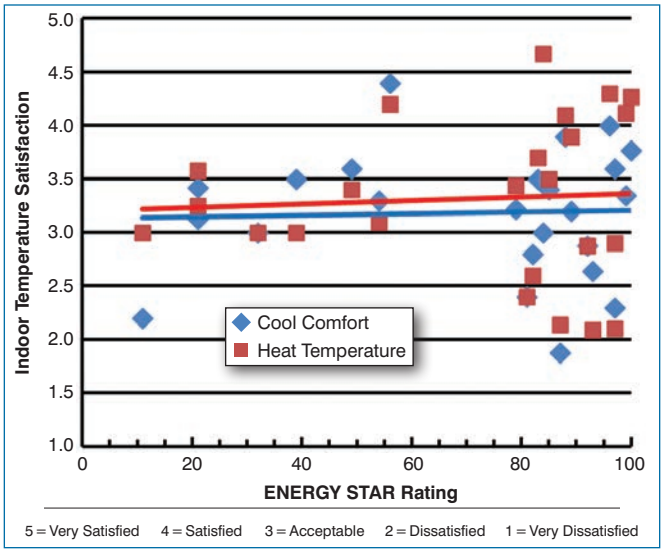

Figure 2: Occupant room comfort satisfaction vs. ENERGY STAR rating.

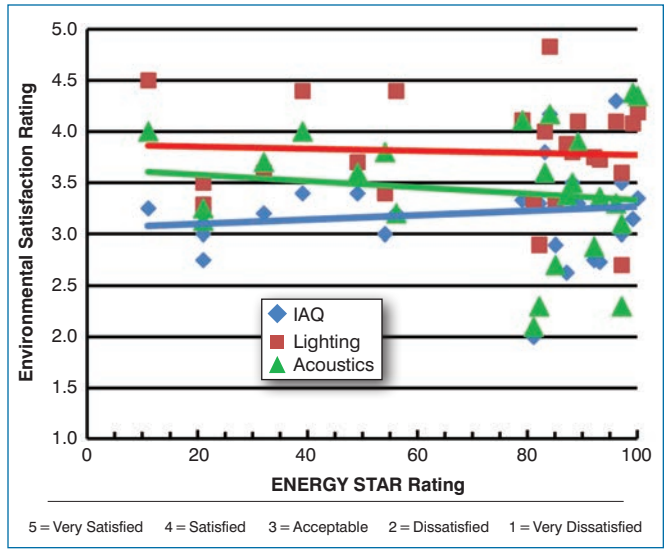

Figure 3: Occupant IAQ, lighting, and acoustic satisfaction vs. ENERGY STAR rating.

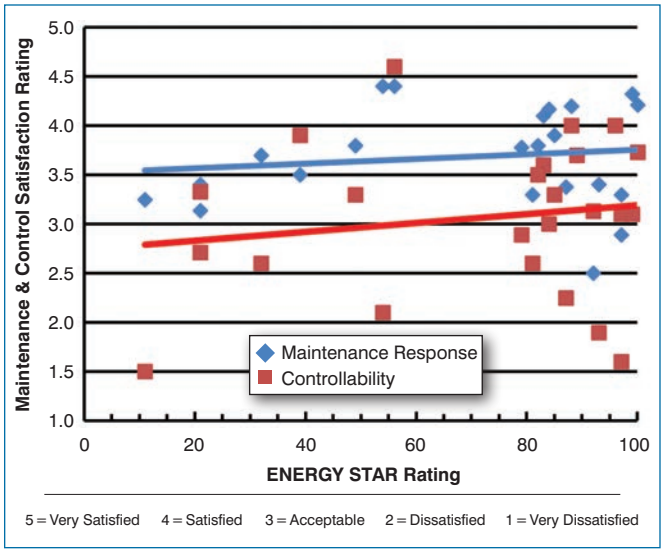

Figure 4: Maintenance response and controllability satisfaction vs. ENERGY STAR rating.

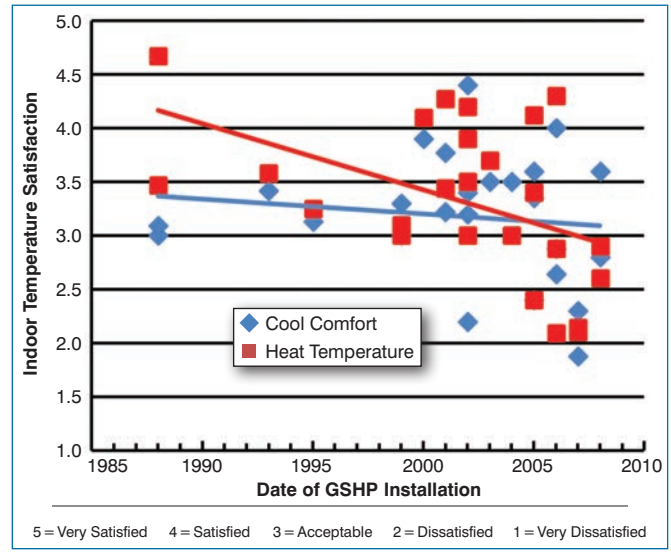

Figure 5: Occupant room comfort satisfaction vs. ground source heat pump installation date.

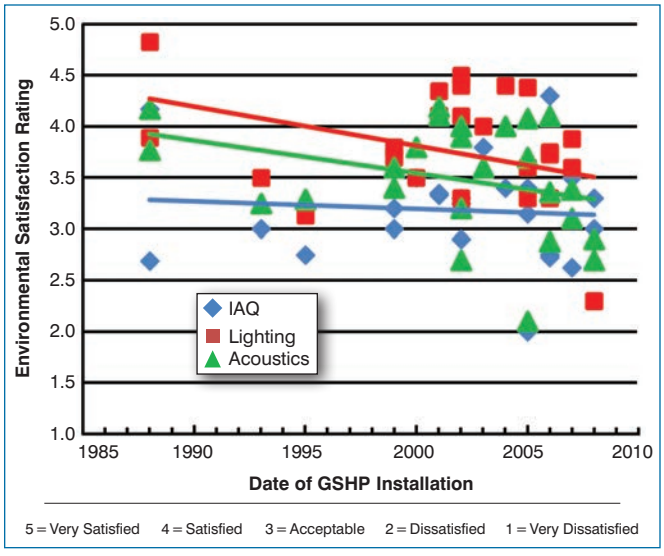

Figure 6: Occupant IAQ, lighting and acoustic satisfaction vs. ground source heat pump installation date.

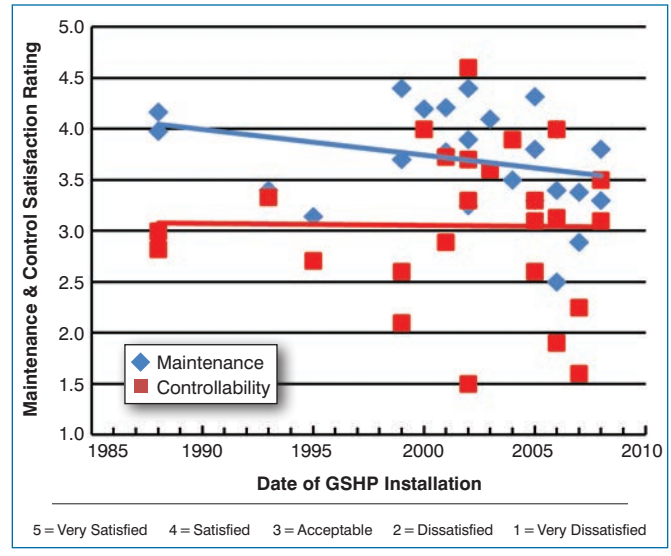

Figure 7: Maintenance response and controllability satisfaction vs. ground source heat pump installation date.

equipped with "smart boards" that were difficult to view with the lights (and heat pumps) off.

The average satisfaction rating for acoustics was near 3.5 (acceptable/satisfied) with a downward trend with higher ENERGY STAR rating. The downward trend for acoustics is influenced by five sites rated below 3.0. The heat pumps at two of these sites are console units in offices and hallways and in-space classroom units. The other three sites have a combination of console units in offices and hallways and heat pumps in closets adjacent to classrooms. Although several sites received acceptable acoustic ratings when equipment was in the space, it is likely the results at the lower rated sites were influenced by the nearby presence of the compressors and fans.

Figure 4 demonstrates the occupant satisfaction with maintenance response and controllability. The average satisfaction levels for maintenance were just below 4.0 (satisfied) with an upward trend with higher ENERGY STAR ratings. The two highest rated sites have ENERGY STAR ratings of 56 and 54. Only 29% of the floor of one site was conditioned by GSHPs, and the surveys were given only to occupants in this area. The inadequate performance of the ventilation air heat recovery device for the locker room resulted in high energy use at the second site. The device was ineffective, and ventilation air was heated with the auxiliary electric furnace. The site also had ventilation air equipment capable of delivering 34 cfm/person (16 L/s per person), which also could contribute to higher energy consumption. Of the sites with maintenance response ratings above 4.0, five had thermostat control, and two had EMS control.

The average satisfaction level for controllability was 3.0 (acceptable) with an upward trend with higher ENERGY

Comments on High Satisfaction Buildings

Middle School in Alabama

Overall Satisfaction = 4.1
ENERGY STAR = 56 (29% of school served by GSHP)
Common Loop, Classroom Units in Space, Thermostat Control

- It is humid.
- It is either freezing or burning. No happy medium.
- Maintenance could not be better.
- Equipment noise makes it is hard to hear my students when they answer questions.
- Air quality is good when unit is running but is poor when it is not running.

Elementary School in Illinois

Overall Satisfaction = 4.0
ENERGY STAR = 96
One-Pipe Loop, Classroom Units in Space, Thermostat Control

- I love that I have the control to turn the settings up or down. This makes it nice if I need to turn it off because of noise when we are doing something important.
- Machine is very noisy and is either blowing hot air or very cold air. It is constantly running. I wish it would reach the setpoint and stop. Sometimes I turn the lights off to stop it.
- The ability to change the temp in my classroom makes a huge difference. I'm satisfied with the acoustics of the system while it is running, but when it turns off it's very disruptive.
- It is wonderful! Light switches connected to the heat pump, which can make the room too hot or too cold upon entrance. This is usually resolved within 10 to 15 minutes after turning on the lights.
- When using video without lights, it can get either too cold or hot.
- Very noisy
- The system is great. I love being able to control the temperature. When it turns on it is very loud, so I try to control the temperature, so I know when it turns on and off.
- It is very humid in my classroom in August and September.
- Humidity has been the biggest negative in my classroom in the summer.

Senior Apartments in Florida

Overall Satisfaction Rating = 3.9
ENERGY STAR = 88
Central Loop, Units in Closets Adjacent to Living Rooms, Thermostat Control

- Air quality is good. Too noisy!
- Cigarette odor and doggie odor are noticeable on the fourth floor.
- Air conditioner is too loud.
- Halls are too cold at 72°F.
- The air conditioning ducts may need cleaning (dust and allergens).
- First floor hall is very cool.
- Too much heat comes through glass: East side is hard to cool from noon-4pm.
- Ceiling fans constantly must be on to move air.
- Very noisy; have to adjust TV and music when HVAC system turns on or off.
- Too much pet odor in the first floor hallways.

STAR ratings and a high degree of scatter. The three sites that achieved a satisfaction level of 4.0 (satisfied) or above were controlled by thermostats. Two had thermostats mounted on classroom units and the third site had them on the heat pump closet wall. Eight sites had ratings below 2.8, and all were controlled by an EMS. Four of these sites attained ENERGY STAR designation with an average rating of 90. Four sites did not achieve ENERGY STAR and had an average rating of 30.

Figures 5, 6 and *7* (Page 34) are plots of satisfaction ratings with respect to the year of the GSHP installation and results indicate a trend toward lower satisfaction for all seven areas with newer installations. The most marked decline is with the heating mode temperature. The slope of this decline is influenced significantly by ratings for the five sites with large capacity ventilation air equipment and two sites where heat pumps were disabled when students were viewing "smart boards" with the lights off. The rate of decline for cooling mode comfort was modest.

Figure 6 indicates the rate of decline for IAQ also was modest. The larger decline for acoustics is somewhat influenced by the low average satisfaction ratings (2.8) for the seven sites with many console and classroom heat pumps. Six of these systems were installed between 2005 and 2008. Although it may not be entirely true, the most obvious explanation for the decline in lighting satisfaction is the much lower Standard 90.1-2010 lighting power density allowances.

As seen in *Figure 7* controllability satisfaction was low, but it remained constant with date of GSHP installation. There is no clear explanation for maintenance satisfaction decline. This will be discussed more directly in the next article of this series that provides insights from the maintenance personnel perspective.

Summary and Conclusions

It is recognized that the design of the survey, the nature of the results, and the methods of interpretation are not well-established procedures. Standard 55-2010 does suggests a more detailed survey of occupants, and while Standard 62.1-2010 defines acceptable as, "…a substantial majority (80% or more) of the people exposed do not express dissatisfaction", no survey method is suggested. It is also recognized the data set is limited, and continued data collection is warranted to improve the universality of the conclusions. In the interim, the following summary and conclusions are provided.

- The average rating with cooling comfort, room temperature in heating, and IAQ were above acceptable with a modest improvement with increasing ENERGY STAR rating.
- The average satisfaction rating with lighting approached satisfied while the rating with acoustics was between acceptable and satisfied. Both had a modest decline with increasing ENERGY STAR rating.
- The average satisfaction rating with controllability was less than acceptable for systems with low ENERGY STAR

Comments on Low Satisfaction Buildings

Office in Tennessee

Overall Satisfaction Rating = 2.9
ENERGY STAR = 11
Central Loop, Units in First Floor Equipment Room, Energy Management System Control

- Always very cold in cooling season.
- Usually okay in the winter.
- Maintenance always tries, just can't ever seem to get temperature regulated.
- We wish we had more freedom to adjust the thermostats ourselves.
- Thermostats don't reflect true settings.
- Reported cold temperatures, attempts have been made, but cannot get system regulated.
- No middle ground, temperature is either 68°F or 78°F.
- Unit is loud and chirps or clicks.
- Personnel are open to complaints but seem to have their hands tied about fixing it.
- The thermostat is useless. It does not adjust the temperature at all.

Elementary School in Kentucky

Overall Satisfaction = 2.7
ENERGY STAR = 97
Central Common Loop, Single Unit in Closets Serving Two Classrooms, Energy Management System Control

- Have been without heat many weeks.
- Thermostat doesn't always work.
- If you adjust the thermostat setting, temperature in the next room changes drastically.
- Different temperatures throughout the library.
- At times not warm enough.
- In my three different classrooms, temperatures exceeded 86°F on a regular basis.
- My classroom stayed between 61° and 64° for most of the winter season.
- When it is too hot in the rooms, air is really stuffy.
- We routinely have to bring fans from home to keep kids from overheating.
- At times, when the heat or air tries to come on, it makes a very loud squealing noise.
- We can try to adjust thermostat, but it doesn't work.
- Easy to send maintenance an e-mail but little changes. Repair only lasts for a week or two.

Elementary School in Kentucky

Overall Satisfaction Rating = 2.6
ENERGY STAR = 81
Central Loop, Units in Equipment Rooms and Classrooms, Energy Management System Control

- Too cold in the building.
- My room feels very stuffy at times.
- Always feels damp in my room. Room is often stuffy, which is bad for the instruments.
- Either hot or cold: no in between.
- Constant noise that must be spoken above.
- Very humid and loud.
- The units are very loud and disruptive to students.
- Terrible: it is either freezing or so hot you cannot breathe.
- Hot one minute, cold the next.
- Temperature fluctuates. Warm air blown, then suddenly cold.
- Too noisy when trying to teach if the unit is on.

rating but improved to above acceptable with higher ENERGY STAR rating.

• The average rating with maintenance responsiveness was above acceptable and improved to satisfied with higher ENERGY STAR ratings.

• Four sites with ENERGY STAR designation had indoor comfort and temperature satisfaction levels below 2.8, which indicates the possibility of being out of compliance with Standard 55-2010.

• A strong correlation exists between low satisfaction with indoor temperature in heating and higher than average ventilation air equipment capacity.

• Four sites with ENERGY STAR designation had IAQ satisfaction levels below 2.8, which indicate the possibility of being out of compliance with Standard 62.1-2010.

• Sites with ventilation equipment capacity greater than 40 cfm/person (19 L/s per person) had below average IAQ satisfaction ratings.

• The sites with the highest level of satisfaction were controlled by thermostats which the occupants could adjust.

• The sites with the lowest level of satisfaction were controlled by energy management systems which the occupants could not adjust.

• Satisfaction declined in all areas with newer GSHP systems. For some areas, the decline was significant.

• Comments received with the surveys are insightful but difficult to quantify. Two sidebars are provided for examples of results from buildings with high and low satisfaction ratings.

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References

1. EPRI. 2012. Long-Term Performance of Commercial Ground Source Heat Pumps. *Final Report Draft*. EP-P40851/EP-P40852. Electric Power Research Institute. Palo Alto, Calif. ■