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- Focus on Energy

# Dehumidification and Subslab Ventilation in Wisconsin Homes

## A Field Study

June, 2010

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## REPORT SUMMARY

- The annual energy consumption of stand-alone dehumidifiers in the 63% of Wisconsin homes that report using dehumidifiers is estimated at 477 KWH.
- Summertime operation of subslab ventilation systems in homes built to WESH standards will result in increased dehumidification loads in some homes, and decreased loads in other homes. We have not developed clear predictors for which homes are likely to see increases or decreases. The most likely result appears to be an increase in dehumidification energy use of around 1.5 KWH per day.
- If active dehumidification is not in use, summertime operation of a subslab ventilation system will most commonly result in a modest increase in basement relative humidity, although some homes may experience a decrease.
- Electrical energy consumption of a typical subslab ventilation system is 1.2KWH per day.
- It seems likely that the impact of subslab ventilation on basement humidity and/or dehumidification load is the direct result of home depressurization and increased air leakage into the home with fan operation. It is possible that a high degree of sealing of the basement slab and slab edge, and the use of smaller fans or passive venting systems that develop lower pressures across basement floor slabs, would mitigate the increased humidity loads we identified.
- Additionally, it appears likely that increased air leakage associated with subslab vent systems would provide a drying effect on the basement during much of the year outside the summer season. This may be especially true during cold weather in homes in which stack effect pressures and significant basement floor leakage result in drawing significant amounts of moist air from the subslab area into the home. In this case, subslab depressurization (combined with sealing of the slab as needed) can be expected to reverse the direction of flow, eliminating a significant moisture source.

## INTRODUCTION

Subslab ventilation (also known as Active Soil Depressurization, or ASD) systems employ an exhaust fan connected to the soil space beneath the foundation slab to de-pressurize the sub-slab space relative to the house and outdoors. The original reason for developing and installing such systems was to reduce radon migration into homes. More recently, the systems have gained attention as a possible means of reducing basement humidity loads, are being marketed as performing this function, and have been qualified as an applicable measure under some energy efficiency programs. Little field research has been performed on the dehumidification effects of subslab ventilation, and on overall impact on electric loads. Indeed, there is little empirical data in general on dehumidifier energy use in Midwestern households.

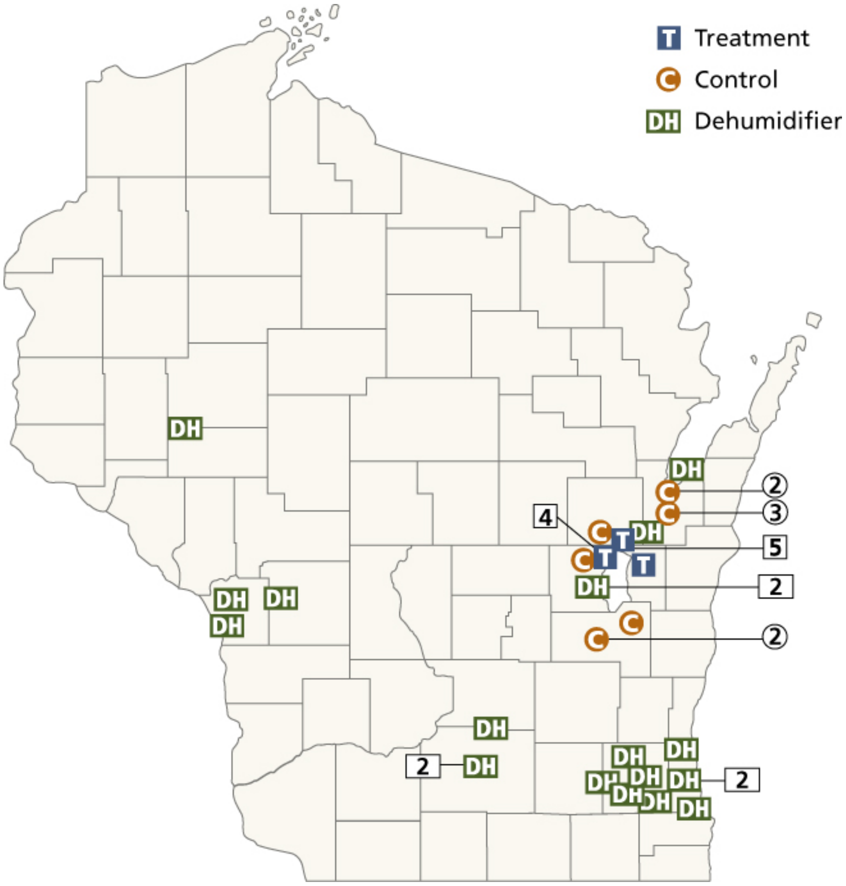
Objectives of this project include:

- Assess the net electricity savings from sub-slab ventilation systems installed in Wisconsin Energy Star Homes that use basement dehumidifiers.
- Obtain general field data on dehumidifier operation (hours and energy use) in Wisconsin homes to serve the sub-slab research objective above as well as to support potential additional energy-saving strategies related to this end use.

## METHODS

Field data collection for the project had two basic parts. The first was a factorial experiment involving 10 Wisconsin Energy Star Homes (WESH) with subslab ventilation systems. We disabled the subslab system on these “treatment” homes for a study period of about half of the summer season in order to determine the effect of operation on dehumidifier energy use. The treatment group was balanced, i.e. the ventilation systems were disabled for the first half of the season in 5 of the homes, and for the second half of the season in the other 5. The factorial experiment included a control group, also comprised of WESH homes, some with and some without subslab ventilation. No intentional change in operation was imposed on the control homes. In order to reduce variability in weather across the treatment and control groups, these 20 homes were all selected from the Fox Valley region, extending from about Neenah to Green Bay (Figure 1).

**Figure 1. Location and number of homes in subslab ventilation and general dehumidification samples.**



The other basic group in the study was selected to represent dehumidifier use in homes sampled from the general population. The group consisted of a randomly generated sample of all homes in 3 areas of Wisconsin, roughly weighted by population. The 3 areas selected were Milwaukee, Madison, and Eau Claire. None of these homes were built to WESH standards. Appendix A lists characteristics of the homes and dehumidifiers studied.

Focus on Energy staff were directly involved in the selection and solicitation process, and generated letters to sampled households to explain the project and invite participation. In cooperation with Focus staff, we selected a final group of 10 treatment and control homes, and 20 additional general dehumidifier sample homes.

## MONITORING METHODS

The following equipment was installed in all 40 homes (treatment, control, and general dehumidifier samples):

- WattsUp watt hour meter on dehumidifier. These meters measure voltage, current, and true power, and can record any of these measurements over time. The WattsUp lacks a real-time clock, with the result that time stamps are relative to startup time. As a result, data recorded after a power outage of unknown duration may be difficult to coordinate with real time. To avoid this potential problem, we incorporated an active power monitor in each system, which provided time-stamped records of any power outages. By asking participants to unplug the power monitoring system periodically, we established reference points for coordinating the data. Ultimately, there appeared to be no unintended power outages of any significant duration through the monitoring period. Another feature of the WattsUp meters is an automatically adjusting data recording interval, which collapses the data by half when the memory is nearly full. This feature means the interval varies by site, from a minimum of about 4 minutes to a maximum of about 17 minutes. This had some minor implications for data analysis, e.g. in limiting our ability to estimate compressor cycling rates.

- Temperature and relative humidity logger in basement. We used Hobo data loggers to measure and record these parameters periodically. Each Hobo was placed in the same general space with the dehumidifier. When this was an open basement, we typically located the Hobos 20 to 30 feet from the dehumidifier, to monitor general basement conditions.

Monitoring was more extensive in treatment homes, and included the following parameters:

- Subslab fan monitors. We installed current sensors and recorders on subslab fan power wiring, to verify that the fans remained in the intended enabled or disabled mode throughout each test period.
- State loggers recording turn-on and turn-off times of HVAC blower and air conditioning compressor.
- Current draw and/or true power of air conditioning system. For the first period, we installed current sensors that provided a periodic measurement of air conditioner operating current. In the second period, we replaced these with watt hour loggers.

On site visits to treatment group homes we verified that dehumidifiers were set so that operation was triggered during our site visit, or, in cases in which home owners appeared to have experience with operation, asked them to use a typical setting. We further asked homeowners not to change settings during the study. Other variables, such as fan speed, were generally left as found. Control group and general sample dehumidifiers were left operating as found, and home owners were asked not to change settings.

To further minimize the behavioral component associated with emptying a dehumidifier drain pan in the treatment group, we equipped dehumidifiers with hoses to a floor drain where they were not already in use. Additionally, in several cases in the treatment group, where there was significant filter loading, we cleaned filters.

## PHYSICAL MECHANISMS INVOLVED IN DEHUMIDIFICATION

The general model implicit in our consideration of humidity loads in basements is that there are several sources of moisture that may come into play in basements, including air from below the floor slab, air from outdoors, and air from the main living level. Indoor moisture production from human activity is a factor, but probably minor in most basements that do not have baths and are not heavily used as living space. Diffusion of moisture through floor slabs and walls is a probable moisture source throughout the year in most homes, but much less so in modern homes that use a vapor retarder under the floor slab, and less with concrete foundation walls than with block walls. Moisture is removed by ventilation with air at a lower absolute humidity level than indoor air, and by mechanical cooling and dehumidification. Moisture storage provides a damping effect on changes.

Subslab ventilation fans are expected to depressurize homes to at least a slight degree (because floor slabs are not generally absolutely air tight), and to induce the flow of outdoor air into homes. Under winter conditions, we can assume that outdoor air is routinely dryer in absolute humidity terms than indoor air, and that added outdoor air ventilation will generally have a drying effect on both the main living spaces and on basements in most homes. (Outdoor air is also likely to be dryer than air coming from below the slab during the winter, so offsetting infiltration from soil to basement with infiltration from outdoor air to basement is also likely to have a net drying effect.) Under summer conditions, when outdoor air can hold much more moisture, added outdoor air ventilation may have the effect of increasing moisture loads.

## RESULTS

We will discuss results in several parts. First is characterization of the operation and energy use of dehumidifiers in Wisconsin homes. Following sections discuss the first-order findings concerning the effect of subslab ventilation systems on dehumidification energy use, the application of regression analysis to dehumidification data, and analysis of additional house ventilation induced by subslab fan operation.

### DEHUMIDIFER OPERATION AND ENERGY CONSUMPTION

Dehumidifiers are most commonly used in Wisconsin homes during the summer season, though they are used throughout the year in many homes. We summarized dehumidifier energy use by “season” and defined the seasons applicable to the period of our study as follow:

| | |
|---|---|
| Summer | July 1 through August 31, 2009 |
| Fall | September 1 through 31, 2009 |

#### Energy Consumption

The daily average electric energy use of dehumidifiers ranges widely among the homes studied (Table 1).

**Table 1. Daily average dehumidifier energy consumption across all sites, summer and fall 2009.**

| SEASON | AVE DAILY KWH | MEDIAN DAILY KWH | MINIMUM DAILY KWH | MAXIMUM DAILY KWH |
|---|---|---|---|---|
| Summer | 6.49 ± 1.22 | 6.07 | 0.01 | 17.0 |
| Fall | 4.81 ± 1.18 | 4.45 | 0.00 | 14.5 |

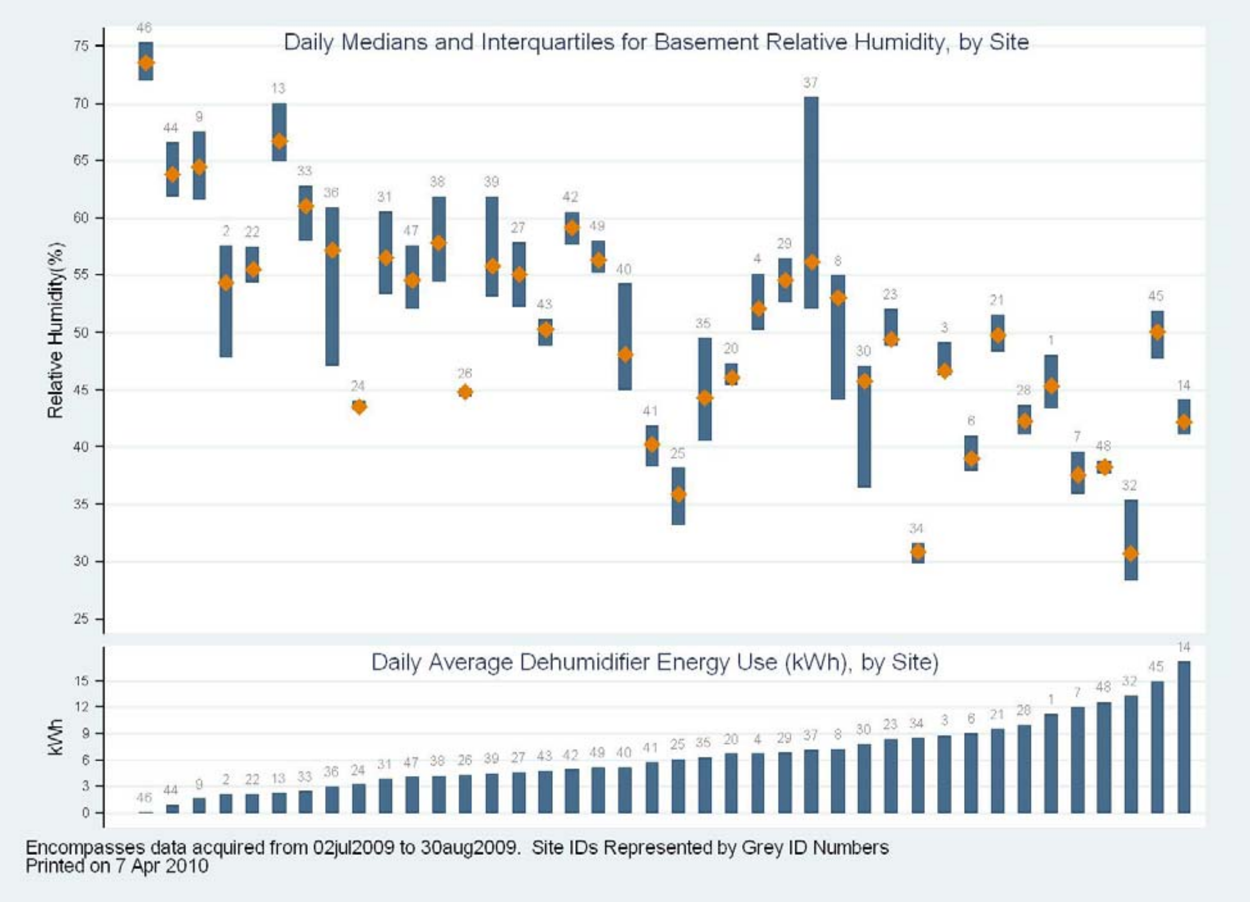
Within the overall sample are two basic groups of homes: 20 homes built to WESH standards (used for subslab ventilation system treatment and control homes), and 20 homes selected from the general population of Wisconsin residences. Table 2shows dehumidifier energy use broken down by season and by housing type.

**Table 2. Daily average dehumidifier energy consumption in Wisconsin, for WESH and non-WESH homes, summer and fall 2009. n=20 for each group.**

| | DAILY AVERAGE KWH | | DAILY MEDIAN KWH | | STANDARD DEVIATION IN DAILY AVERAGE KWH | | 25TH AND 75TH PERCENTILES OF DAILY AVERAGE KWH | |
|---|---|---|---|---|---|---|---|---|
| | WESH | NON-WESH | WESH | NON-WESH | WESH | NON-WESH | WESH | NON-WESH |
| Summer | 7.03 | 5.89 | 6.75 | 5.15 | 4.01 | 3.81 | p25=4.26 | p25=4.04 |
| | | | | | | | p75=9.56 | p75=7.10 |
| Fall | 5.47 | 4.15 | 5.64 | 3.61 | 3.82 | 3.60 | p25=2.04 | p25=1.30 |
| | | | | | | | p75=8.74 | p75=5.35 |

While the energy use of an individual dehumidifier is heavily dependent on the characteristics of a specific home (amount of outdoor air leakage, rate of indoor moisture production, dehumidifier setpoint, etc.), there is a very general relationship between the relative humidity measured in basements and dehumidifier energy use (Figure 2). A general decline in relative humidity with increasing energy consumption is evident. The wide range of relative humidity observed in many of the study homes is also evident in this graph.

**Figure 2. Median, 25th percentile, and 75th percentile of daily average basement relative humidity, and corresponding daily average KWH for summer season for all study sites, ordered by KWH.**



Encompasses data acquired from 02jul2009 to 30aug2009. Site IDs Represented by Grey ID Numbers
Printed on 7 Apr 2010

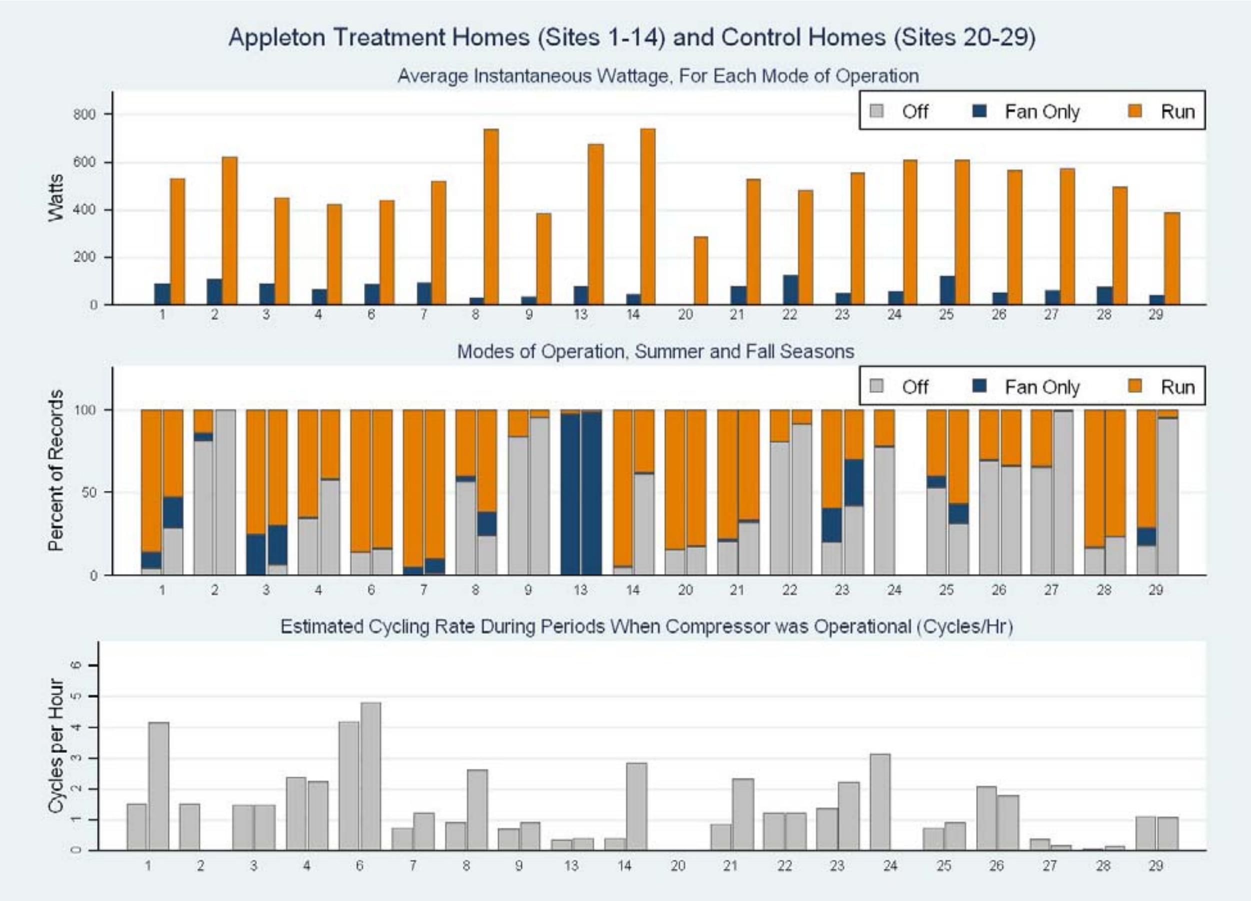
### Operating Modes, Power, and Cycling Behavior

The measured power draw of dehumidifiers at “full power” (with both compressor and fan operating) ranged from under 300 to over 700 watts across sites. Fan-only operation ranged from under 40 to about 120 watts. (Figure 3 and Figure 4 show this and related operating information for the WESH and non-WESH homes respectively.) We evaluated the operating time of each dehumidifier in each of 3 operational modes, defined as follows:

- Off (controls operation only, no fan or compressor)
- Fan (air circulation fan on, compressor off)
- Compressor (compressor and fan on)

The graphs show a wide range of fractional time spent in the 3 modes across sites. The compressor at Site 2, for example, operated for less than 15 percent of the time in the summer season, and never operated in the fall season, while the compressor at Site 7 operated for a very large fraction of the time during both summer and fall. Fan operation without compressor operation is an operating mode commonly employed to clear frost from the cooling coils in dehumidifiers,[1] and observed fan operation at most sites is consistent with use of this strategy. In most cases, the fraction of time spent in fan only operation is higher in the fall than in the summer. This is likely due to lower space temperatures and an increased rate of coil freezing in the fall as compared to summer. At Site 13 the fan operated continually, though the compressor operated very little. This seems likely due to a defect or failure in the controls or compressor circuit, but we did not perform any diagnosis on this unit.

**Figure 3. Average wattage for 3 operating modes, percent of time in each mode split by summer and fall season, and estimated compressor cycling during summer and fall, WESH homes.**



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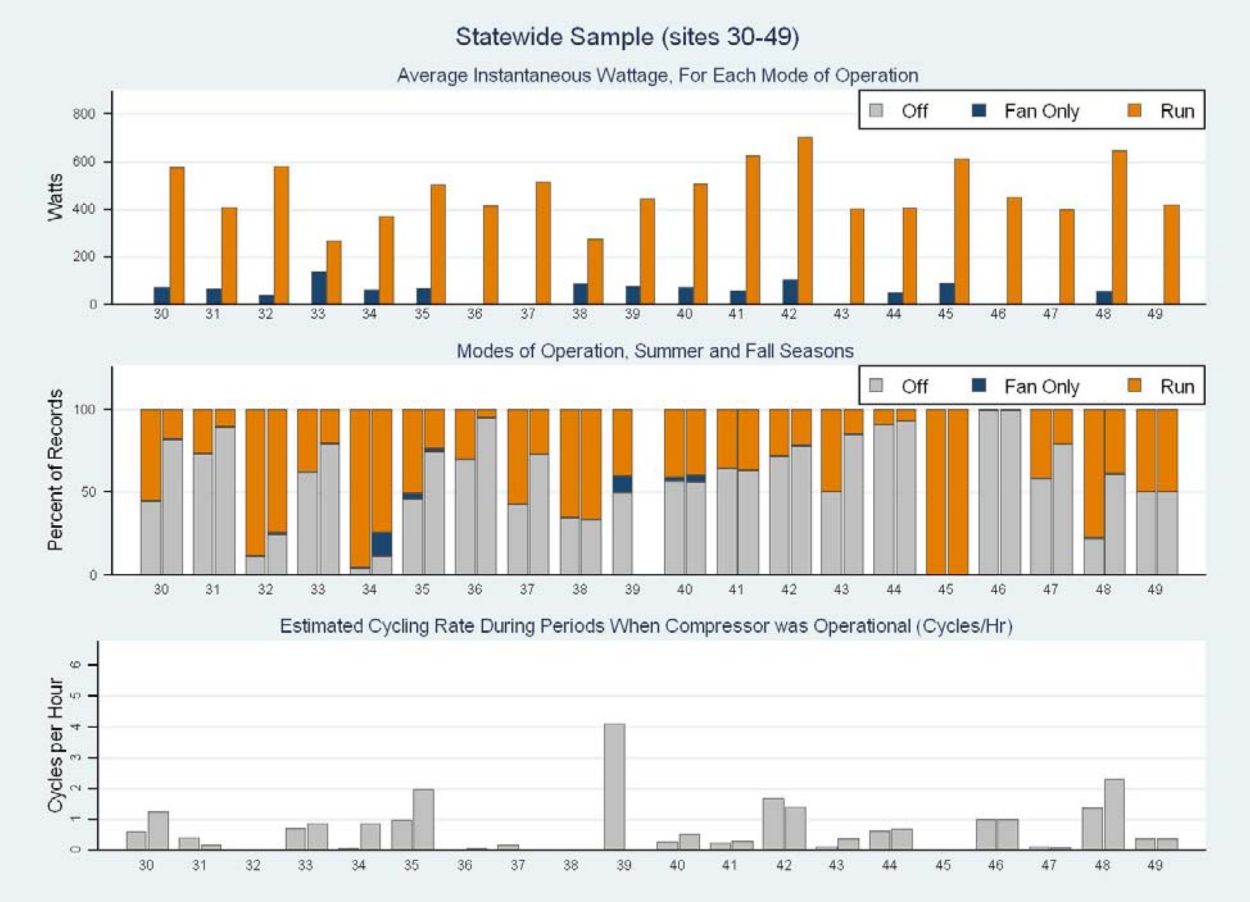
[1] Some dehumidifiers designed for ducted installation use intermittent fan-only operation to sample humidity, but we do not know of any humidifiers in the study that are designed to use this strategy.

**Figure 4. Average wattage for 3 operating modes, percent of time in each mode split by summer and fall season, and estimated compressor cycling during summer and fall, non-WESH homes.**



The lower panel in Figure 3 and Figure 4 show estimated cycling rates of the dehumidifier compressor at each site. We did not monitor compressor operation directly, but relied on average power measurement. Average power consumption that is close to the full-power wattage during any measurement period indicates continuous operation during the interval, while an average that is significantly lower than full-power indicates that at least one cycle occurred during the interval. This estimate was performed for each data record in which the wattage measured at the end of the interval indicated the compressor to be running. The data collection interval was as long as 17 minutes, and cycling rates of less than about half of this interval may be missed. The self-adjusting data collection interval in the power monitoring equipment used means the resolution of the cycling rate estimate varies across sites. Given these limitations, the cycling rate presented should be considered conservative estimates, i.e. actual cycling rates may be higher than the estimates.

Estimated cycling rates range from very low up to nearly 5 cycles per hour. Cycling rate would seem to be determined in large part by dehumidifier design, including the placement of the humidity sensor and any deadband or hysteresis in sensing and control. It seems apparent that high cycling rates would be counter-productive in terms of dehumidification efficacy, largely because there are always losses associated with cycling: the thermal mass of the dehumidifier coils, etc. must be brought down to the dew point temperature before dehumidification can begin, and part or all of this initial cool down energy is subsequently lost at the end of the cycle.[2] We have not attempted to quantify this effect, but question the design of units that operate at over 4 cycles per hour.

In another cycling-related phenomenon, daily average data for several of the systems investigated show a compressor duty cycle “ceiling” (Figure 4). In three cases, this appears to be due to the use of a timer to control dehumidifier operation. Some dehumidifiers have a control setting that cycles the compressor on and off for specific time periods (typically 2, 3, or 4 hours). The operating manuals we reviewed indicate that, using this feature, the compressor will always operate during the on cycle, i.e. operation will not be influenced by the humidity control. One system (Site 49) follows this pattern precisely, with the compressor on and off for periods of 2 hours, and a cycling rate of ½ cycle per hour. In the other system in which an internal timer was used (Site 39), however, the compressor ran about 40% of the time each day, and the cycling rate was much higher (about 4 cycles per hour of compressor operating time), indicating multiple cycles during each period when the compressor was enabled. It’s possible that some manufacturers design this cycling feature so the compressor is controlled by humidity sensor during the enabled period.

For two dehumidifiers (Sites 2 and 3), daily duty cycle values hit a ceiling at about 75 percent. This does not appear to be due to short cycling of compressors,[3] as the estimated cycling rate is around 1.4 cycles per hour. In both units, the fan appears to operate continuously during periods between compressor operation. It seems possible that this cycling is inherent to the design of these dehumidifiers, especially since they are both Whirlpool products with similar model numbers, and since the cycling rate is similar for both.[4]

### Humidity Control

Figure 2 (referenced above) shows interquartile bands for a number of sites that exceed 5 or even 10 RH percentage points. Plots of daily average relative humidity demonstrate this lack of precise control even more clearly (see Appendix B).

In general, basement relative humidity in the homes studied was far from constant. There are several reasons relative humidity may not be tightly controlled in any given home:

- Lack of precision in the sensor and control system in the dehumidifier (which may be due in part to the exposure of a built-in humidity sensor to conditions that are not representative of the room or space where the dehumidifier is placed)
- Drain pans that fill up, disabling the dehumidifier

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[2] Evaporation of condensate from the coils at the end of each cycle may also be a significant cycling penalty.

[3] Many comments referring to short cycling of dehumidifiers can be found on websites.

[4] Operation in defrost mode, when the fan operates without the compressor, is one possibility, but it seems unlikely that properly operating units would enter defrost mode in such a regular fashion throughout the study period.

- Dehumidifier turned off by occupants
- Freezing and defrost operation of the dehumidifier
- Moisture loads that exceed dehumidifier capacity, on a regular or intermittent basis
- Lack of complete mixing of air in a large basement (note that our humidity measurement point was as much as 30 feet from the dehumidifier in some cases)
- Reduction of humidity below the dehumidifier setpoint caused by factors including reduced indoor moisture production, introduction of dryer outdoor air, or dehumidification by an air conditioning system.
- Changes in the dehumidifier setpoint. Some modern dehumidifiers reset themselves to default humidity and fan speed values when power is cycled. We asked participants in the study to cycle power on the monitoring system (including dehumidifier power) about once each month, and this may have resulted in altered setpoints in several cases.

## DEHUMIDIFICATION SURVEY RESULTS

The Midwest Energy Survey, a hybrid telephone and web survey of households in several states completed in 2009, provided information on dehumidifier use in Wisconsin homes.[5] Focus on Energy staff performed a coordinated survey to obtain comparative data on dehumidifier use in homes built to WESH standards.[6] Results of these surveys are included in Table 3.

These results suggest that a higher proportion of WESH homeowners have dehumidifiers than is true among the general population in Wisconsin. When adjusted for reported usage, the number of households that own dehumidifiers and use them more than rarely is about 59 percent in the general population, 60 percent among WESH homeowners, and only 40 percent among all homes built since 2000. Note that the surveys did not address subslab ventilation systems.

The fraction of WESH households with dehumidifiers that drain directly is substantially higher than in the other groups.

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[5] *Midwest Energy Survey*, Energy Center of Wisconsin, 2009

[6] Data provided directly by Focus on Energy

**Table 3 Dehumidifier use in Wisconsin homes, based on Midwest Energy Survey and Focus on Energy survey**.

| | Midwest Energy Survey: All WI homes | Midwest Energy Survey: Homes built in 2000 or later | Focus on Energy: WESH homes |
|---|---|---|---|
| **Do you have a stand-alone dehumidifier in your home?** | | | |
| | n=1329 | n=164 | n=43 |
| Yes | 63% | 46% | 74% |
| No | 37% | 54% | 26% |
| *(Don't know and refused are omitted)* | | | |
| | | | |
| **Which of the following best describes when you use your dehumidifier?** | | | |
| | n=891 | n=95 | n=31 |
| Rarely or never | 7% | 13% | 19% |
| Part of the summer | 32% | 42% | 16% |
| All summer long | 32% | 15% | 42% |
| During the summer and other times of the year | 28% | 30% | 19% |
| Other | 1% | 0% | 3% |
| *(Don't know and refused are omitted)* | | | |
| | | | |
| **Is the dehumidifier connected to drain or do you have to empty it manually?** | | | |
| | n=821 | n=82 | n=23 |
| Drain | 44% | 45% | 78% |
| Manual | 54% | 51% | 22% |
| Other | 2% | 4% | 0% |
| *(Don't know and refused are omitted)* | | | |

## Estimating average annual energy use by dehumidifiers

We have combined reported ownership and usage of dehumidifiers from the Midwest Energy Survey with measured energy consumption from our monitoring to estimate summer and annual dehumidifier energy usage in Wisconsin, as shown in Table 4.

**Table 4 Estimated average electrical energy consumption by dehumidifiers in Wisconsin homes**

| | WI homes with dehumidifiers (63% of all homes) | | All WI homes | |
|---|---|---|---|---|
| | Fraction | Est annual KWH per home | Fraction | Est annual KWH per home |
| No dehumidifier | N/A | N/A | 37% | 0 |
| Dehumidifier seldom used | 7% | 0 | 5% | 0 |
| Dehumidifier used part of the summer | 32% | 265 | 20% | 265 |
| Dehumidifier used all summer | 32% | 530 | 20% | 530 |
| Dehumidifier used during other seasons | 28% | 779 | 18% | 779 |
| Estimated annual average dehumidifier energy use (KWH) | | 477 | | 301 |

In generating these estimates, we assume that

- The mean of the daily recorded dehumidifier energy use in July and August among the 20 general population homes monitored in this study, extrapolated to a 90-day summer season, yields a valid estimate of energy consumption in homes that report summer dehumidifier use.
- Households that report using a dehumidifier for "part of the summer" experience an average of one-half the summertime dehumidifier energy consumption of the monitored sample.
- The mean of the daily recorded energy use in September and October among the 20 general population homes monitored in this study, extrapolated to a 60-day non-summer season, yields a valid estimate of non –summer energy consumption in homes that report dehumidifier use beyond the summer.[7]

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[7] It may be reasonable to assume that dehumidifier use beyond summer would extend to months beyond those monitored under this project (Sept to early Nov). We don't believe we have a sound basis for making this extrapolation, however, so use only the energy consumption during the autumn monitoring period as an estimate of all non-summer usage.

## DEHUMIDIFICATION ENERGY IN HOMES WITH SUBSLAB VENTILATION

Evaluating the impact of subslab ventilation on dehumidifier energy use was a major objective of the project. The factorial design (enabling and disabling the subslab ventilation systems for alternate parts of the season) was intended to provide a direct answer to this question. We planned to analyze dehumidifier energy use data for periods with and without subslab fan operation by simply finding the change in energy use between these two periods. The control homes, with no change in subslab fan status, were to provide baseline data on variability in energy use and any large differences in energy use between periods. This analysis methodology is based on the following assumptions:

- The dehumidifier actively controls basement humidity, i.e. humidity does not exceed a constant setpoint, and an added load does not take the form of higher moisture content in the air or stored moisture.

- Basement moisture load is the primary determinant of dehumidifier energy use. We recognize that air conditioning operation may change somewhat according to the status of the subslab ventilation system (due to possibly increased total house ventilation when the fan operates), and that air conditioner operation in turn may affect basement humidity somewhat, but assume this effect is small.

In practice, we found that tight control of basement humidity is quite rare. This forced us to question whether we can consider humidity to be actively controlled in most of the homes in the study. We will present results based on the analysis as planned in the following section, then discuss other ways of evaluating the data.

### Subslab Ventilation Effects Based on Factorial Treatment Group Comparison

Monitoring was initiated in nearly all the treatment and control group homes by June 25. We performed the changeovers on August 6 & 7, and have defined periods of 6 weeks before and 6 weeks after August 8 as our factorial analysis periods for treatment and control homes. We expected outdoor humidity to be a major driving force in dehumidification loads, and calculated the average outdoor humidity ratio for the two factorial periods. The humidity ratio values for the first and second period are similar: .00945 for the first period, and .0101, or about 7 percent higher, for the second period.

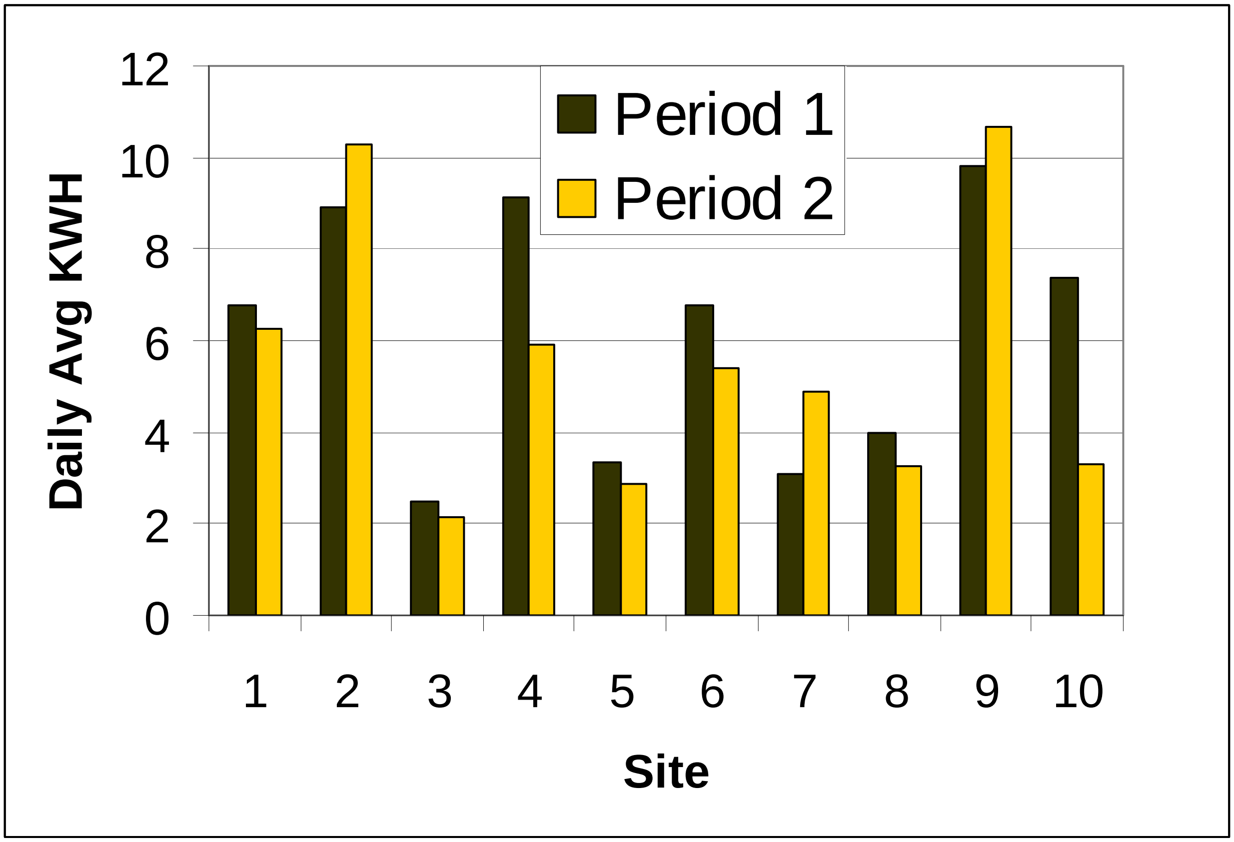
Average dehumidifier energy use in the treatment and control homes, presented by major factor, is shown in Table 5. This summary indicates an increase in energy consumption associated with subslab fan operation (i.e. treatment effect) of around 1.5 to 3 KWH per day. However, there also appears to be a difference in energy consumption between periods as evidenced in the control homes. While period differences should tend to cancel in the treatment homes (since half had subslab fans disabled for the first period, and half for the second period), this bears further inspection.

**Table 5. Simple group analysis of period effect on control homes and subslab fan effect on treatment homes, for 6-week periods before and after 8 August, 2009.**

| GROUP | PERIOD | SUBSLAB FAN STATUS | MEAN OF DAILY AVERAGE KWH ACROSS SITES | MEDIAN OF DAILY AVERAGE KWH ACROSS SITES |
|---|---|---|---|---|
| Control | 1 | NA | 6.17 | 6.78 |
| Control | 2 | NA | 5.50 | 5.15 |
| Control | **Period effect (P1-P2)** | NA | **0.67** | **1.63** |
| Treatment | NA | Off | 6.01 | 7.43 |
| Treatment | NA | On | 9.17 | 8.98 |
| Treatment | NA | **Treatment effect (On-Off)** | **3.16** | **1.55** |

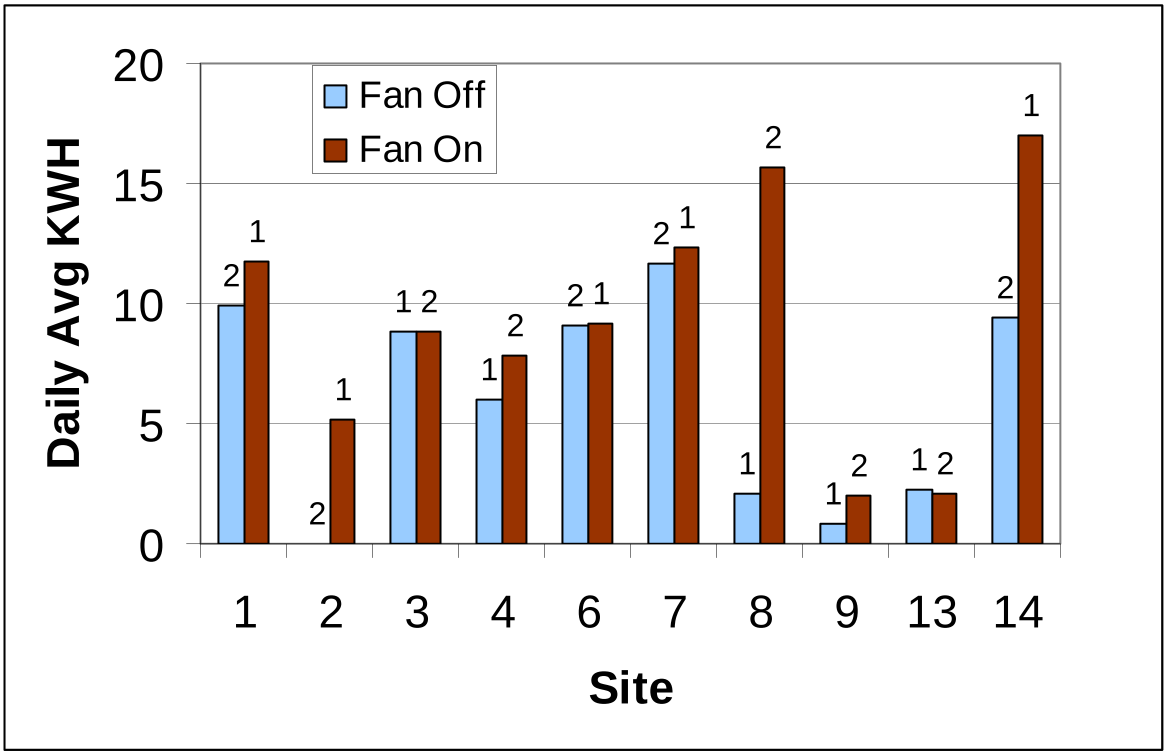
Looking at each control site individually (Figure 5), daily average dehumidifier energy consumption decreases during the second period in 7 of 10 cases, and increases in 3. This suggests there may be a systematic reason for a decrease (e.g. weather factors that affected most of the homes), and that this decease should at least be considered when evaluating subslab ventilation effects.

**Figure 5. Daily average dehumidifier energy use for subslab ventilation control homes by period.**



Looking at the treatment sites (Figure 6), daily average dehumidifier energy consumption increases noticeably with subslab ventilation fan operation for 7 sites, while remaining constant or decreasing slightly at 3 other sites, suggesting subslab ventilation has a real effect of increasing dehumidification load. Applying a period difference as suggested by the control home results could change the direction of the effect in several cases, depending on the magnitude of the effect, but does not change the overall pattern of increasing dehumidification load associated with subslab fan operation.

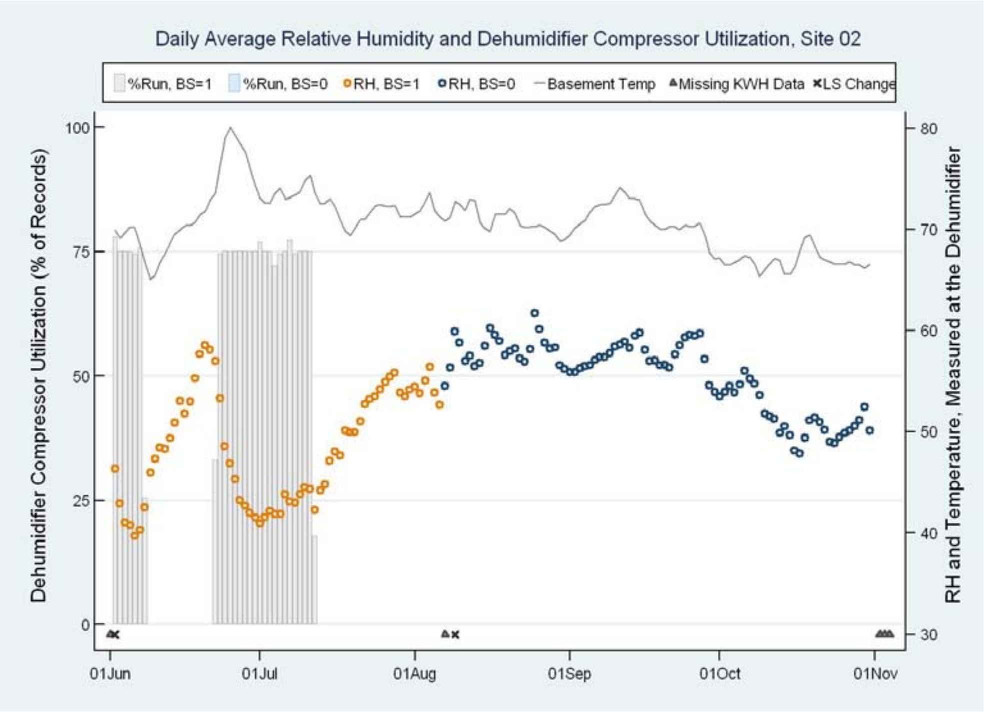
**Figure 6. Daily average dehumidifier energy use for subslab ventilation treatment homes by fan status. Labels above bars indicate period of operation.**

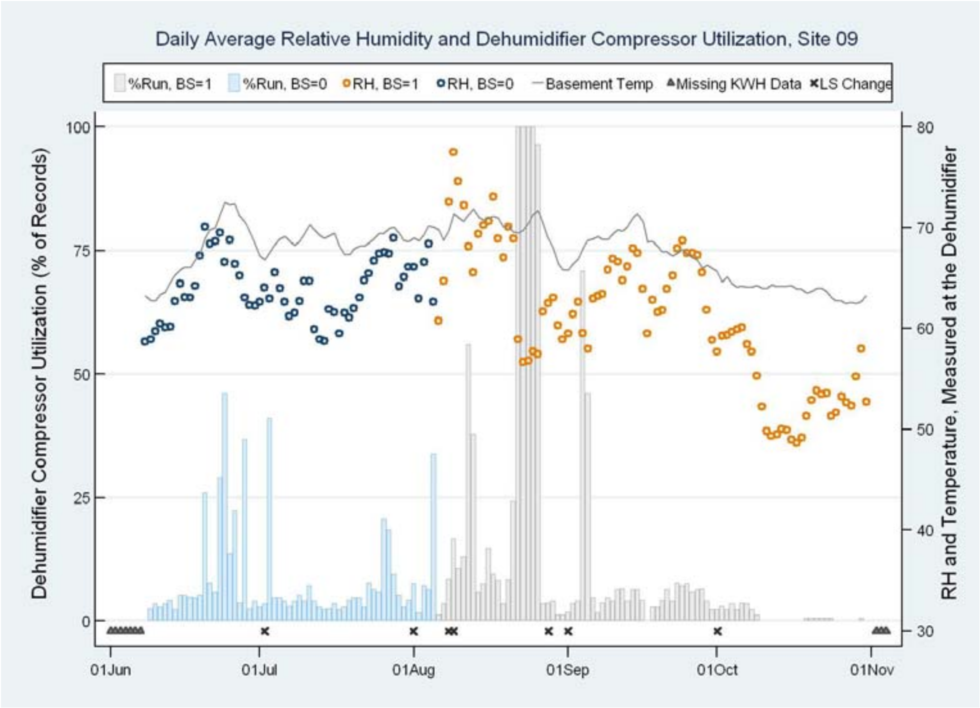


This analysis provides one indication that subslab ventilation fans operating during the summer in WESH homes typically increase dehumidification energy consumption by perhaps 1.5 to 3 KWH per day. These results, however, do not appear very robust, and the approach is suspect due to the fact that the stipulation of actively controlled humidity may be violated in some homes (Figure 7). These sample graphs show a mix of poor humidity control, dramatic changes in dehumidifier duty cycle, periods of 100 percent duty cycle, and days of no operation, each of which challenges the basic assumptions behind a simple factorial analysis. (Graphs for all sites are included in Appendix B.)

As a result, we sought alternative ways of evaluating the field data. Our next step is to apply regression analysis with the objective of identifying factors best able to predict the dehumidification loads and/or humidity conditions in specific homes.

**Figure 7. Daily average dehumidifier duty cycle, basement relative humidity, and basement temperature, subslab ventilation treatment sites 2 and 9.**

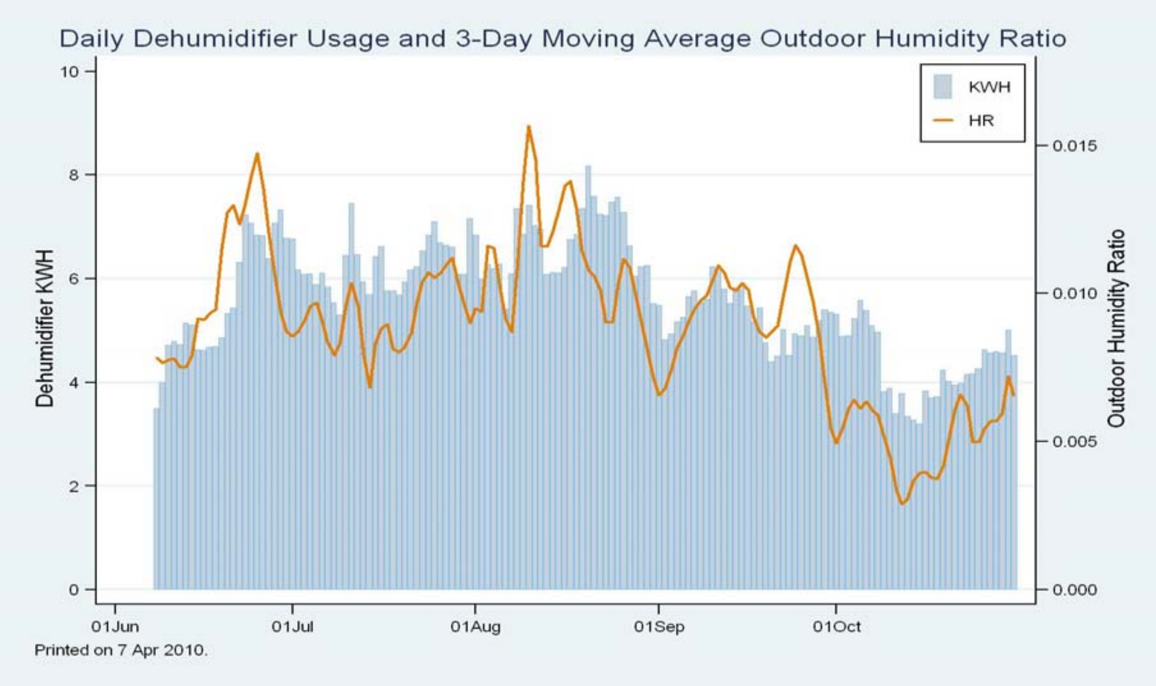




### Explanatory Factors in Dehumidification Energy Use

A simple model of the moisture balance in residential basements was discussed above. For our analysis, we assume that indoor sources driven by human activity are roughly constant over time, or at least do not dominate the variation in humidity found in basements. We assume that the introduction of moisture from outdoor air is proportional to the absolute humidity of the outdoor air.[8] This implicitly assumes that ventilation rates from outdoors to basement are constant. Figure 8 appears to show a general relationship between outdoor humidity ratio and average dehumidification energy consumption.

**Figure 8. Daily Dehumidifier Usage and 3-Day Moving Average Outdoor Humidity Ratio**



The entry of moisture by diffusion is potentially complex, but we initially make the simplifying assumption that diffusion will break down into two components, one that is essentially constant (adding to the human activity constant inputs) and one that varies in rough correlation to ambient absolute humidity (i.e. soil moisture tends to increase with outdoor air moisture). And, as mentioned earlier, diffusion is not expected to be a major factor in homes built to WESH standards.

We further recognize that air conditioning operation may affect basement humidity in several ways. It may, of course, dehumidify basement air through the normal mechanism of condensation on the cooling coil. Air conditioner operation may, however, increase the introduction of outdoor air through depressurization induced by return-air duct leaks, causing a net increase in basement humidity. We monitored the operation of air conditioning systems only at the 10 treatment homes, and included air conditioner run time as a trial parameter in our regression analyses. Using these principles, we

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[8] Throughout this report, we use humidity ratio (the ratio of the mass of water vapor to the mass of dry air) as our measure of absolute humidity.

constructed several simplified regression models, exploring the relationship between dehumidifier KWH, outdoor humidity, basement humidity, air conditioner operation, and subslab fan operation.

We anticipated that a lag may appear in the effect of outdoor humidity on indoor conditions and explored outdoor humidity ratio parameters as follow:

- Current day average
- Previous day average
- 3-day moving average (current day and 2 previous days)
- 3-day modified moving average (current day weighted at ½, previous day weighted fully, and 2nd previous day weighted at ½)
- 7-day declining weight moving average (current day and 6 previous days, each with proportionally declining weight)

The most robust predictions across most sites were obtained with the 3-day moving average, and all results presented here use that parameter to characterize outdoor humidity ratio.

Where humidity is well controlled, we would expect that the energy consumption of the dehumidifier might be a suitable dependent variable, with other driving forces explored as independent parameters. This approach is consistent with our physical model, in which dehumidifier energy use is “caused” by introduction of humidity from constant sources and from the variable source of outdoor air, with possible added effects from subslab fan operation and air conditioning operation. We ran trials of this type of model for all sites.

Where humidity is not well controlled, we cannot expect dehumidifier energy use to “track” the humidification driving forces. In this case, we inverted our model and used basement humidity as the dependent parameter, with outdoor humidity and dehumidifier operation as independent parameters, along with subslab fan and air conditioning operation where applicable. This form of model treats dehumidifier operation as a phenomenon assumed to have a linear effect on humidity, but with no implicit assumption of regular or well-controlled dehumidifier operation. We tried both relative humidity and humidity ratio as parameters characterizing basement conditions.

Overall, we attempted more than 400 different regressions, with results that varied wildly. We calculated $r^2$ values, t statistics for individual parameter coefficients, and f statistics for each model. Based on evaluation of all results, no single approach works for a large number of sites. There are a number of models that performed well across a number of sites, however, and some parameter estimates that show consistency across a number of sites.

The common features of the most useful models are shown in Table 6.

**Table 6. Features of Successful Regression Models**

| MODEL TYPE (DEP PARAM) | NUMBER OF WESH SITES | NUM OF NON-WESH SITES | RANGE OF $R^2$ | RANGE OF F | RANGE OF CONSTANT | RANGE OF COEFFICIENT: OUTDOOR HUMIDITY RATIO X 1000 | RANGE OF COEFFICIENT: DEHUM KWH | RANGE OF COEFFICIENT: AIR CONDITIONER OPERATION | RANGE OF COEFFICIENT: SUBSLAB FAN STATUS |
|---|---|---|---|---|---|---|---|---|---|
| Dehum KWH (# 1) | 1 | 0 | .82 | 103 | 3.98 | .55 | NA | 7.00 | 2.46 |
| Basement humidity ratio (# 7) | 2 | 2 | .26 to .56 | 18.0 to 62.9 | 5.36 to 7.52 | .08 to .31 | NA | NA | NA |
| Basement humidity ratio (# 5) | 1 | 3 | .48 to .79 | 30.5 to 84.8 | 5.15 to 8.58 | .08 to .31 | -0.10 to -0.36 | NA | NA |
| Basement relative humidity (# 11a) | 2 | 0 | .60 to .79 | 34.2 to 81.3 | 30.3 to 40.2 | .67 to .79 | NA | NA | 1.24 to 1.55 (n=2) |
| Basement relative humidity (# 9) | 1 | 1 | .47 to .53 | 56.1 to 59.4 | 39.5 to 44.2 | 1.03 o 1.48 | NA | NA | NA |
| Basement relative humidity (# 11) | 5 | 8 | .45 to .88 | 12.2 to 795 | 29.2 to 62.0 | -0.14 to 1.84 (low val not sig) | -0.81 to -2.06 | NA | 0.43 (not sig) |
| Basement relative humidity (# 12) | 1 | 0 | .86 | 145.6 | 30.2 | .37 | NA | 11.64 | 5.54 |
| Basement relative humidity (# 10) | 3 | 0 | .79 to .91 | 65.7 to 185 | 48.6 to 57.2 | 0.70 to 1.27 | -0.56 to -1.52 | -1.83 to -9.0 (small value not sig) | -6.28 to +2.93 |

The models included in the table cover 30 of the 40 homes investigated. For the models listed, all coefficient estimates were significant to about a .10 or lower probability level unless noted. The parameter estimates from these models also generally fit with our physical understanding of basement moisture.

We consider models for 8 of the 10 treatment homes to be acceptable. The coefficients for subslab fan status derived from these models appear in Table 7. Note that the units of the estimate vary with the model type. We include the estimated daily average KWH effect of subslab fan operation from the earlier factorial analysis in the last column for comparison (note this is the simple difference between fan on and fan off periods, with no correction for seasonal effects). In the sole case in which we found a KWH model that adequately represented the data (Site 1), the estimated impact of fan operation derived from regression analysis is similar to that derived from factorial analysis. In all other cases, the regression is estimating the impact of subslab fan operation on basement relative humidity, with the coefficient representing the shift in average relative humidity for a summer period with fan operation compared to a period without operation.

**Table 7. Estimated coefficient for subslab fan status derived from regression models**

| SITE | MODEL TYPE | SUBSLAB FAN STATUS COEFFICIENT | UNITS OF COEFFICIENT | T STATISTIC | ESTIMATED KWH EFFECT FROM FACTORIAL ANALYSIS |
|---|---|---|---|---|---|
| 1 | KWH (#1) | 2.46 | KWH/day | 13.51 | 1.86 |
| 2 | RH (#10) | -6.28 | Avg percent RH | -12.25 | 5.13 |
| 3 | RH (#11a) | 1.55 | Avg percent RH | 8.31 | 0.01 |
| 6 | RH (#11a) | 1.24 | Avg percent RH | 4.54 | 0.03 |
| 7 | RH (#12) | 5.54 | Avg percent RH | 19.85 | 0.65 |
| 8 | RH (#10) | -5.56 | Avg percent RH | -4.23 | 13.54 |
| 9 | RH (#11) | 0.43 | Avg percent RH | 0.80 (not significant) | 1.14 |
| 13 | RH (#10) | 2.93 | Avg percent RH | 8.33 | -0.18 |

According to this analysis, subslab fan operation appears to yield a net increase in basement relative humidity in 6 homes, while it results in a marked decrease in relative humidity in 2 homes. It is interesting to note that the two sites that showed the most distinct *increase* in dehumidifier energy consumption when evaluated as a simple factorial are the two sites (2 and 8) that show the greatest *reduction* in humidity when analyzed by regression. We consider both forms of analyses of these two homes as problematic due to marked changes in dehumidifier operation between the factorial periods, with large variations in observed relative humidity. In general, however, we believe that the regression-based models for these sites are more robust than the simple factorial analysis, and believe the regressions provide confirmation that subslab ventilation most commonly yields a net increase in summertime basement humidity loads.

### House Airflow and Humidity Load Induced by Subslab Fan Operation

A net increase in ventilation, when incoming air has higher moisture content than the indoor air it replaces, means an increase in indoor humidity load. In our case, a comparison of basement humidity ratio to outdoor humidity ratio shows that, during our monitoring periods, the average moisture content of outdoor air is higher in nearly every case than that in the basement (Table 8). Site 9 shows a negative relationship, i.e. the basement average humidity ratio is higher than the outdoor average for both defined periods. Site 9 is characterized by higher moisture levels than most of the basements in the study (sites 9 and 13 are the only sites with daily average relative humidity values routinely greater than 60 percent).

**Table 8 Difference of outdoor average humidity ratio and basement average humidity ratio, by season (6-week period before and after fan status switch).**

| Site | Period 1 Humidity Ratio, Outdoor - Basement | Period 2 Humidity Ratio, Outdoor - Basement |
|---|---|---|
| 1 | 0.002111 | 0.003080 |
| 2 | 0.000822 | 0.000338 |
| 3 | 0.001788 | 0.002187 |
| 4 | 0.001028 | 0.001727 |
| 6 | 0.002786 | 0.003558 |
| 7 | 0.002786 | 0.004255 |
| 8 | 0.001505 | 0.002795 |
| 9 | -0.000576 | -0.000231 |
| 13 | 0.000294 | 0.000247 |
| 14 | 0.001156 | 0.002062 |

If we can quantify an increased ventilation rate associated with subslab fan operation, assume makeup air comes from above-grade outdoor conditions, and know the average moisture content of the indoor and outdoor air, we can estimate the change in moisture load imposed on the home. In practice, we use house pressure measurements with the subslab fan on and off in combination with airflow simulation to estimate the change in whole-house ventilation under fan-on as compared to fan-off conditions, and apply measured values for absolute humidity to calculate moisture transfer associated with this airflow. We don’t have a basis to break out the location of the added incoming airflow (i.e. basement or above grade), so the differential moisture load represents a whole-house value. An additional caveat is that, if some part of the increased ventilation from outdoor air is offset by a decrease in infiltration from soil gas, the net effect of this change in the source of ventilation air will depend on moisture content of the soil gas and outdoor air. We will address this question later.

During the mid-summer visits to the 10 treatment homes, we performed a test of the zonal pressure impact of operating the subslab ventilation fan in each home. This test consisted of switching the subslab fan on and off for alternate periods of 75 seconds, while monitoring the pressure difference between the outdoors and the basement. The decrease in basement pressure during the fan-on periods as compared to fan-off periods, in combination with information about the air leakage characteristics of each home, can provide a quantitative estimate of the added ventilation induced by subslab fan operation.[9] The results show that subslab fan operation does indeed reduce basement pressures in each of the homes tested (see Table 9.)

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[9] The test protocol included asking occupants to keep windows and doors closed, and to avoid use of any exhaust ventilation equipment during the test period.

**Table 9 Impact of subslab fan operation on pressure difference between outdoors and basement, July 6 & 7, 2009.**

| Site | Fan on test Pfan-zone (Pa) | Zone pressure, fan off Pout-Pzone (Pa) | Zone pressure, fan on Pout-Pzone (Pa) | Zone pressure diff On-Off (Pa) | T statistic for difference of mean pressures | Mean of standard deviation of observations, fan off & fan on |
|---|---|---|---|---|---|---|
| **1** | -204 | -0.023 | 1.902 | **1.9249** | -19.501 | 1.843 |
| **2** | -233 | 0.918 | 1.595 | **0.6767** | -30.427 | 0.390 |
| **3** | -132 | 0.112 | 1.022 | **0.9095** | -57.271 | 0.285 |
| **4** | -135 | -0.376 | -0.157 | **0.2185** | -9.833 | 0.428 |
| **6** | -483 | 0.304 | 0.438 | **0.1344** | -3.801 | 0.529 |
| **7** | -159 | -0.046 | 0.136 | **0.1825** | -4.759 | 0.634 |
| **8** | -182 | -0.495 | 1.753 | **2.2488** | -107.573 | 0.380 |
| **9** | -130 | -1.014 | -0.828 | **0.1860** | -2.862 | 1.278 |
| **13** | -152 | 2.028 | 2.704 | **0.6755** | -7.697 | 1.771 |
| **14** | -170 | -0.049 | 0.445 | **0.4933** | -15.513 | 0.601 |

The zone pressure difference associated with subslab fan operation is modest, ranging from 0.13 to 2.2 Pascals among the test homes. The values are all positive, however, as expected if the fan operation induces airflow from the basement, and the T statistic values for each case show that the zone pressures with fan on are different than those with fan off at a level of statistical significance of over 99.9 percent probability in each case. This demonstrates that there is some connection between the subslab ventilation system and the basement interior in each of these homes, most likely in the form of leakage at the edge or interior of basement slabs. The standard deviation of the test pressures varies widely, which we attribute to varying windiness during the tests.

This test alone does not quantify the ventilation impact of fan operation, however, and to do this we turned to CONTAM.[10] This software performs detailed airflow simulations of buildings, and details of leakage area, type, and location, temperature differences, wind, and mechanical ventilation can be described and included in analysis. We used generalized modeling input files developed for use with CONTAM analysis,[11] selecting homes that match our project test sites in terms of number of stories, basements, and attached garages, and adjusting parameters as needed to describe our test homes.

In modifying the models for our project, we left in place the approximately uniform distribution of leakage across the above-grade envelope of each home, but concentrated basement leakage at the top of the basement walls for homes with fully below-grade basements, and moved about 10% of this leakage to the bottom of the basement wall when modeling walkout basements. We used a CONTAM feature that

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[10] CONTAM 2.4 software, National Institute of Standards and Technology Building and Fire Research Lab, 2008

[11] A Collection of Homes to Represent the U.S. Housing Stock, A. Persily, A. Musser, D. Leber, U.S. Dept of Housing and Urban Development, 2006

mimics the effect of a blower door test to help us adjust the overall building leakage coefficient to match the results of the WESH testing performed on each home. Finally, we modeled a small leak across the basement floor in each case, and added a zone (space) below the basement floor, set to a negative pressure matching the estimated effects of the subslab ventilation systems for each home.[12]

Once the known properties of each home were entered, we ran steady state simulations for each home, under the temperature conditions that existed when our testing was done to find a baseline zone pressure under fan-off conditions. We then progressively increased the size of the basement floor slab leak until the zone pressure changed by the amount observed in our field zone pressure test. The resulting exhaust airflow through the basement slab is our estimate of added ventilation induced by the subslab fan, and the size of the slab leak is an estimate of the actual leakage area. The resulting estimates of additional ventilation induced by subslab fan operation vary from 5.4 to about 74 cfm, while the estimated size of the floor slab leaks range from 0.13 to 1.79 sq in (see Table 10).

**Table 10 Estimated induced ventilation resulting from subslab fan operation in treatment homes.**

| Site | Fan on test Pfan-zone (Pa) | Zone pressure diff On-Off (Pa) | WESH blower door results (cfm at 50Pa) | Induced leakage matching oberved zone press diff (cfm) | Est size of floor leak (sq in) | Avg of std dev fan off & fan on | Estimated daily average added dehumidification load (KWH) |
|---|---|---|---|---|---|---|---|
| **1** | -204 | 1.9249 | 988 | 58.6 | 1.58 | 1.843 | 2.60 |
| **2** | -233 | 0.6767 | 1216 | 73.8 | 1.65 | 0.390 | 1.27 |
| **3** | -132 | 0.9095 | 615 | 22.2 | 0.79 | 0.285 | 1.02 |
| **4** | -135 | 0.2185 | 1216 | 16.3 | 0.57 | 0.428 | 0.59 |
| **6** | -483 | 0.1344 | 917 | 9.1 | 0.13 | 0.529 | 0.53 |
| **7** | -159 | 0.1825 | 372 | 5.7 | 0.16 | 0.634 | 0.33 |
| **8** | -182 | 2.2488 | 623 | 82.7 | 2.14 | 0.380 | 4.85 |
| **9** | -130 | 0.1860 | 580 | 5.4 | 0.19 | 1.278 | -0.03 |
| **13** | -152 | 0.6755 | 1167 | 56.2 | 1.59 | 1.771 | 0.29 |
| **14** | -170 | 0.4933 | 1057 | 52.2 | 1.38 | 0.601 | 1.27 |

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[12] To allow for airflow pressure drops occurring in piping connections and gravel layer, we multiplied the measured pressure in the suction pipe by 0.70 for use in CONTAM analysis.

As mentioned above, this analysis implicitly assumes that any change in airflow from soil to basement is small by comparison to the change in air flowing from outdoors. (Air flowing in from the soil could be expected to have different moisture content than air from outdoors, and without knowing the moisture content of this leakage we can't include it in our analysis.) The fact that the pressure applied across the slab by the subslab vent systems are on the order of 100+ Pascals, while normal building operating pressures due to stack effect and other drivers are on the order of a few Pascals means that the volume of air flowing across the slab during fan operation is likely at least an order of magnitude greater than the flow (in either direction) of air resulting from normal driving forces, so we conclude that this assumption is sound.

The product of the estimated induced airflow and the humidity ratio difference between outdoor and indoor air, calculated for each home, yields the average net moisture input associated with fan operation. Applying a typical performance factor for dehumidifiers,[13] we have estimated the additional expected dehumidification load (see last column in Table 10).

The assumptions and estimates included in this method are such that we don't believe the results should be used to explain quantitative performance differences among our test homes. The sign and magnitude of the results is consistent with our other methods, however, and support the idea that summertime subslab fan operation tends to increase humidity loads and dehumidifier operation. It should be noted that this analysis would indicate a drying effect in most homes during a substantial portion of the year, when the moisture content of outdoor air is routinely lower than that of indoor air.

### Subslab Ventilation Fan Energy Consumption

We measured the current draw of 8 subslab fans during the study. Seven of these had current draws of 0.46 to 0.51 amps, and one drew 0.30 amps. Using 0.48 as a typical current value, assuming 120 volt power, and a power factor of .85, a typical fan draws about 49 watts, or about 1.2 KWH per day. This energy consumption is significant, and should be considered in weighing the impact of subslab ventilation on the whole home.

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[13] We use 1.4 liters of moisture removal per KWH, a typical value based on nameplate ratings of the units we studied.

## APPENDIX A

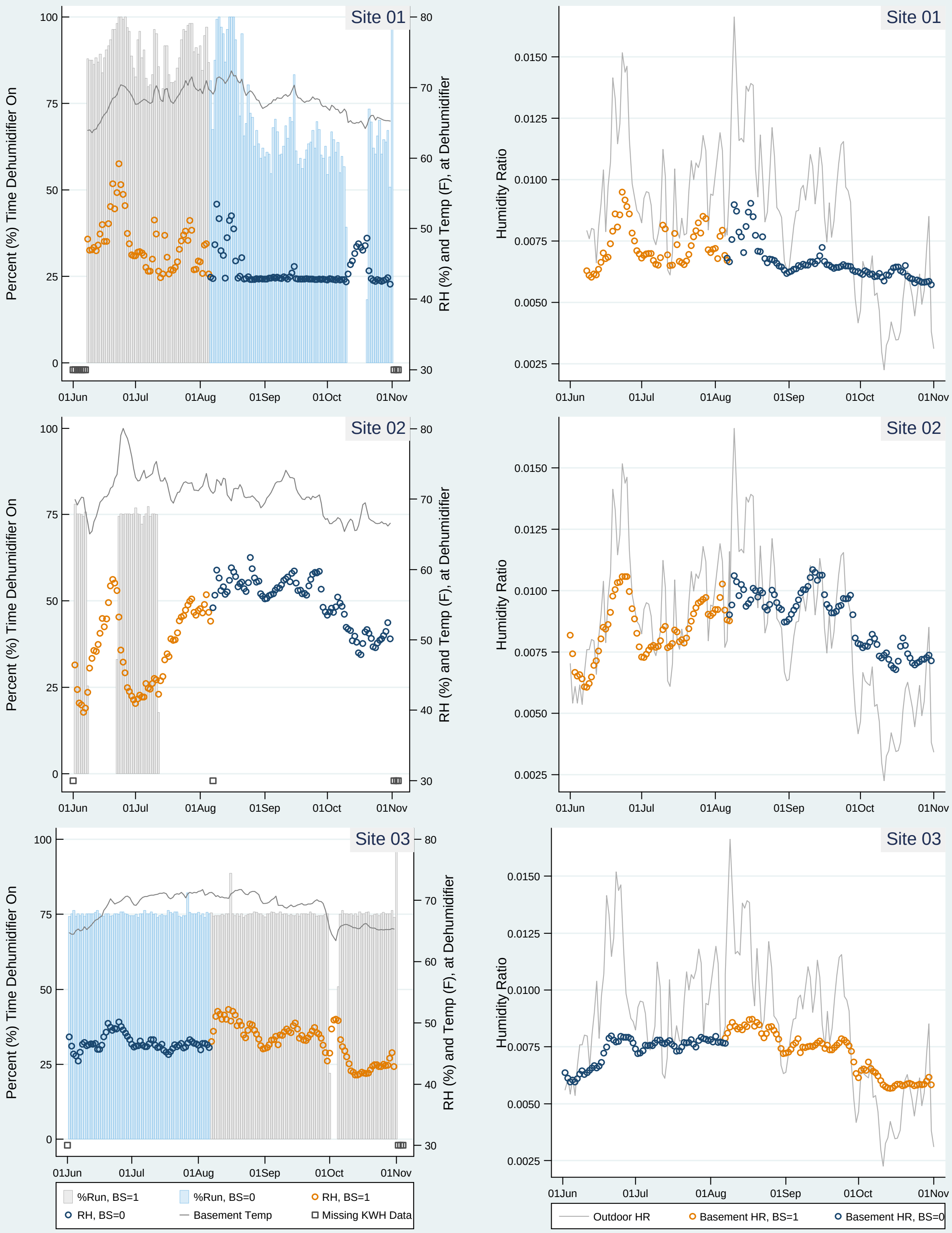
# Characteristics of homes

| Group | Site ID | Active / Passive Subslab Fan? | City | Ab grade | Bel grade | Fdn wall | Dehumidifier Use | Brand | Model | Nom pts/ day | Nom amps | Liters / KWH | Drain type | Subslab blower measured Amps |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | **1** | Y | Appleton | 1780 | 1780 | CIP | All year | Frigidaire (Electrolux label) | FDL50S1 | 50 | 5.3 | 1.60 | Floor | 0.48 |
| Treatment | **2** | Y | Neenah | 5543 | 2000 | CIP | Never used | Whirlpool | AD50USL5 | 50 | 6.2 | 1.35 | Floor | 0.48 |
| Treatment | **3** | Y | Appleton | 1680 | 1680 | CIP | Summer only | Whirlpool | AD40USL3 | 40 | 5.0 | 1.30 | Floor | |
| Treatment | **4** | Y | Neenah | 1900 | 1900 | CIP | Never used | Kenmore | 580.54501801 | 50 | 5.4 | 1.75 | Floor | 0.51 |
| Treatment | **6** | Y | Appleton | 1900 | 950 | CIP | Summer only | Kenmore | 580.54351800 | 35 | 4.7 | 1.40 | Floor | 0.30 |
| Treatment | **7** | Y | Appleton | 2250 | 1125 | CIP | Year round | Frigidaire (Electrolux label) | FDL50S1 | 50 | 5.3 | 1.60 | Floor | 0.49 |
| Treatment | **8** | Y | Neenah | 2050 | 1025 | CIP | Never used | Hampton Bay | HB50-L | 50 | 7.5 | 1.39 | Floor | 0.53 |
| Treatment | **9** | Y | Hilbert | 1320 | 1320 | CIP | Summer only | Crosley | DCW25-1 | 26 | 4.5 | 1.20 | Floor | 0.46 |
| Treatment | **13** | Y | Appleton | 1850 | 925 | CIP | Summer only | GoldStar | D65EL | 65 | 7.8 | 1.54 | Floor | |
| Treatment | **14** | Y | Menasha | 2500 | 1700 | CIP | Minimal summer use | Hampton Bay | HB50-G | 50 | 7.5 | 1.39 | Floor | |
| Control | **20** | Y | Neenah | 3100 | 2100 | CIP | Cooling season | White Westinghouse | MDH25YW2 | | | | Pan | |
| Control | **21** | N | DePere | 2300 | 2300 | CIP | | Haier | AHD25 | | | | Pan | |
| Control | **22** | Passive | Malone | 2100 | 2100 | CIP | Summer | GE | AHG40LAG1 | | | | Floor | |
| Control | **23** | N | DePere | 1560 | 1560 | CIP | All year | GE | AHM40LKG1 | | | | Floor | |
| Control | **24** | N | Green Bay | 1700 | 1700 | ? | | LG | LHD65EBLY7 | | | | Floor | |
| Control | **25** | Passive | Fond du Lac | 2300 | 2300 | CIP | All year as needed | Thermastor | Santa Fe 4021400 | | | | Floor | |
| Control | **26** | N | Green Bay | 1700 | 1700 | CIP | Summer | LG | LHD65EBLY7 | | | | Floor | |
| Control | **27** | N | Fond du Lac | 2480 | 2480 | CIP | Summer | Kenmore | 106.5750079 | | | | Floor | |
| Control | **28** | Y | DePere | 1901 | 1901 | CIP | Summer | Goldstar | DH40 | | | | Pan | |
| Control | **29** | Y | Greenville | 2000 | 2000 | CIP | All | Whirlpool | AD4061 | | | | Floor | |
| Gen'l | **30** | N | Holmen | 1250 | 650 | CIP | | Kenmore | 580.54701700 | | | | Floor | |
| Gen'l | **31** | N | Milwaukee | 980 | 700 | CIP | | Haier | AHD25 | | | | Pan | |
| Gen'l | **32** | N | Madison | 1300 | 200 | Block | | Whirlpool | AD40G1 | 40 | 6.8 | 1.40 | Floor | |
| Gen'l | **33** | N | LaCrosse | 1500 | 1500 | Block | | Tru Cold | UAN3171A | | | | Floor | |
| Gen'l | **34** | N | Sparta | 1000 | 120 | Block | | Magic Chef | DH25L | | | | Pan | |
| Gen'l | **35** | N | Morisonville | 1400 | 1400 | CIP | | Fedders | A7DH45B2A*A-R | | | | Pan | |
| Gen'l | **36** | N | Elm Grove | 1900 | 300 | CIP | Always on | ComfortAire | BHD-501-D | | | | Sump | |

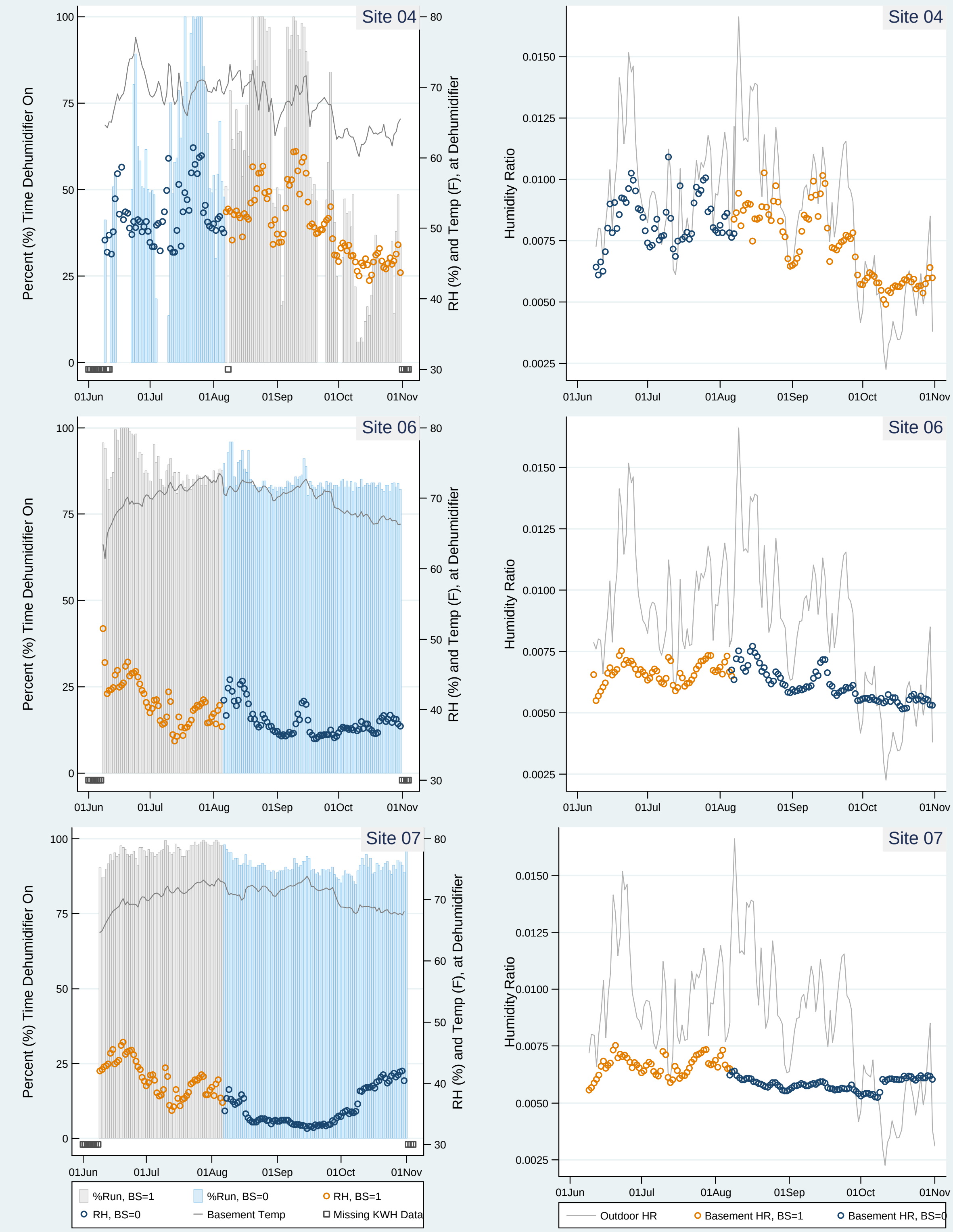
| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gen'l | **37** | N | Green Bay | 1568 | 1128 | Block | Frequently | Frigidaire Signature 2000 | 93202C | | | | Floor | |
| Gen'l | **38** | N | Oshkosh | 1100 | 1100 | Block | | Gibson | MDH25YG3 | | | | Pan | |
| Gen'l | **39** | N | Waukesha | 2300 | 800 | Block | Summer | Goldstar | DH404EY7 | | | | Floor | |
| Gen'l | **40** | N | Oshkosh | 2140 | 750 | CIP | | Maytag | M70H432A | | | | Pan | |
| Gen'l | **41** | N | Eau Claire | 1011 | 1011 | CIP | Summer | Kenmore | 580.54701700 | | | | Pan | |
| Gen'l | **42** | N | Milwaukee | 1280 | 900 | Block | Regularly (year-round?) | Goldstar | LX86HAQG | | | | Floor | |
| Gen'l | **43** | N | Appleton | 1700 | 900 | CIP | | White Westinghouse | ED238J6 | | | | Pan | |
| Gen'l | **44** | N | Mequon | 1750 | 1000 | Block | Year-round | Kenmore | 580.52650100 | | | | Floor | |
| Gen'l | **45** | N | Oak Creek | 1875 | 500 | CIP | | Frigidaire | FDH30J2 | | | | Floor | |
| Gen'l | **46** | N | Wales | 1800 | 450 | Block | Minimal | Chambers | BPDH2500F50 | | | | Floor | |
| Gen'l | **47** | N | Madison | 18968 | 900 | CIP | | Edison 25 | DHE25WG-1 | | | | Floor | |
| Gen'l | **48** | N | Muskego | 2000 | 1000 | Block | | LG | LHD65EBLY7 | | | | Floor | |
| Gen'l | **49** | Y | Sussex | 1974 | 1974 | Block | | LG | LHD65EBLY7 | | | | Floor | |

# APPENDIX B

## Dehumidifier operation and humidity levels in all homes



Abbrivations: HR = Humidity Ratio, BS = Blower Status where 0=Off and 1=On,



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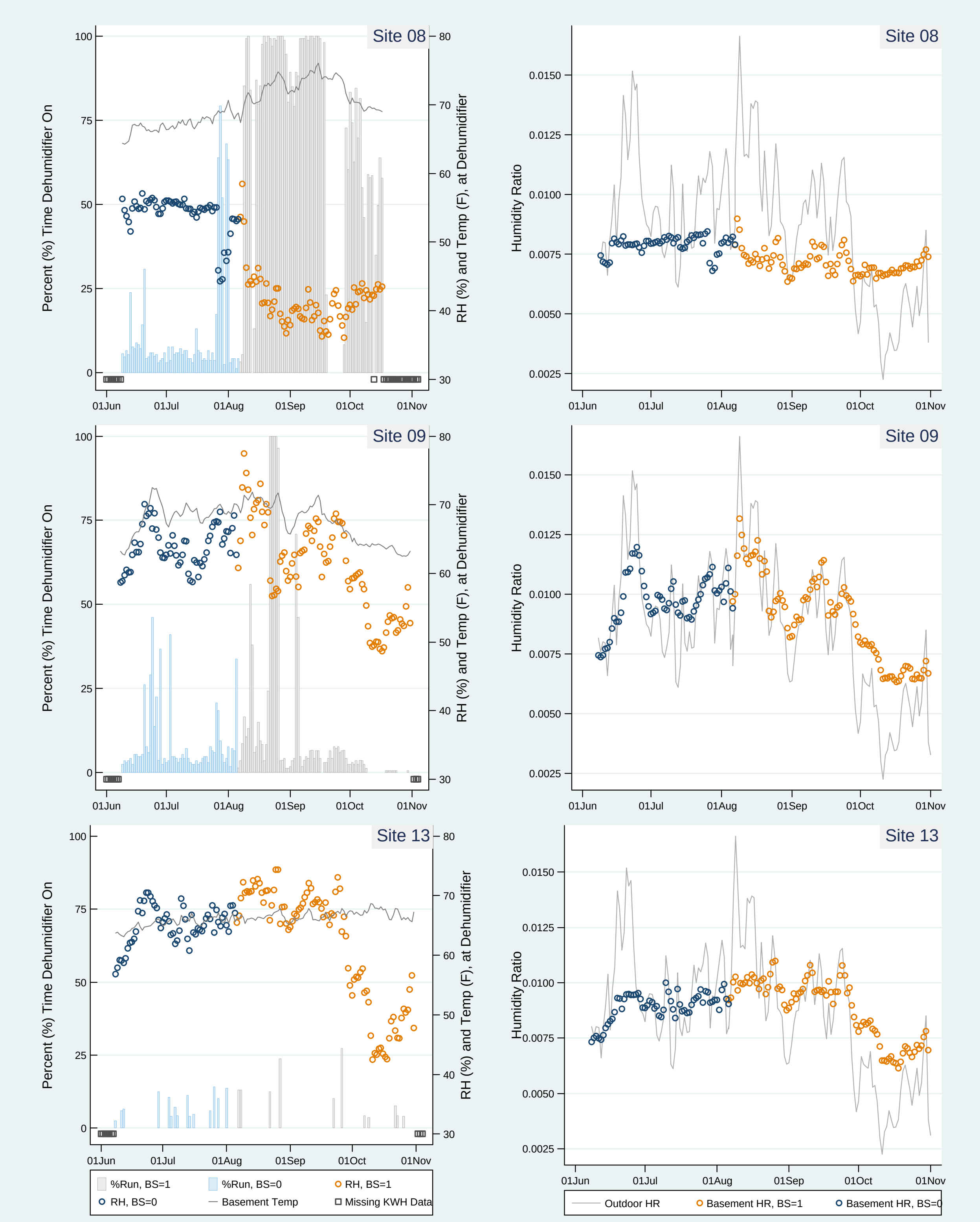

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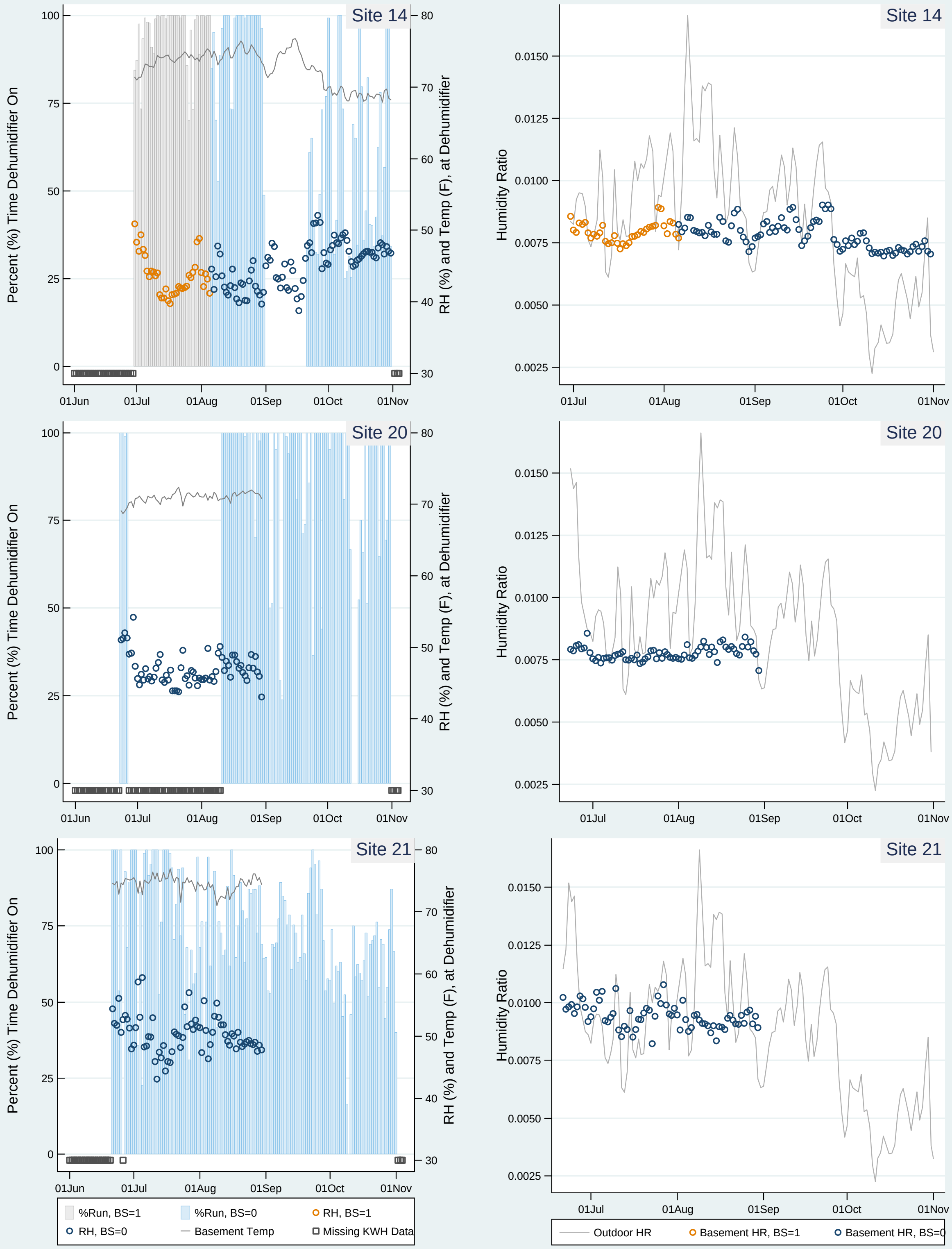

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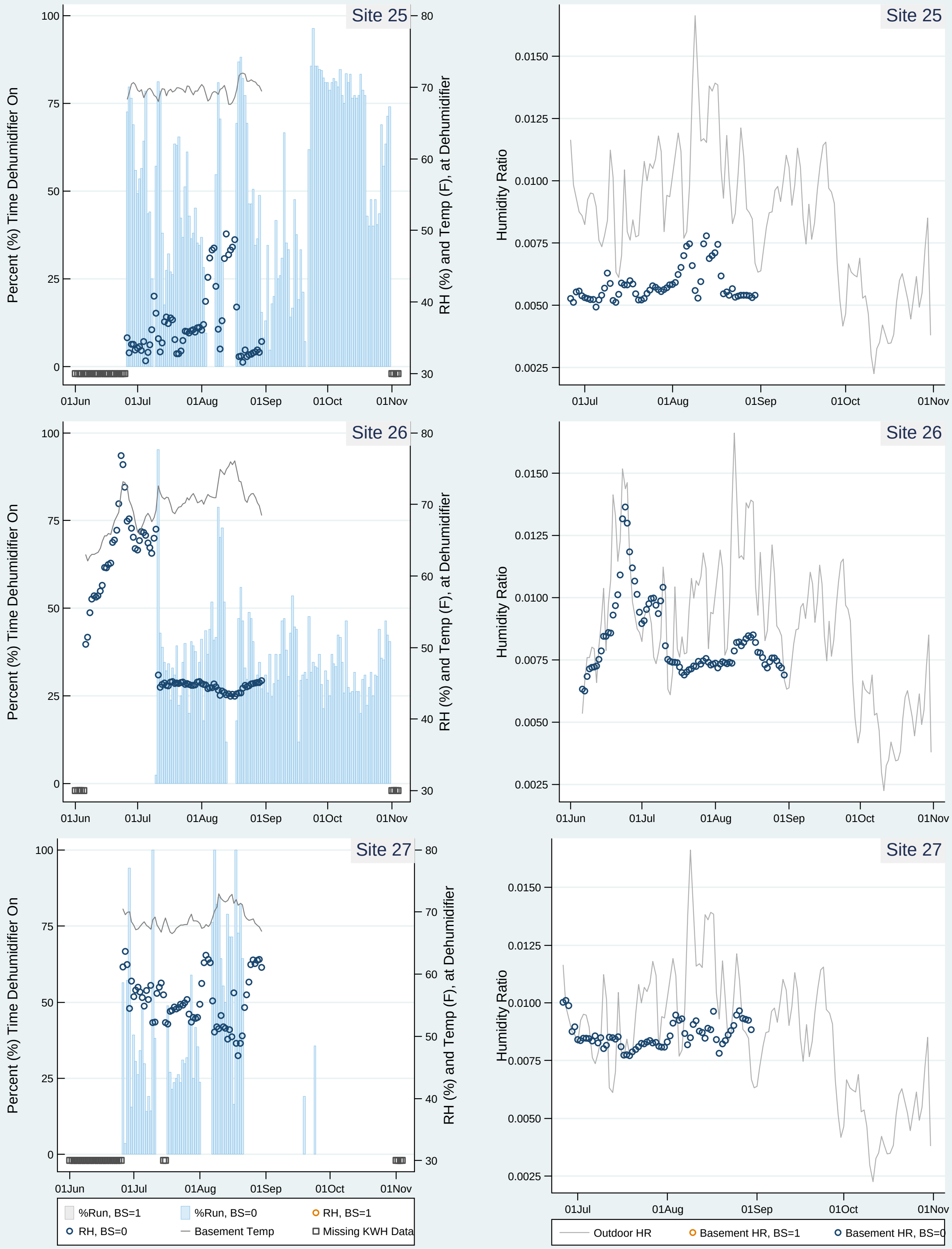

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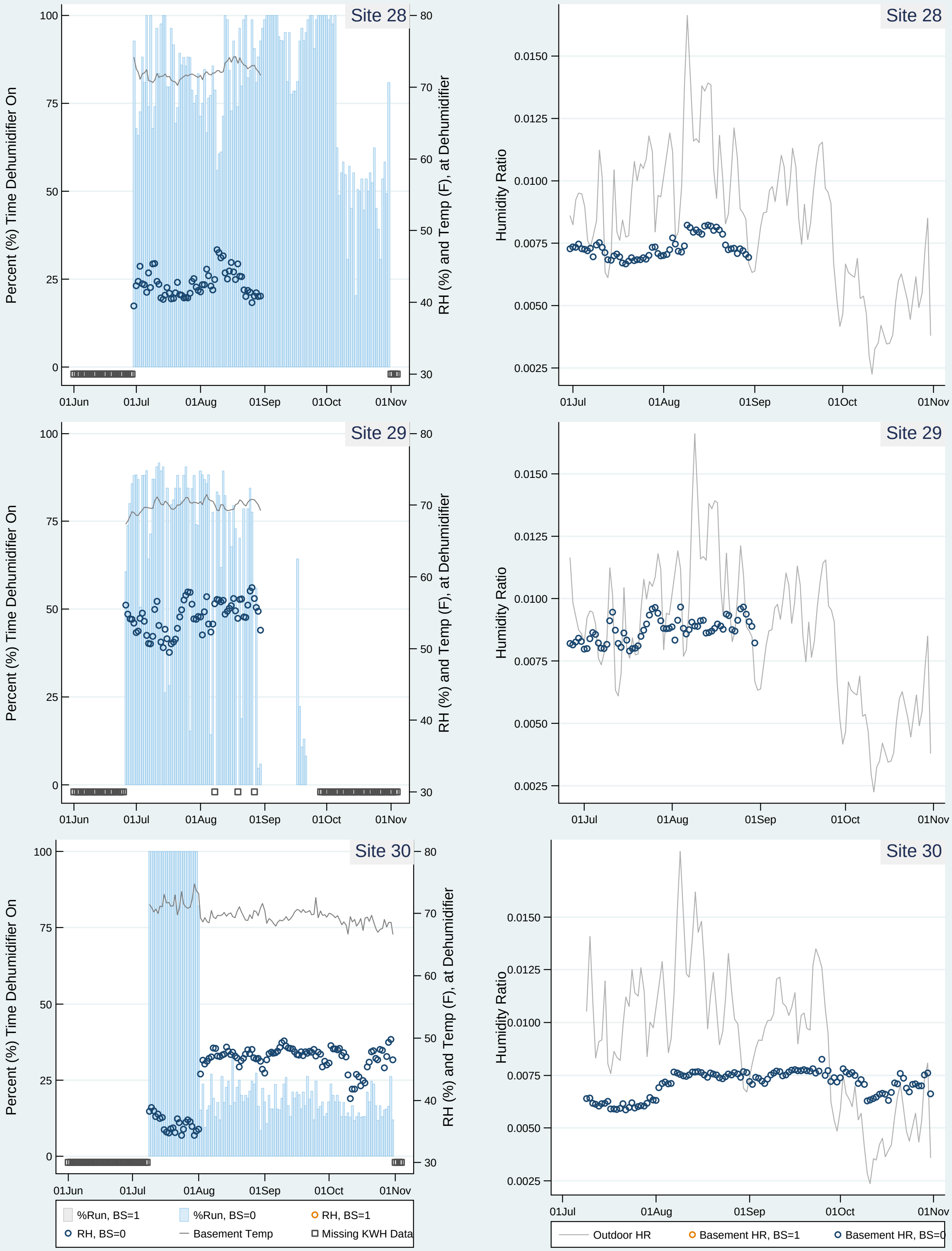
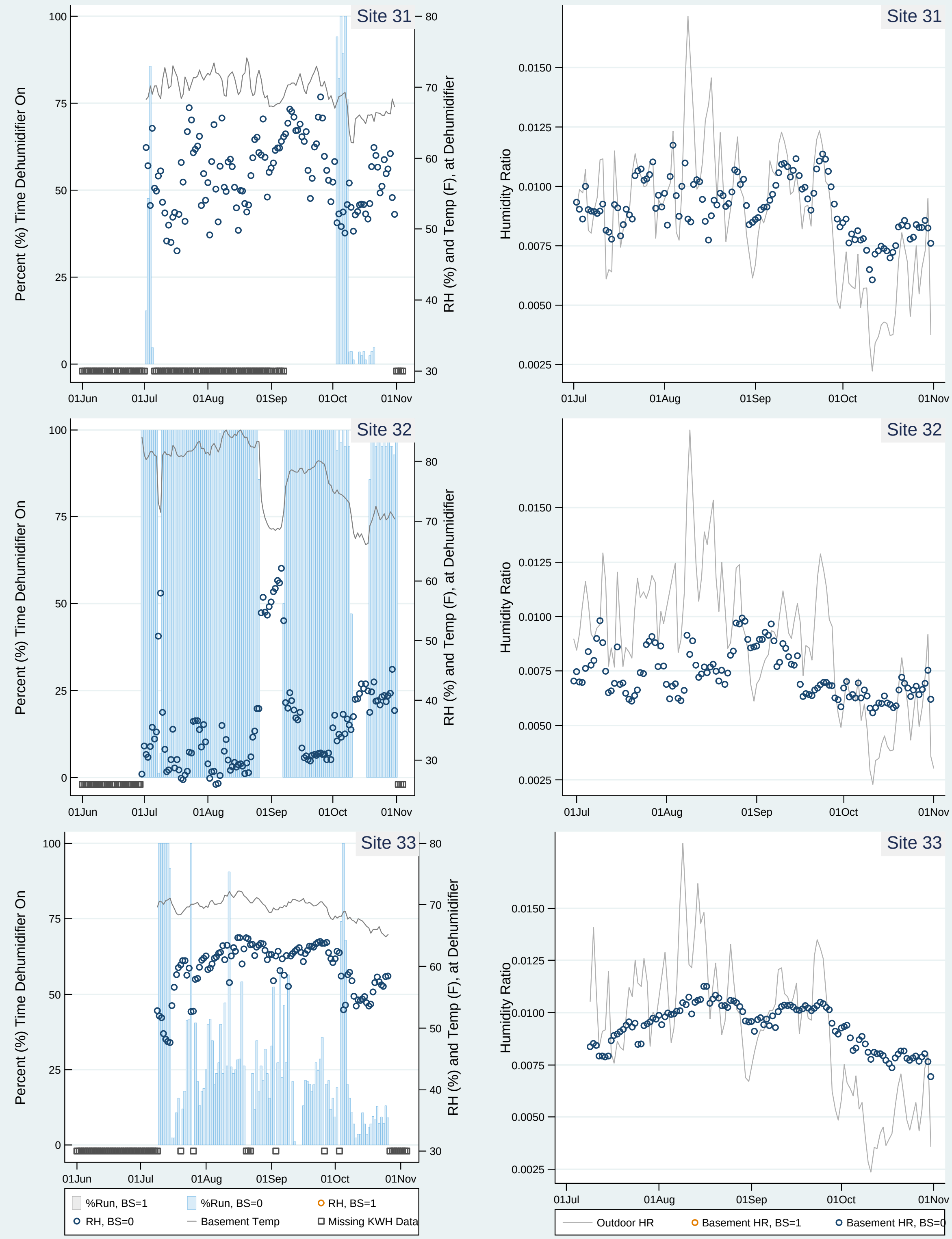
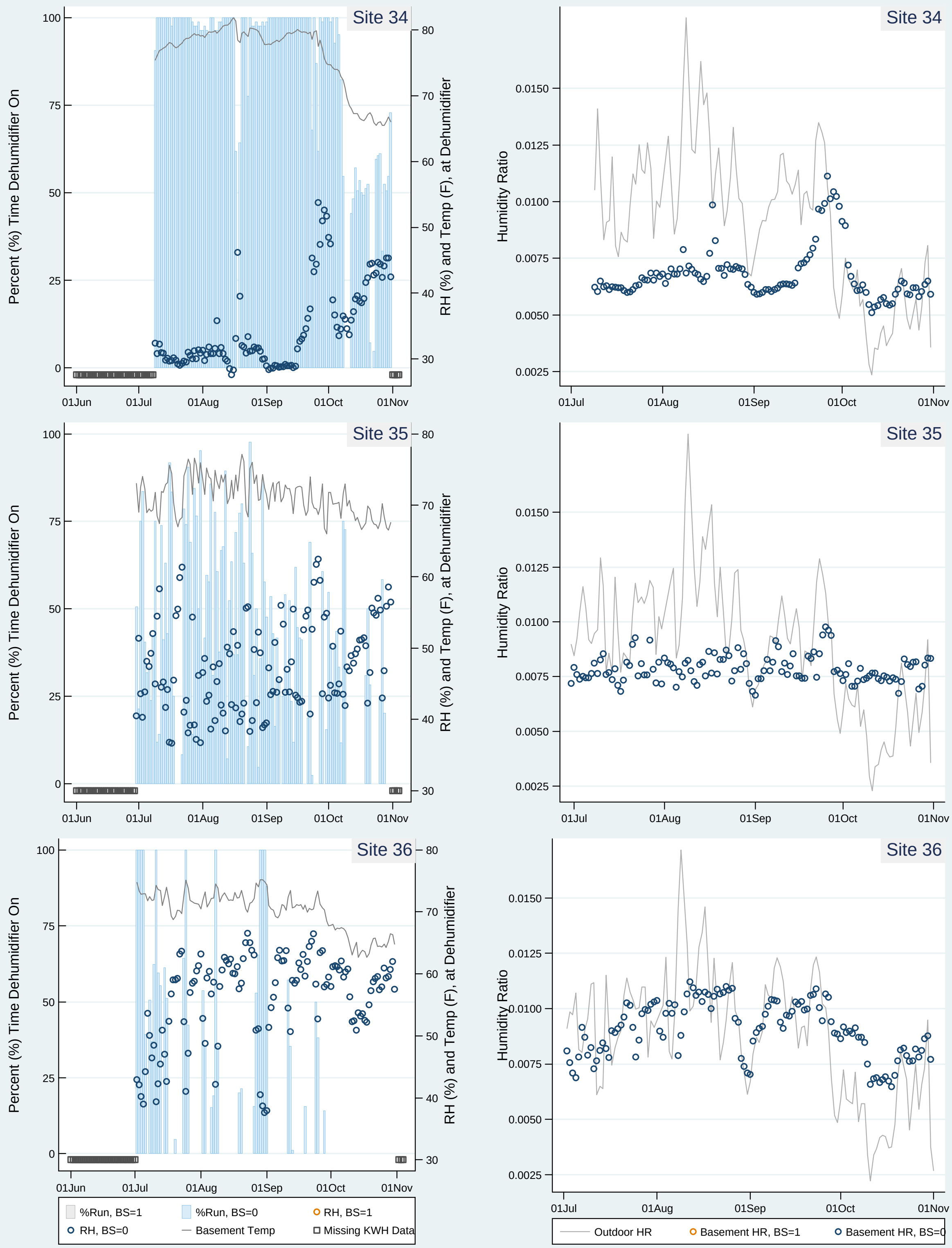


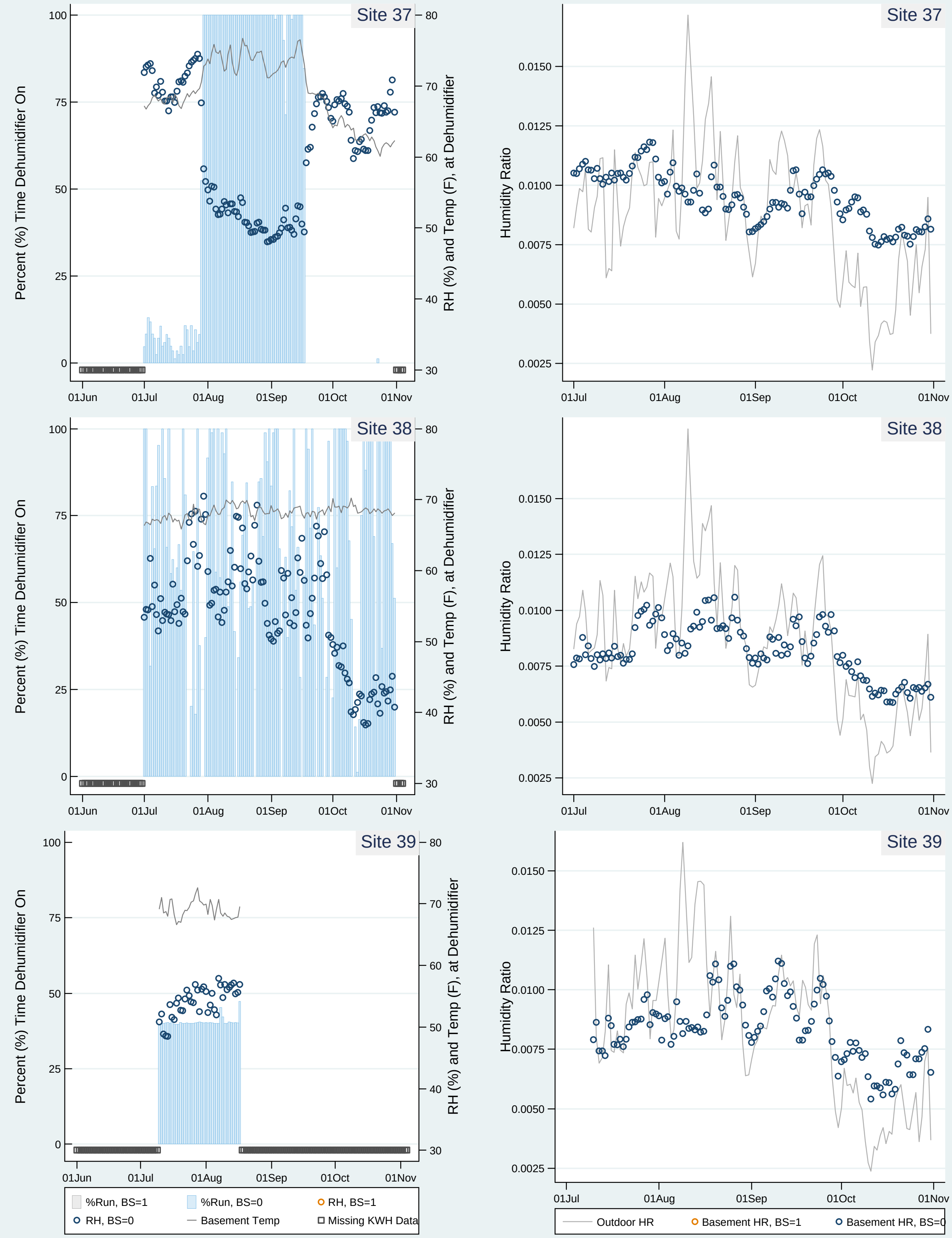
Abbrivations: HR = Humidity Ratio, BS = Blower Status where 0=Off and 1=On,



Abbrivations: HR = Humidity Ratio, BS = Blower Status where 0=Off and 1=On,



Abbrivations: HR = Humidity Ratio, BS = Blower Status where 0=Off and 1=On,



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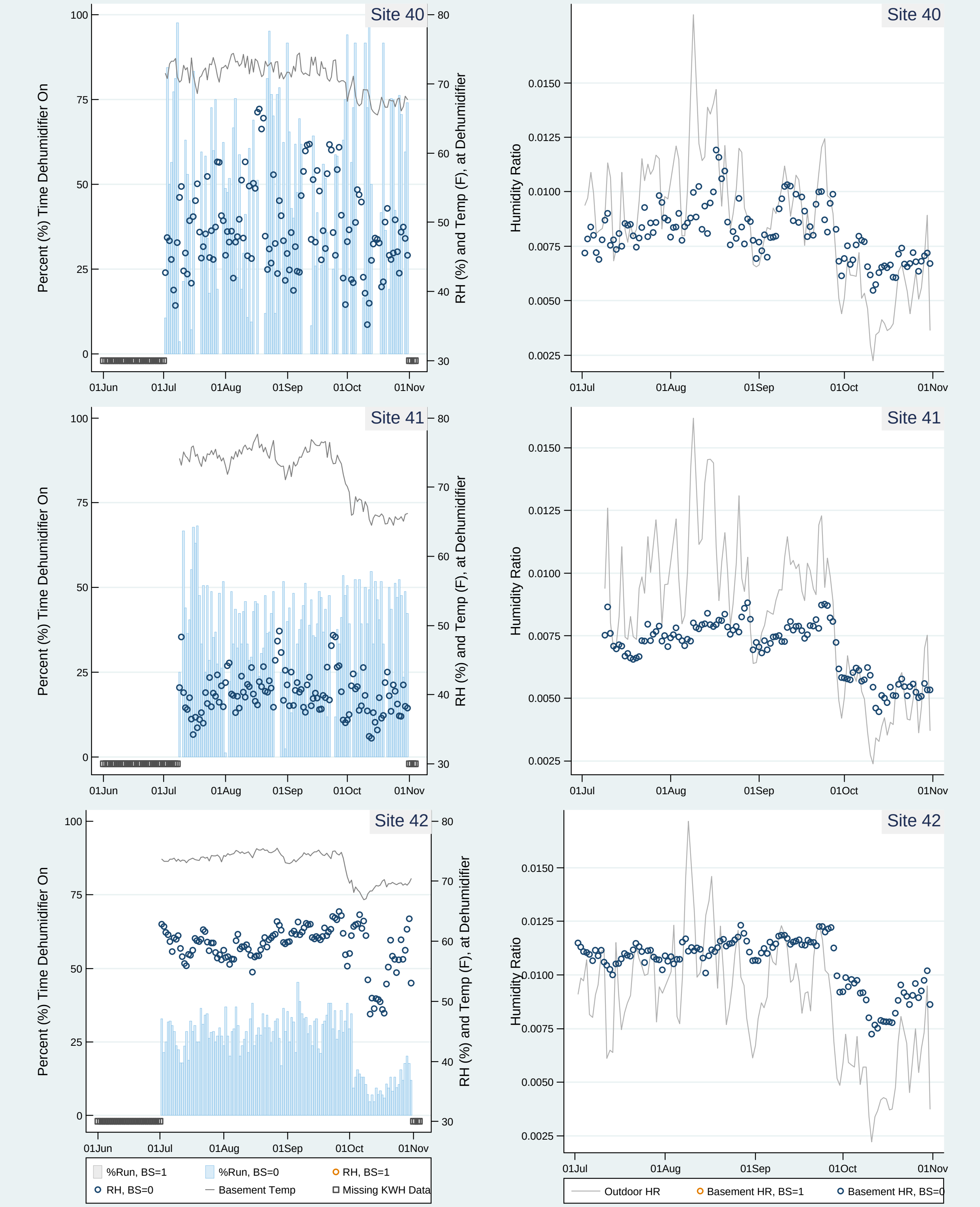

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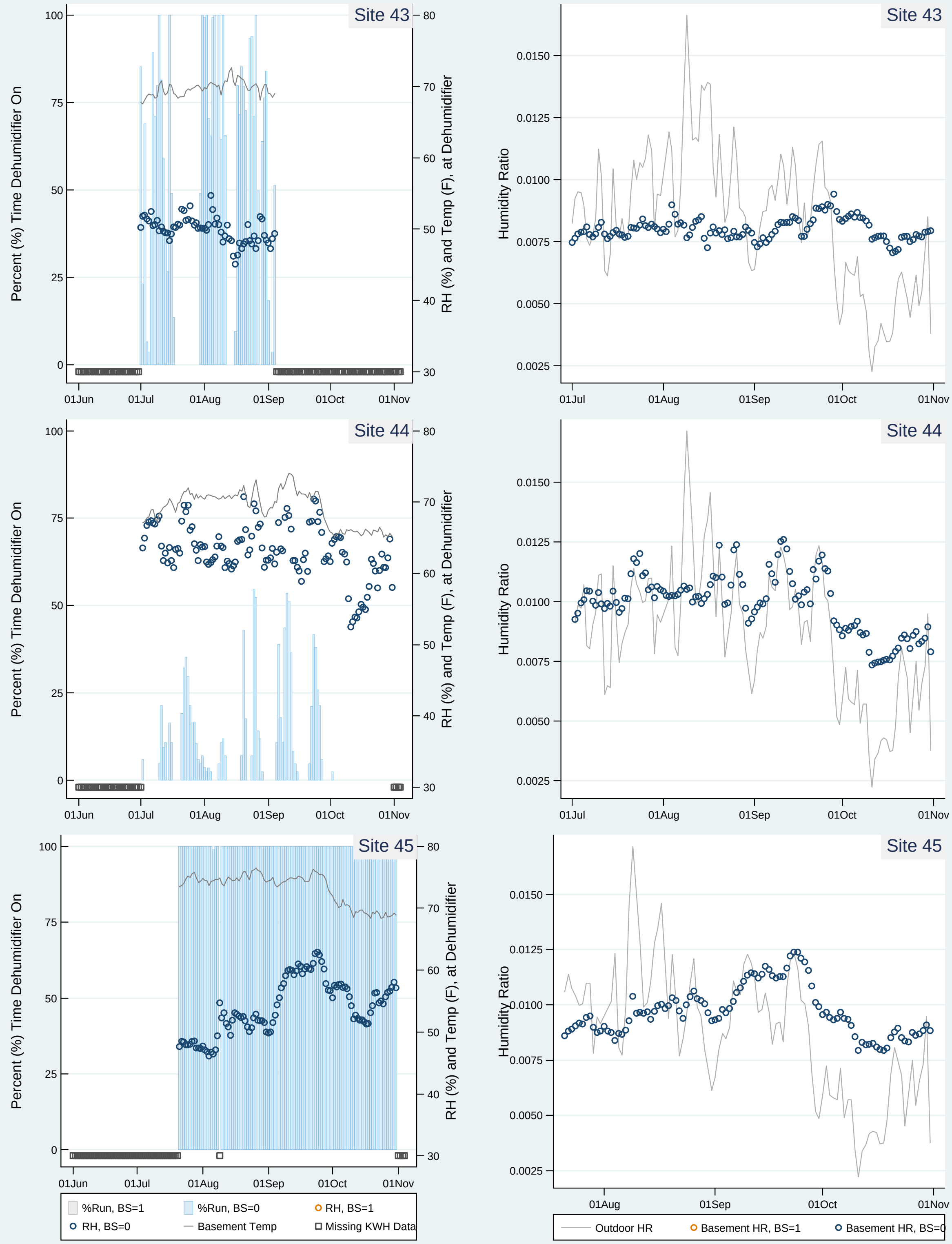

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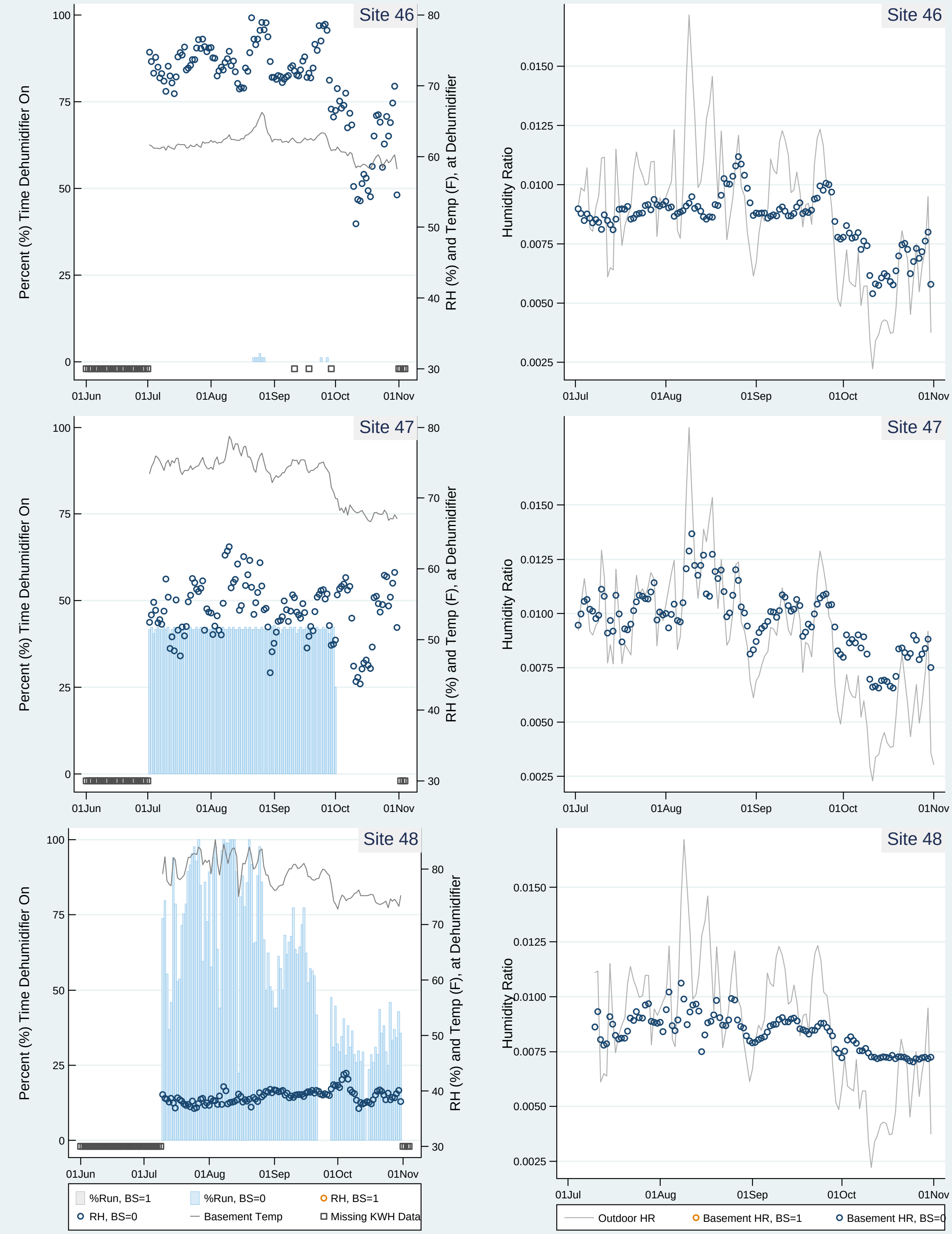

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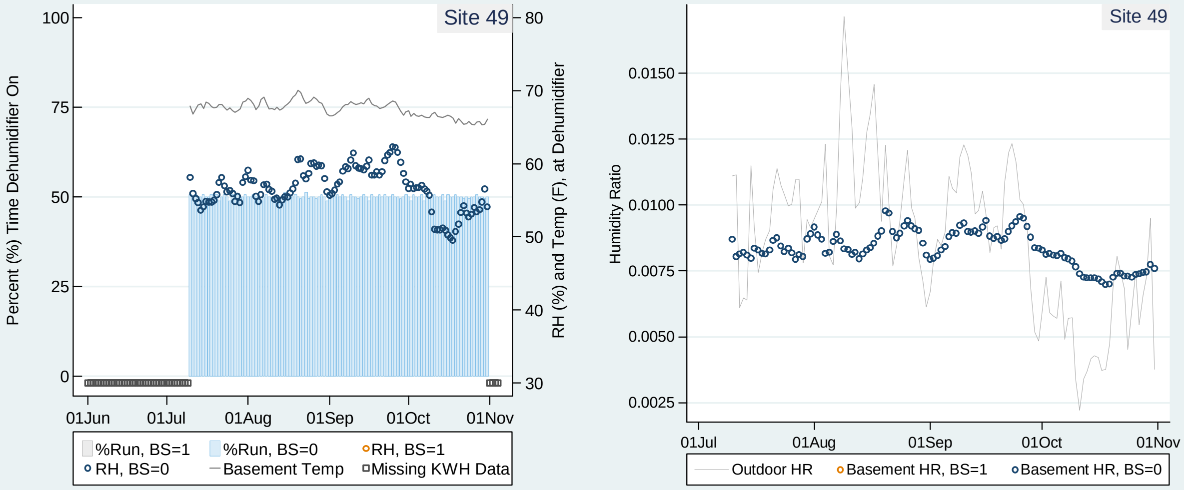

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