FOCUS ON ENERGY EERD REPORT:

Dehumidification in Wisconsin – Savings Opportunities, Program Potential, and Flexible Load Research

Center for Energy and Environment

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Executive Summary

The purpose of this project is to help Focus on Energy (Focus) identify potential savings opportunities from new, energy efficient standalone (portable) dehumidifiers for single-family basement applications and to explore the load flexibility and demand savings of these units via testing curtailment during peak load conditions. The project conducted research and analysis in four areas:

I. Energy Efficiency Potential
II. Existing Program Review & Program Opportunities
III. Load-Flexible Dehumidifier Literature and Equipment Review
IV. Load-Flexible Dehumidifier Testing

General

Dehumidifiers play an important role in Wisconsin homes. By removing excess humidity in cool, below grade spaces they maintain comfort, indoor air quality, building health, and minimize the conditions which lead to microbial growth. They fill this niche at relatively low total cost compared to alternative strategies, but evolving efficiency standards enable newer units to meet these loads using significantly less electricity than older units.

Furthermore, the ENERGY STAR® rating program has been highly successful in the dehumidification market such that a large majority of available units are ENERGY STAR certified and this efficiency has no cost premium compared to lower efficiency models or previous ENERGY STAR standards.

However, dehumidification outcomes can be greatly improved by cost-effectively retiring old units and following basic guidance. Survey work has identified that one common source of older standalone dehumidifier units is through a hand-me-down process, whereby a unit replaced by an energy efficient model continues to operate in another application, often a new load. Therefore, recognizing savings requires retiring units and removing them from service.

- Remove older (especially pre-ENERGY STAR 3) units from service.
- When replacing existing units, prefer smaller (≤ 30 pints/day) capacity units unless loads are consistently greater than 10 pints/day.
- Encourage ENERGY STAR 5-unit replacements; there are no cost savings by purchasing minimum efficiency units.
- Set up units to automatically drain where possible to maintain better humidity control and improve quality of life.
- Measure relative humidity levels using remote hygrometers to connect notions of basement relative humidity with measured levels.
- Relative humidity levels should be set at 50 - 55% and increased or decreased based on specific needs.
- For retrofit measures, deemed savings vary between 343 kWh/yr and 566 kWh/yr based on size and efficiency. The most likely deemed savings value is 343 kWh/yr.
- For replace on fail measures, deemed savings vary between 37 kWh/yr and 331 kWh/yr. The most likely deemed savings value is 88 kWh/yr.

New Program Opportunities

It was expected that the existing Appliance Recycling Program from Focus could be extended to include dehumidifiers as addons, as allowed in other jurisdictions. However, that program has ended due to an undesirable cost effectiveness. CEE recommends exploring new program opportunities that can overcome cost effectiveness limitations of the previous appliance recycling program by using existing community events to lower the costs of dehumidifier recycling. These programs can leverage or extend community engagement by educating consumers on dehumidifier savings potential and the importance of recycling existing units, as well as providing them with recommendations that improve dehumidification outcomes and improve quality of life. Four alternative program options were identified. All can be explored concurrently by Focus, but we highlight Option 2 here:

- Community Clean Sweeps, Appliances and Electronics collection days, Dumpster Days, among others, provide an opportunity to build on existing engagement platforms to recycle dehumidifiers, educate consumers on basement dehumidification, and tie incentives for energy efficient units to recycling old units. This should help reduce the cost barriers associated with individual pickups and improve cost-efficiency by partnering with existing community events.

Load Flexibility

This research investigated existing work on controlling plug loads, identified currently available equipment to remotely control dehumidifiers, and field tested a subset of this equipment to understand whether dehumidifiers could be remotely curtailed for peak load control and its consequences on indoor humidity levels.

- Measured results show that dehumidifier operation is very reliably controlled and completely curtailed during simulated four-hour load flexibility events.
- The smallest, most efficient units use about 280 W of electricity and have coincidence factors of about 65%, suggesting that >180 W/unit of peak load shedding resource is available.
- Furthermore, there is little consequence to indoor humidity levels due to this disruption of regular operation. At the 6 sites in this study, existing relative humidity setpoints were recovered in less than 5 hours of post-event operation.
- Suitability of these off-the-shelf controls for peak load programs is mixed. Plug load and timer-based controls lack verification ability; however, smart dehumidifier and smart thermostat controls may be low-effort additions to existing smart thermostat peak control programs, especially if pressure is placed on manufacturers by utilities and load aggregators to provide this functionality.

Key Takeaways

Standalone dehumidifiers represent strong energy efficiency savings potential for Focus

Average savings of 343 kWh or higher can be expected from relatively simple swap outs of existing dehumidifiers for new ENERGY STAR 5 rated units. Caveat: Old units must be retired to guarantee savings.

While program design is challenging due to resource constraints, community-based programs merit consideration

Programs that verify retirement of existing dehumidifier are key to savings; community-based approaches that can accumulate many old dehumidifiers for simultaneous recycling will target cost barriers troubling conventional appliance recycling programs plus they enable additional engagement with customers on energy use and dehumidification best practices. Additionally, community focused efforts are aligned with Focus's strategic interests.

There are added load management benefits to be realized alongside energy efficiency savings

Standalone dehumidifiers are high energy use plug loads. They consume moderate power, but devices run extensively during peak residential load periods. This research has shown dehumidifiers can be reliably interrupted via remote control to affect appreciable demand savings. The effort to integrate smart dehumidifiers into existing load management programs, especially for manufacturers already active in this space, seems especially low. It may be a reliable and unobtrusive way to expand load management programs by activating an additional 180W+ of demand savings per unit on top of anticipated energy savings when replacing old units. While load management benefits primarily accrue to utility partners, these EE/DR partnerships are important to Focus and play an important role in the macro policy decisions in Focus quadrennial planning.

Introduction

Background

Dehumidification loads occur from the natural entry of moisture through a home's shell envelope. Moisture can also be generated inside the home from occupancy (respiration) or from building services such as domestic hot water use or cooking. Natural moisture sources bring moisture into the home via air movement (infiltration) or via liquid water entry through cracks or diffusion through below grade building materials. These natural moisture sources vary seasonally. Depending on temperatures and comfort levels, indoor air is usually between about 0.7% to 1% water. Typically, in north midwestern climates, outdoor air moisture exceeds desired indoor levels beginning in the beginning of May through the end of September. During this time, air exchange with the outside environment adds moisture to conditioned spaces and increases indoor humidity levels.

Dehumidifiers typically operate to remove moisture during this period of the year to maintain a desired indoor relative humidity level. The most common dehumidification technology and the subject of this study are the refrigerant-based systems that operate on the same vapor compression cycle as air conditioners (ACs) and refrigerators. Whereas refrigerators and AC systems move heat from one heat exchanger to another, dehumidifiers have co-located heat exchangers. Humid air passes through the first heat exchanger (evaporator) and water condenses on the cold surface, which drains from the unit. The heat from the evaporator dissipates in the second heat exchanger (condenser). The dry, cool air immediately passes through this heat exchanger, and the air stream warms back up over its original temperature. The overall effect is that a humid air stream enters the dehumidifier and a dried heated air stream exits the device. This configuration enables dehumidifiers to control humidity levels without cooling the space.

In the Midwest, below grade spaces tend to be cooler than above grade spaces due to ground coupling. Lower temperatures in basement spaces yield higher relative humidity levels for the same absolute moisture level. High humidity levels lead to discomfort, microbial growth, and potential deterioration of building materials and personal property. Standalone dehumidifiers, also known as portable dehumidifiers, are the primary consumer-level devices used to control moisture levels in these spaces.

Dehumidifiers are a higher percentage of total energy use than most other household appliances. They are usually run during the humid time of year (late spring through fall in the Upper Midwest U.S.) Today's most efficient dehumidifiers use about 280 to 300W to remove up to 20 to 22 pints of moisture per day in a typical basement environment. Larger units, and nearly all older dehumidifier units use more power. However, field measurements have shown that most units, even today's smallest, tend to have excess capacity in that they do not run 100% of the time during peak dehumidification season. This suggests an opportunity to control when dehumidifiers operate with minimum impact. Controlling dehumidifiers to limit their use during peak load events is a promising way to reduce demand during peak load events.

Dehumidifiers are rated according to their moisture removal capacity (Pints/day) and their efficiency (Energy Factor or Integrated Energy Factor) (L/kWh). Standalone dehumidifier capacities typically range between 20 - 95 pints/day. They are subject to two efficiency standards, the federal minimum appliance standards (Table 1) and the Energy Star program (Table 2). Some units will refer to Energy Factors as the Energy Efficiency Verification (EEV).

Table 1: Federal minimum efficiency standards for standalone vapor compression dehumidifiers

Effective Date (Month/Year)	Max Capacity (Pints/day)	Minimum Energy Factor (L/kWh)
10/2012	35	1.35
10/2012	45	1.5
10/2012	54	1.6
10/2012	75	1.7
10/2012	>75	2.5
06/2019	25	1.3*
06/2019	50	1.6*
06/2019	>50	2.8*

* Integrated Energy Factor (IEF) replaces Energy Factor (EF)

Table 2: Energy Star energy efficiency standards for standalone dehumidifiers

Version	Effective Date (Month/Year)	Max Capacity (Pints/day)	Minimum Energy Factor (L/kWh)
ES 1	01/2001	10	1.20
ES 1	01/2001	25	1.30
ES 1	01/2001	>35	1.50
ES 2	10/2006	25	1.20
ES 2	10/2006	35	1.40
ES 2	10/2006	45	1.50
ES 2	10/2006	54	1.60
ES 2	10/2006	>75	1.60 - 1.8 (Tier 1, 2)
ES 2.1	06/2008	74	1.60 - 1.8 (Tier 1 ,2, 3)
ES 2.1	06/2008	185	2.5 (Tier 1, 2)
ES 3	10/2012	75	1.85

Version	Effective Date (Month/Year)	Max Capacity (Pints/day)	Minimum Energy Factor (L/kWh)
ES 3	10/2012	>75	2.8
ES 4	10/2016	75	2.00
ES 4	10/2016	185	2.8
ES 5	10/2019	25	1.57*
ES 5	10/2019	50	1.8*
ES 5	10/2019	>50	3.3*

* Integrated Energy Factor (IEF) replaces Energy Factor (EF)

Both standards have been subject to changes over the years, resulting in a confusing landscape of overlapping performance metrics. Congress established an initial Federal Minimum Efficiency standard for dehumidifiers as part of the Energy Policy Act of 2005 and updated those standards in the Energy Independence and Security Act (EISA) of 2007. This standard specifies the testing methodology to determine the Energy Factor (EF). Units with higher values of energy factor are more energy efficient. In 2016, DOE finalized new standards for dehumidifiers, which took effect in 2019. The most recent revision modifies the Energy Factor to consider fan and standby power alongside steady state cycle energy. The new metric is called the Integrated Energy Factor (IEF). The testing conditions also changed under the new standard. Previously, dehumidifiers were tested at an ambient temperature of 80 °F and 60% RH. The new standard reports IEF at 65 °F and 60% RH, which better reflects typical operating conditions in the Upper Midwest single family basements.

The ENERGY STAR program has evolved to identify and promote energy efficient options. ENERGY STAR has undergone six iterations since 2001. While ENERGY STAR classifications have improved over the years, the various standards themselves are cause for confusion as the capacity requirements have changed and the branding does not typically reference the version of the ENERGY STAR standard. Furthermore, many qualified units have no ENERGY STAR branding meaning there are more ENERGY STAR eligible models than those model numbers listed on the ENERGY STAR website.

The initial ENERGY STAR 5 units available are ENERGY STAR 4 units de-rated on capacity and energy factor; this is often reflected by documentation that still cites their ENERGY STAR 4 ratings. For example, 30 pint units under ENERGY STAR 4 are now 22 pint units under ENERGY STAR 5. Similarly, their performance requirement decreases by 30% from 2.0 L/kWh to 1.57 L/kWh. About 2% of this change is due to the inclusion of fan and standby energy, while the remainder reflects performance at the new operating condition (65°F / 60% RH). As time passes under the new standard, more units designed for ENERGY STAR 5 are coming to market.

Justification

Dehumidifiers are common household appliances in single-family homes. Penetration levels we have observed in prior work are approximately 55% to 66% in Upper Midwestern single-family homes [1]. They are typically used to remove moisture from the air in below-grade spaces (i.e., basements). They can also consume a significant amount of energy, up to 2,000 kWh annually — in many cases this is the largest plug load, if not the largest end use, in the home. Individual units draw as much as 800W while running and they cycle on and off continuously to maintain humidity settings. Their diurnal loads are highly flexible and suitable for scheduling to optimize grid benefits without loss of homeowner comfort. However, no programs exist to achieve this and they contribute significantly to summer peak loads.

Efficiency standards set minimum values for this metric based on size and application, and they have evolved greatly over the past 20 years. The fifth iteration of the ENERGY STAR program was launched in late 2019 — it's the first efficiency standard to consider dehumidifier operation in basement spaces, where most Midwestern units operate. While the efficiency standards have continuously evolved, most dehumidifiers in the field pre-date the newest versions and many pre-date them entirely. Our research shows that 20, 30, and even 40-year-old units remain in use [1]. The combined effect is that the installed base has very low efficiency, potentially less than one-half of that of state-of-the-art units.4 In other words, single-family dehumidification loads may be met using less than half the current energy and operating costs. Further, we hypothesize that much of this energy use can be shifted away from peak system loads when necessary.

Over the last few years, several manufacturers have released smart dehumidifier models that feature such as Wi-Fi control or integration with smart speakers and home energy systems. In all cases, these units have been rated to the most recent ENERGY STAR standard, but there are no ENERGY STAR requirements for these features. This hardware is the basic requirement to enable software-based remote controls, such as those commonly found in smart thermostats. Further, other internet of things (IoT) devices that enable this functionality, such as smart plugs, continue to evolve. On the surface, this functionality is an opportunity to implement cost-effective remote control during peak load periods. However, there remain practical questions about this application, the suitability of existing control options, participation and savings measurement and verification, coincidence with peak load conditions, and consequences for indoor humidity levels if humidity-based control is superseded by load control events or a load shifting schedule.

Research Objectives

The fundamental question we seek to answer is if and how Focus on Energy (Focus) can take advantage of the remote-control hardware on dehumidifiers to create a combined energy efficiency and load shaping offering. Our research suggests that the energy efficiency and load control potential from dehumidifiers is high and that Wi-Fi controls and other models can offer a low-cost method to capture load shaping potential. This load shaping potential represents an added value stream for participating utilities that could further justify and help fund Focus program investments, as dehumidifiers are currently a gap in Focus's portfolio. Specifically, we seek to help Focus answer the following questions:

Objective 1: What is the energy efficiency potential of the existing fleet of dehumidifiers compared to the new energy efficiency standards that took effect in 2019 (Federal Minimum Efficiency Testing Standard and ENERGY STAR v5.0)?

Objective 2: What controls or strategies are available and most effective for remote dehumidifier control?

Objective 3: What are the potential demand savings from controlled dehumidifiers?

Objective 4: What are the impacts on performance, comfort, and building health when remotely controlling standalone dehumidifiers in Wisconsin homes?

Focus EERD Dehumidifier Research

Energy Savings from Energy Efficient Dehumidifiers

This study developed two TRM workpapers for standalone dehumidifiers and also consulted on the dehumidifier measure for the 2020 Focus on Energy Potential Study. Deemed savings values were developed based on field measurements from single-family basement dehumidifier use in Minnesota during the 2018-2019 seasons [1]. That work carefully selected 20 sites chosen to statistically represent dehumidification applications in Upper Midwest single-family homes. Dehumidifiers and ambient conditions were monitored at those sites for two years and multiple interventions were performed (including installing new energy efficient dehumidifiers) to estimate savings and cost effectiveness. These TRM measures cover replace-on-fail and retrofit opportunities based off those measurements.

- For retrofit measures, deemed savings vary between 343 kWh/yr and 566 kWh/yr based on size and efficiency. The most likely deemed savings value is 343 kWh/yr.
- For replace on fail measures, deemed savings vary between 37 kWh/yr and 331 kWh/yr. The most likely deemed savings value is 88 kWh/yr.
- In addition to deemed savings, both TRM measures provide normalized curve fit parameters which can be used to compare dehumidifiers rated to different standards or give customized savings estimates for a particular dehumidification use case.

Retrofit measures see significantly higher average savings due to the large number of old and inefficient units in operation. In contrast, replace-on-fail measures see relatively small savings due to relatively high federal minimum efficiency standards that went into effect in 2019.

Additionally, savings will vary across the population according to the specific unit and application. The most important factor is the unit's age and existing energy factor rating. Relatively little savings are available from dehumidifiers built after 2012 or adhering to ENERGY STAR 3+ standards. The majority of savings will be found on older units that adhere to older ENERGY STAR standards, unrated units, and those units over 20 years old.

The second most important factor will be application specific. For example, homes with very high dehumidification loads or aggressive setpoints (<45%) will see very long runtimes and higher annual savings by switching to more efficient units. Whereas easy savings are possible through education efforts that advocate for higher setpoints (50%), predicting dehumidification load is not reliable without time consuming measurements.

The above savings estimates take these factors and others into account and should yield reliable savings estimates that are possible when ENERGY STAR 4, ENERGY STAR 5, and higher efficiency dehumidifier units replace existing units in basement applications in Upper Midwestern single-family homes.

Existing Program Models

Refrigerator and freezer harvesting programs are common and have been implemented by many different utilities across the country. In these programs, customers typically schedule a free pick-up for their working refrigerator or freezer and receive an incentive for it. For some of these programs, dehumidifiers and room air conditioners, which must also be in working condition, can be picked up at the same time for a smaller incentive, however, they must be picked up with a refrigerator or freezer to qualify. This approach takes advantage of both the existing appliance pick-up infrastructure and program savings. It captures savings from those that may be unable to move the appliance or who may otherwise find use for it in a different application.

Focus offered an Appliance Recycling Program that provided a free pick-up and a $20 incentive to retire an old, working refrigerator or freezer. This program stopped scheduling new pick-up appointments ending December 15, 2020 and shut down completely on January 22, 2021.

In 2019, a total of 9,627 participants participated in the Appliance Recycling Program and a total of 10,124 appliances were recycled. Table 3 shows total program cost and savings from 2019 for Focus's Appliance Recycling Program.

Table 3: Focus on Energy's Appliance Recycling Program Cost and Benefits (2019)

Costs	
Administration cost	$0
Delivery costs	$1,119,630
Incremental measure costs	$506,893
Incentive costs	$218,725
Total non-incentive cost	$1,626,523
Savings and Benefits	
Verified Gross Per-Unit Energy Savings	783 kWh/year
Cost effectiveness TRC B/C Ratio	1.31

Similar recycling programs are offered by other utilities across the Midwest. In Minnesota, Xcel Energy's Refrigerator Recycling program offers free pick-up for a working refrigerator or freezer. Customers can schedule a pick-up online or by phone. For each working unit recycled, customers will receive a $50 check in the mail with a limit of two per year.

In Illinois, Commonwealth Edison's Fridge and Freezer Recycling program offered a free pick-up of working refrigerators and freezers. However, Commonwealth Edison (ComEd) recently ended this offering in March 2020. While active, customers received a $50 rebate for their appliance. Ameren currently offers a similar refrigerator and freezer recycling program to their residential electrical customers. Customers can schedule a free pick-up online or by phone. The refrigerator or freezer to be recycled must be standard size and in working condition to be eligible. Their program states customers will receive a $50 rebate within six weeks of pick-up.

Likewise, in Michigan, Consumers Energy's Appliance Recycling Rebates program offers free pick-ups for standard size, working refrigerators or freezers. Other eligible items are working room air conditioners or dehumidifiers, which must be picked-up at the same time as the larger appliances. Customers will receive $50 for each eligible refrigerator or freezer and $15 for each eligible room air conditioner or dehumidifier. Customers are limited to recycling two large appliances and four small appliances per year.

Data on program costs and savings from these appliance recycling programs are shown in Table 4.

Table 4: Appliance recycling program costs (2019)

Utility	Overall costs	Program Delivery Costs	Total number of units	Gross Savings (per unit)
Xcel Energy (MN)	$844,287	$485,652	6,000 refrigerators 110 dehumidifiers	743 kWh
ComEd (IL)	$8,596,087	NA	51,822 total units 40,543 refrigerators 2,286 dehumidifiers	790 kWh
Consumers Energy (MI) (2018 data)	$5,127,315	NA	19,996 refrigerators 5,278 freezers 1,560 dehumidifiers 1,306 room ACs	1,135 kWh (refrigerators) 944 kWh (freezers) 139 kWh (dehumidifiers) 113 kWh (room ACs)
Ameren (IL)	$1,637,563	$1,285,657	5,422 total units 4,196 refrigerators 1,226 freezers	966 kWh (refrigerators) 893 kWh (freezers)

Review of existing appliance recycling programs indicates that dehumidifier savings alone are too low to justify pickup. However, it is fairly common to include them as add-ons with large recycling programs. Nonetheless recent closure of large appliance recycling programs in Focus territory as well as ComEd demonstrates the difficulties in cost effectiveness with this program model even when savings are 2 to 5 times higher than is possible on average from standalone dehumidifier recycling. Hence it appears unlikely that individual dehumidifier recycling is a viable program model.

Alternative Program Models

We estimate about 343 kWh on average savings when retiring an old dehumidifier model and upgrading to a newer, more efficient model. Appliances, including dehumidifiers, are banned from landfills and incinerators in Wisconsin so retirement through official channels should be encouraged to prevent 1) illegal dumping and 2) use in a different application, or 3) long term storage that may lead to refrigerant release. As previously demonstrated, existing utility appliance recycling programs are commonly targeted towards larger appliances such as refrigerators and freezers. Some recycling programs are willing to pick up a dehumidifier, but only as an add-on to a larger appliance pick-up. This limitation makes the traditional appliance harvesting, specifically the pick-up approach, challenging to make cost effective for retiring old dehumidifiers. A cheaper program alternative designed specifically to retire old dehumidifiers is needed. Below are some possible program alternatives to consider.

Option 1: Leverage county or local government drop-off sites

We identified over 150 waste sites and businesses throughout Wisconsin that accept dehumidifiers. Most sites charge a per-unit fee to drop off an appliance, with fees ranging from $5 to $30. Most sites identified are county-operated waste sites and available to residents within a certain town or municipality. However, residents from outside the area can use the site for an additional cost. We also searched for recycling businesses within counties that accept dehumidifiers. These businesses include salvage yards that will pay customers for old dehumidifiers, with the intention of reselling them, scrapping them for parts, or recycling them if nothing else can done. Most of the identified sites are drop-off only, with a few exceptions that offer pick-ups for an additional fee. See Appendix A for a for a complete list and map of these locations as well as their published recycling fees.

With drop-off disposal fees ranging from $5 to $30, consider collaborating with county-operated waste sites to subsidize the cost of or incentivizing the dropping off a dehumidifier. This approach benefits from local and county infrastructure aimed at keeping these appliances out of landfills and the relatively higher ease of transportation of a dehumidifier compared to a refrigerator or freezer. To make this partnership more effective, vouchers or rebates for new, ENERGY STAR dehumidifiers could be offered for each recycled unit and marketing assistance could be provided to the county.

Option 2: Leverage community events

Many Wisconsin counties, townships, and municipalities host an organized community clean-up event once or twice a year. There are community Clean Sweeps, Appliances and Electronics collection days, Dumpster Days, among others. The department organizing the event, the Department of Recycling or Department of Solid Waste, outsources to vendors who are certified with the WI DNR to haul and dispose of electronics, including appliances containing refrigerants. The event is held in a central location and residents can haul their items to the location during operating hours. If there is a fee to dispose of an item, for example if it costs $40 to throw away a refrigerator, residents are responsible for that charge. The department organizes and advertises the event, and the event is staffed by volunteers.

We spoke with two Wisconsin county staff to learn more about their events, including cost, challenges, and success. One county staff shared that there is a fee to hire the external vendor. However, this county received funding from the WI Department of Agriculture, Trade and Consumer Protection (DATCP), which was used to cover some of the vendor cost. Both reported that there is taxpayer money that goes into funding some of the event costs, such as advertisement cost. When asked about challenges, staff said hosting the event once or twice a year only makes it challenging for residents to participate. Another challenge is to find volunteers to staff the event. However, both said that the events were successful and well-attended.

Residential dehumidifiers are small and relatively easy to haul (<50 lbs). Hosting a similar type of community event in a central location may be effective. One of the sites we spoke with expressed interest in the possibility of collaborating with Focus to provide vouchers or rebates for residents when they drop off an old model. The second site said they would need to discuss the opportunity with their committee to determine the financial feasibility of participating in this program.

In a similar fashion to Option 1, this approach takes advantage of existing community offerings. Consider partnering with community event organizers and vendors to facilitate the ease of drop-off of inefficient dehumidifiers by reducing the cost barrier. While targeting savings from retiring old dehumidifiers, this approach could also serve to bridge any gap left over by the previous Appliance Recycling Program. While aimed at community solid waste reduction, one site spoke about how vital they thought these events were in regard to community education about waste reduction. This could easily be paired with community outreach and education for other energy or waste-related programs. To address the cost challenges marketing assistance could be provided, for both the event and the volunteers that run the event.

Option 3: Community curbside pickup

Transportation and scheduling conflicts are possible barriers and challenges to residents' participation in community events or transporting an appliance to a waste site. To mitigate barriers, an alternative is to organize a community curbside pickup event. Residents can place their old dehumidifiers at the curb by a certain time, attach a flyer to the dehumidifier to indicate ownership of the appliance and to confirm their address, and a truck will drive through the neighborhoods to pick up the dehumidifiers and collect the flyers. An incentive or discount voucher will be mailed to the resident. The dehumidifiers will then be transported to a waste site. The vendor in charge of picking up and hauling the dehumidifiers must be certified with the WI DNR to safely transport this appliance. We also asked county staff whether their departments would be interested in the possibility of collaborating or co-hosting with Focus on this option. Both county staff responded positively.

Option 4: Include dehumidifiers as an eligible item for pick-up through Focus's Appliance Recycling Program

While Focus's Appliance Recycling Program ended during the course of this study, this recommendation is included for posterity. Focus's Appliance Recycling Program offered a $20 incentive and free pick-up for working refrigerators and freezers to encourage responsible recycling. Eligibility required standard size refrigerators and freezers in working condition, participants' utility must participate in Focus on Energy, and participants must reside in single-family housing units or multifamily houses with less than four units. The program allowed for two appliances to be recycled per household each year. The incentive check was mailed to participants within four to six weeks of pick-up.

As stated in the Existing Program Models section of this report, this program ended in early 2021. However, if Focus decides to bring the program back, dehumidifiers should be included as an eligible item for pick-up with a small incentive offered. Picking up a dehumidifier in addition to a larger appliance may not increase the overall program cost, with the exception of the small incentive for the dehumidifier. However, it is estimated that only 15% of existing program participants[1] also have a dehumidifier, in addition to a larger appliance, that needs to be recycled. Therefore, we do not recommend picking up a dehumidifier without a larger appliance as it is not likely to be cost-effective.

Cost Effectiveness

The cost benefit ratio of the now retired Focus Appliance Recycling Program was 1.31 (from the program administrator perspective) in 2019, somewhat below their residential portfolio average of 1.7 but still positive. This breaks down to $0.46/kWh and $0.22/kW respectively. After reviewing the proposed options, we have made preliminary estimates of cost effectiveness for the Community pickup approach (Options 2) and Appliance Recycling Addon (Option 4). These options are compared with the existing Appliance Recycling Program and Residential Portfolio in Table 5. The community approaches compare favorably to the existing appliance recycling program, perhaps matching the overall residential portfolio cost effectiveness. The improved cost effectiveness here comes from the community drop off; labor and transit costs are essentially offloaded onto residential customers who are responsible for bringing units to a central location. Hiring a local vendor to make a single trip for collection and disposal of many units (e.g. 30+) substantially increases the cost effectiveness compared to individual pickups. On the other hand, including dehumidifiers into the existing appliance recycling program also offers an improvement in cost effectiveness. While only 15% of appliance pickups are estimated to include a dehumidifier, the increased effort and cost for adding a is low for the additional 343 kWh savings,.

Table 5: Dehumidifier recycling cost comparisons

Cost effectiveness	Program Cost	Program Benefit	Cost per kWh
Residential Portfolio	$36,704,651	170,669,058 kWh*	$0.22/kWh
Appliance Recycling Program	$1,626,523	3,560,424 kWh	$0.46/kWh
Option 2: Community Approach (at least 30 units)	$30 incentive and $30 marketing help per unit	343 kWh per unit	$0.23/kWh - $0.27/kWh
Option 4: Pick-up Add-on Approach	$1,626,523	4,055,733 kWh**	$0.40/kWh

*Focus on Energy's 2019 MMBtu savings in kWh

**Approximately 15% of Appliance pick-ups would include an old dehumidifier

Program Recommendations

The program alternatives can be piloted concurrently or in a hybrid fashion pending available opportunities. We recommend starting in communities that express interest, have existing community-based energy or waste-program engagement, and ideally have access to other funding sources. These experiences may help streamline these approaches and increase willingness to participate and engagement by other communities. Having a baseline understanding of what a community needs will

[1] Estimated from 2018 Consumers Energy Program Data (Table 4), whereby dehumidifiers could only be included alongside larger appliances.

help with selecting the most fitting program alternative and allow the program to reach its full potential in capturing and retiring old dehumidifiers. Some communities may need or benefit from considering a hybrid of these three program models, depending on their existing community efforts.

Further, getting residents to participate in program initiatives is key. It may be beneficial to provide educational information on the importance of savings potential of retiring old dehumidifier models. Educational efforts can include informational flyers, community events, or an informational YouTube video and can include helpful consumer recommendations (Appendix B) on dehumidifier purchasing, operation, savings, and troubleshooting.

Dehumidifier Load Flexibility

In this section we will cover possible ways of controlling residential standalone (portable) dehumidifiers to curtail residential demand during peak load events. While the effect of load shaping control of air conditioners on humidity has been investigated, the same application has not been studied for dehumidifiers. This section will look at the direct effect of the relative humidity level in the house due to dehumidifier curtailment during peak load events.

Load Flexibility Objectives

The purpose of this project phase was to assess the flexibility of standalone dehumidifiers to respond to peak load shaping events. There were two research objectives of this work:

1. Demonstrate the ability of standalone dehumidifiers to provide load flexibility—either from a remote-control signal or by scheduling off-peak operation.
2. Understand how controlling dehumidifier operations impacts dehumidification efficacy and indoor relative humidity levels.

The first objective was to determine whether dehumidifiers could be reliably controlled to respond to simulated peak load events. This objective requires dehumidifiers to power off remotely or maintain an off-peak operating schedule. This functionality could be provided by the dehumidifier itself or from a third-party controller such as a smart thermostat or a smart plug. These three options were investigated in the field.

The second objective was to understand the impacts of dehumidifier control on indoor humidity levels. Dehumidifiers are typically controlled and operated according to an onboard humidistat. When local relative humidity levels exceed the setpoint, the unit will run (typically with a minimum cycle time of 3 minutes). When the setpoint is reached, the compressor will shut off and the blower will clear remaining humidity off the heat exchanger (typically for 3 minutes). This natural operation will be disrupted by the implementation of remote control or scheduling.

Literature Review

We reviewed literature on load shaping work that emphasizes residential plug load systems, and some relevant findings are discussed below. The review for this paper was focused on the control of plug loads, specifically window AC units and standalone dehumidifiers. Various devices can be used to communicate and control household appliances. Multiple terms are used to describe these devices. Home energy management system (HEMs) products can include smart plugs and smart thermostats, whereas advanced plug load management devices (APMDs) include communicating smart plugs and advanced power strips. These systems also allow third parties or utilities to control and schedule plug loads.

Most recent applicable research on plug load control is due to the proliferation of relatively low-cost technology over the past decade. This technology has allowed for real-time communication between plug load devices (or HEMs gateways) and external entities (e.g. program implementers and utilities). Prior work investigated HEMs used for peak load control [2], peak load program design and management for plug loads [3,4,5], and residential dehumidifier energy use [6]. Other topics include barriers to plug load Demand Response (DR) [6,7], incentive structures for automated DR equipment [3], and plug load saturation and load shape data [2,7].

Lamoureux et al. [2] investigated the control of plug loads via smart plugs in a multistate study in the Northeast. They used smart plugs on HVAC systems, electronics, pool pumps, as well as standalone dehumidifiers. They found that dehumidifiers were high-energy appliances, second only to pool pumps in their consumption, averaging between 2 and 8.4 kWh/day. Subsequently, controlling dehumidifiers during peak loads showed a greater potential for savings than most other home appliances. The authors suggested that program designs should consider only turning off units if the targeted humidity was met, in order to maintain a certain humidity level. By including coaching for some of the customers, they were able to increase customer engagement. That said, they found homeowners generally do not want to do the scheduling, so a more effective program will minimize those requirements. Thus, they advised program implementers to include professional installation and device programming, scheduling and/or controlling. They did not address how humidity was affected via remote control. Additionally, they noted that use of continuous draining helps to maximize the benefits of using a dehumidifier.

Bickel et al. [4] investigated the potential for energy savings of various plug-load devices and appliances using smart plugs and power strips. They also reviewed various smart plugs available at the time. According to their research dehumidifiers ranked eighth out of 23 for savings potential for miscellaneous electrical loads in U.S. annual residential site electricity consumption in 2015 [8]. The study did not control dehumidifiers to reduce peak load or investigate the impacts to indoor humidity levels. They presented barriers to adoption by electric utilities of smart plugs and similar devices that include lack of awareness of what products are available and lack of functionality, citing rapid technological change. Additional barriers noted were uncertainty in savings and consistency of advanced plug load management device performance. They also concluded that more field work and data were necessary to quantify savings and set incentive levels.

Overall, existing research into peak load control of standalone dehumidifiers is limited. Most of the research addressed peak plug load control for air conditioners and other plug loads. However, there is some relevant work that does present the potential for savings from plug load control of dehumidifiers [2,4,6]. The impact of dehumidifier control for peak load events on indoor humidity levels has not been investigated in previous research. Consequently, the field work proposed in the present study fills an important gap in the knowledge base.

Requirements for Controlling Dehumidifier Loads

Three critical requirements for load-flexible standalone dehumidifiers are as follows:

1. The main requirement is that dehumidifier loads can be properly shed in such a way that they can be verified by a third party. The dehumidifier must have the ability to be turned off or reduce power from an external signal or peak load event.
2. Unit must have the ability to successfully restart and retain device settings after event.
3. Control must not interfere with short-cycling prevention (compressor timeout).

Mainly these requirements establish that a dehumidifier can be curtailed during critical periods without impacting regular operations. Ideally, the dehumidification load can be met at another time, if necessary. Additionally, while not required, verification of the load reduction, for example via two-way communication with the device, will quantify and potentially guarantee the load reduction at both the device and aggregated resource levels, which may be important for program implementation.

Dehumidifier compressors are single-speed devices so the means of load reduction are limited. Two options are available; the easiest option is to turn the dehumidifier off during the duration of an event. A second option, requiring the device to be Wi-Fi enabled, could be to change the set point before and/or after an event to enable the device to coast (or cycle less frequently) during the event, thereby lowering average dehumidifier power. The latter option is similar to modern load shaping programs that use smart thermostat controls, whereas the former option is similar to older radio-based switching gear that cycles HVAC equipment. Additionally, whatever methods that are used should ideally be controllable and/or verifiable from the utility (or whatever entity that is offering rebate/service/discount).

Another requirement is that when restarted, the dehumidifier must retain its previous control settings such that third party timers or smart plugs do not impact regular operation. When activated, timers and smart plugs break the electric circuit to the dehumidifier, typically using a relay. When the circuit is reenergized, the dehumidifier must return to regular operation without operation interaction.

Lastly, most consumer-oriented dehumidifiers have a 3-minute fan-only mode proceeding a compressor cycle to prevent compressor short cycling and dry the condenser heat exchanger. Frequent interference with this by external controls may lead to excessive compressor wear and premature compressor failure.

Methodology

Recommended Controls

Several potential methods to affect standalone dehumidifier operation for peak load control were considered for use in this project. These general strategies are outlined in Table 6, including a description as well as a set of advantages and disadvantages of each control scheme. Strategies include direct control of connected Wi-Fi enabled standalone dehumidifiers (smart dehumidifiers), smart thermostats with the ability to control wired dehumidifiers, mechanical or digital timers, smart plugs (a Wi-Fi connected outlet that can control connected plug loads), and custom controls. With the exception of timers, each of these solutions requires internet connectivity and scheduling via a phone app. The expectation is that a successful program would issue commands directly to a connected unit such that a phone app and participant intervention are not necessary.

Table 6: Five potential strategies for controlling dehumidifiers

Strategy	Description	Advantages	Disadvantages
Smart dehumidifier	Standalone dehumidifier models equipped with Wi-Fi connectivity and remote scheduling	• Higher relative energy efficiency compared to older units • Potential integration with other smart thermostat DR offerings • Verification potential	• New dehumidifier required • High up-front cost • Poor consumer ratings

Strategy	Description	Advantages	Disadvantages
Smart thermostat	Wi-Fi connected thermostat that can control a wired dehumidifier	• Potential integration with other smart thermostat DR offerings •Verification potential	• Limited dehumidifier compatibility (whole home units)
Timer	A plug-based mechanical or digital timer with a set (peak-avoidance) schedule	• Low cost • Existing dehumidifier compatibility	• No compressor lockout • Lack of flexibility (fixed schedule) • No verification • Power disruption
Smart plug	Wi-Fi connected smart plug that can control power to a connected device	• Low cost • Existing dehumidifier compatibility	• No compressor lockout • No verification • Power disruption
Custom controller	Custom hardware & software to enable arbitrary control	• Enable any functionality • Existing dehumidifier compatibility	• Proof-of-concept for future development • Extensive development required

Smart Dehumidifier

Smart dehumidifiers, or connected dehumidifiers, enable scheduling and/or control via a Wi-Fi connection and the use of a phone app. Using the dehumidifier itself enables additional functionality such as changing setpoints and lack of interference with typical cycling operations. One key advantage is that some smart dehumidifier brands also have smart thermostat products, which potentially offers a relatively easy way to integrate smart dehumidifiers into existing load shaping programs. The major disadvantage of the smart dehumidifier is the large expense of a new dehumidifier.

Smart Thermostat

Smart thermostats are an established solution for enabling peak load control of connected HVAC devices. Products typically only work with dehumidifiers designed to accept hard-wired control, such as whole-house dehumidifiers. As with smart dehumidifiers, one major advantage is that the connected dehumidifier may be more easily exposed to existing utility load control programs that leverage the smart thermostat platform. Permanent wired control also enables a higher level of verification compared to plug-based control mechanisms. While their incidence is much lower than standalone units, whole-home dehumidifiers are also typically larger devices with higher peak load reduction potential compared to standalone units.

Timers

Simple mechanical or digital timers are another option to control dehumidifier operation during peak loads. These devices vary from simple analog devices to more sophisticated digital interfaces with built-in humidistats for specialty applications. The advantage of these units is that they are cheap. However, they have several disadvantages. They disrupt power which may interfere with dehumidifier settings and operation depending on the specific dehumidifier. They also may place the burden of scheduling on the homeowner. Lastly, they lack any potential for savings verification and can easily be disabled or circumvented without the knowledge of the program provider.

Smart Plug

Smart plugs are essentially a remotely operated switch that enable a dehumidifier to be controlled and scheduled remotely. They are a timer with remote connectivity. This functionality enables dehumidifiers to be scheduled off or on a fixed schedule or as needed in response to specific events. They also tend to be relatively low-cost devices, with some potential to link with existing load control platforms through a software platform. Some smart plugs can also measure power of connected devices, which may have some verification potential. The major disadvantage is the same as with timers; they disrupt power which may interfere with dehumidifier settings and operations depending on the specific dehumidifier. Lastly, depending on the model, they may be disabled or circumvented without the knowledge of the program provider.

Custom Controller

Custom controllers were considered, but ultimately rejected for this demonstration. While they may enable all desired functionality, the project budget does not allow for controls development. Furthermore, anything developed here would at best be proof-of-concept for additional development. It was instead decided that key research questions can be evaluated using off-the-shelf solutions. Project outcomes may then dictate whether this idea warrants additional attention.

Conclusion/Recommendations

The team settled on three strategies based on the goals of the project and budget considerations. This project deployed two smart dehumidifiers, used one existing smart thermostat to control a whole house dehumidifier, and three smart plugs to control existing dehumidifiers. These six applications enabled remote scheduling to simulate peak-load events. Smart thermostat and smart dehumidifier solutions also enable more sophisticated approaches that involve pre-conditioning by manipulating dehumidifier setpoints. Specific details of these approaches are outlined in the next section.

Testing protocol

Six sites were selected for field testing. Five sites used standalone dehumidifiers and one site used a whole-house dehumidifier ducted into the air distribution system and controlled via a smart thermostat. All the dehumidifiers were set up to continuously drain condensate and therefore required no user intervention. One site (#2) had previously been setup to be manually emptied before the project due to a clogged drain in the basement floor. Before we started testing, we set the dehumidifier up to drain into a working sink. The other five sites were already set-up to continuously drain.

Existing occupant preferences for relative humidity levels varied between 40% and 55%. One occupant set their level at 40%, one set it at 55%, and four set 50% relative humidity levels. Fan speeds were set to low or auto. These dehumidifier settings were maintained over the course of the testing, except for some simulated events where relative humidity setpoints were temporarily decreased to pre-dry before an event and temporarily increased during an event to promote, but not mandate, lower energy use.

Five sites had air conditioning systems, four of them with central air conditioning and one with a portable air conditioner. One site had no additional cooling or moisture removing devices. The air conditioning systems were not controlled or monitored in this study.

Temperature, relative humidity, and dehumidifier power were monitored at each site using sensors detailed in Table 7.

Table 7: Instrumentation details

Sensor Model	Sensor Type	Accuracy	Location
HOBO UX100-011A	Temp/RH	± 2.5%	Near thermostat
HOBO UX100-011A	Temp/RH	± 2.5%	Near dehumidifier
HOBO UX120-018	Plug Load	± 0.5%	Dehumidifier

Instrumentation setup and placement

Each site was equipped with two loggers that measure both temperature and relative humidity. One logger was placed next to the thermostat on the main floor of the house, as shown in Figure 1, while the other was placed within a few feet of the dehumidifier in the basement. In addition to the temperature and RH logger, each site had plug load logger. This logger, shown below in Figure 2, was plugged in series with dehumidifier. Figure 2 also shows how the smart plug was placed in series with the dehumidifier and plug load logger where applicable. This allowed the plug load logger to always have power and made sure the only device that was controlled by the smart plug was the dehumidifier.

Figure 1: Temperature/RH HOBO loggers next to main floor thermostats.

Figure 2: Plug load logger setup with dehumidifier and Wemo smart plug (site 6)

Chosen strategies and controls

Three control strategies used in the field tests are as shown in Table 9. Smart dehumidifiers were installed (Honeywell & Emerson) to displace older dehumidifiers at two sites. Three existing dehumidifiers were controlled using Kasa and Wemo smart plugs. One existing Honeywell smart thermostat was used to control an existing whole-house dehumidifier.

Table 8: Dehumidification equipment by site

Equipment	Brand	Model	Type	Site
Smart Dehumidifiers	Honeywell	TP50AWKN	Standalone	2
	Emerson	EAD50SE1H	Standalone	3
Dehumidifiers	Soleus Air	HMT-D70E-A	Standalone	1
	SantaFe	Ultra98	Whole House	5
	GE	ADEL50LWW1	Standalone	4
	Pelonis	PAS20C1AWT	Standalone	6
Smart Thermostat	Honeywell	Prestige IAQ		5
Smart Plugs	Kasa			4
	Wemo			1, 6

The field tests are summarized in Table 9 and Table 10. Ten peak-events were randomly scheduled over the six-week field study and dehumidifiers were otherwise operated in their normal manner. Three types of events were scheduled. The main test was called a peak event, a 4-hour event between 3 pm and 7 pm to coincide with typical summer residential peak loads. Dehumidifiers were remotely powered off during these events. A second type of event was the back-to-back (B2B) event, whereby peak events were called on three consecutive days. These events were designed to simulate peaking events that often occur on consecutive days during heat waves. A third type, the pre-dry event, leveraged the additional control enabled by the smart dehumidifiers. During these events, the dehumidifier setpoints were remotely decreased from 2pm to 3pm to pre-dry the space. During the peak load window, from 3pm to 7pm, the setpoints were temporarily increased. While only possible at two of the sites, this test balanced the need for peak load control with the necessity of maintaining indoor relative humidity levels. All scheduling and control were accomplished remotely using smart phone applications.

During the analysis we found that the recovery time—the time it took for the RH to return back to the desired range after an event, was usually complete within a few hours of the end of the event. This meant that by 9 pm the RH had returned to the desired range. Because this was 18 hours before another back-to-back event took place, we could consider the-back to-back events the same as the peak event. As they are essentially the same event, they will be referred to as type 1 peak events for the remainder of the report.

Table 9: Event type and related actions

Type	Name	Action	Start	End
1	Residential Peak	Turn off dehumidifier	3:00 PM	7:00 PM
1	Back-to-Back Peak	Turn off dehumidifier	3:00 PM	7:00 PM
2	Pre-Dry	Adjust setpoint down	2:00 PM	3:00 PM
		Adjust setpoint up	3:00 PM	7:00 PM

Table 10: Field schedule

Site	Start	End	Total days	Peak Events	B2B Events	Pre-Dry Events
1	5-Jul	29-Aug	55	6	5	-
2	7-Jul	25-Aug	49	3	3	3
3	7-Jul	1-Sep	56	4	3	3
4	13-Jul	30-Aug	48	5	4	-
5	19-Jul	27-Aug	39	6	3	-
6	19-Jul	24-Aug	36	7	0	-

Smart phone apps

The smart phone apps used are shown below in Table 11. For the most part, the apps were chosen as they were the default app when looking at the product page for each item. Even though the Honeywell smart dehumidifier app is made by Jmatek, it is the one that is linked in the Honeywell product page. The Total Connect Comfort app (by Resideo Tech) that was used for the Honeywell smart thermostat was the one that the homeowner already had set up, so we continued using that one.

Table 11: Smart phone apps used for dehumidifiers, smart plugs, and whole-house dehumidifier

App Type	Brand	Model	Retail Cost	App name
Smart Dehumidifier	Honeywell	TP50AWKN	$345	Honeywell Air-Comfort (Jmatek Limited)
Smart Dehumidifier	Emerson	EAD50SE1H	$250	ConnectLife
Smart Plug	Wemo	na	$49	Wemo
Smart Plug	Kasa		$10	Kasa
Whole House Dehumidifier	Honeywell			Total Connect Comfort (Resideo Tech)

Smart dehumidifier apps

The apps for the Honeywell and Emerson smart dehumidifiers both allowed instantaneous control as well as the ability to schedule actions for each day of the week. Overall, the Honeywell app was more user friendly, but both were reliable and capable of doing the work we needed for the study. Figure 3 shows screenshots for the Emerson smart dehumidifier, while Figure 4 shows screenshots for the Honeywell smart dehumidifier.

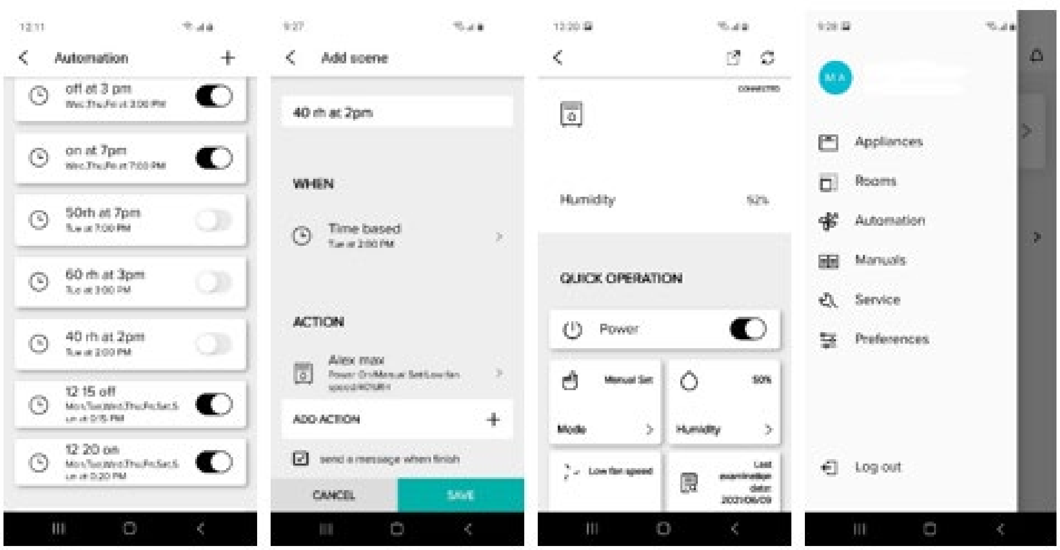

Figure 3: Connect Life app screenshots for Emerson smart dehumidifier

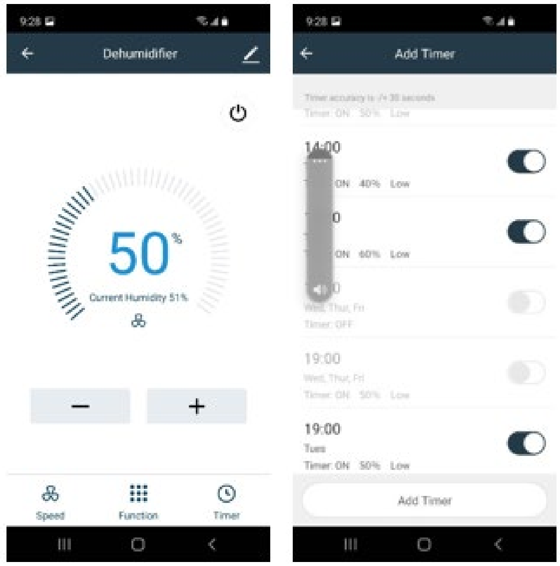

Figure 4:Honeywell Air screenshot apps for Honeywell smart dehumidifier

Smart plug smart phone apps

The two smart plugs used for the project both had their own accompanying smart phone app. Figure 5 shows a screenshot for turning on and off a scheduled action in the Kasa smart phone app. Figure 6 shows a screenshot showing the rules for an action in the Wemo smart phone app. Both of the apps allow for setting up actions for given days of the week and times of the day. These actions are limited to turning power on or off from the plug. The actions were easy to setup and the apps were both intuitive and easy to use. Overall, these worked well, but seemed to be more subject to error if the Wi-fi was disconnected.

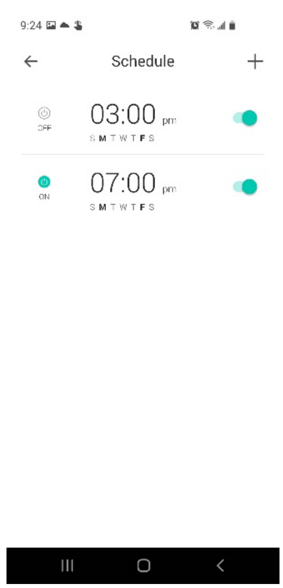

Figure 5: Kasa app screenshot for Kasa smart plugs

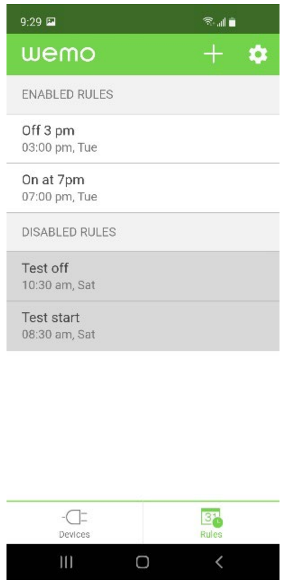

Figure 6: Wemo app screenshot for Wemo smart plugs

Results

Typical Dehumidification Cycle

An example dehumidifier cycle is shown in Figure 7. Under these specific ambient conditions, the dehumidifier completes one cycle approximately every 22 minutes. At the beginning of the cycle the compressor and fan are powered on when the unit's humidistat reads a relative humidity value that exceeds the relative humidity setpoint. The unit takes a few seconds to reach its operating power and begins lowering the ambient relative humidity and dry out the space. Once the unit's relative humidity setpoint is reached, the compressor turns off and the fan is left running for three minutes. This fan-only period serves as a lockout to prevent short-cycling of the compressor as well as clean off excess moisture remaining on the condenser heat exchanger. After the fan is off the cycle is complete. A new dehumidification cycle will begin when the humidistat reads a value exceeding the relative humidity setpoint.

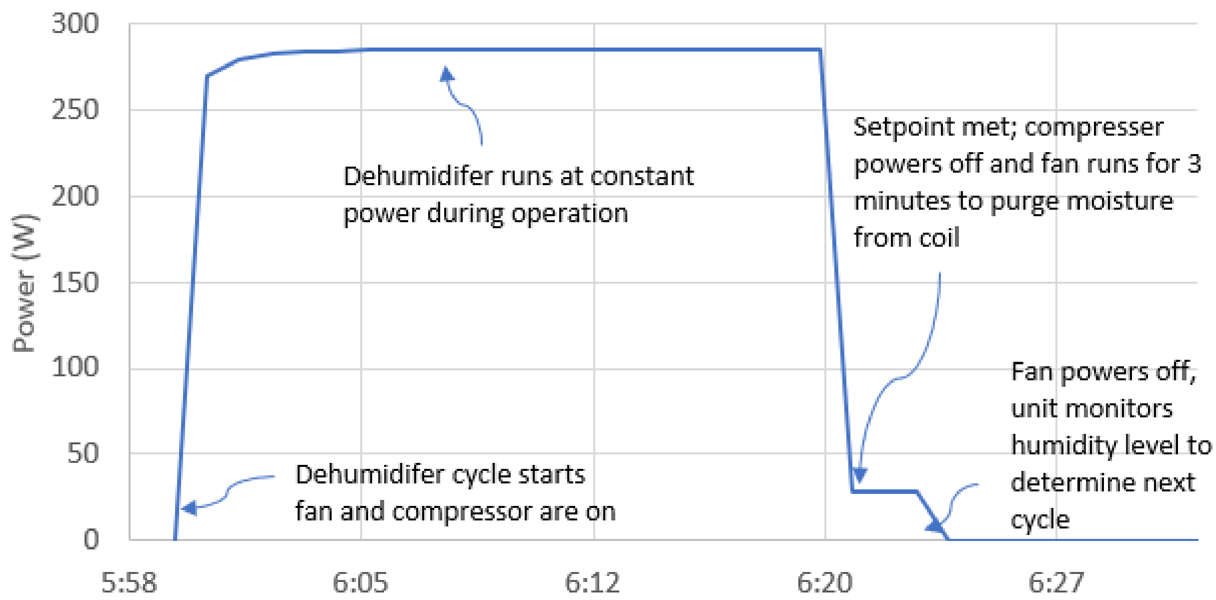

Figure 7: Typical dehumidification cycle

Baseline Dehumidifier Load Profile

In Figure 8 the average runtime (or coincidence factor) of all of the sites during the project's monitoring period on non-event days for each hour of the day. The coincidence factor/runtime is the amount of power the dehumidifier is using compared to full load. The fleet of six dehumidifiers in this study ran from an average of 49% to 65% of full capacity during July and August. This is approximately 5-10% less than prior Minnesota work, but the previous study had used smaller dehumidification units resulting in increased runtimes. Also, from this plot we can conclude that there is still significant capacity to spare in the current applications, which will aid in recovery.

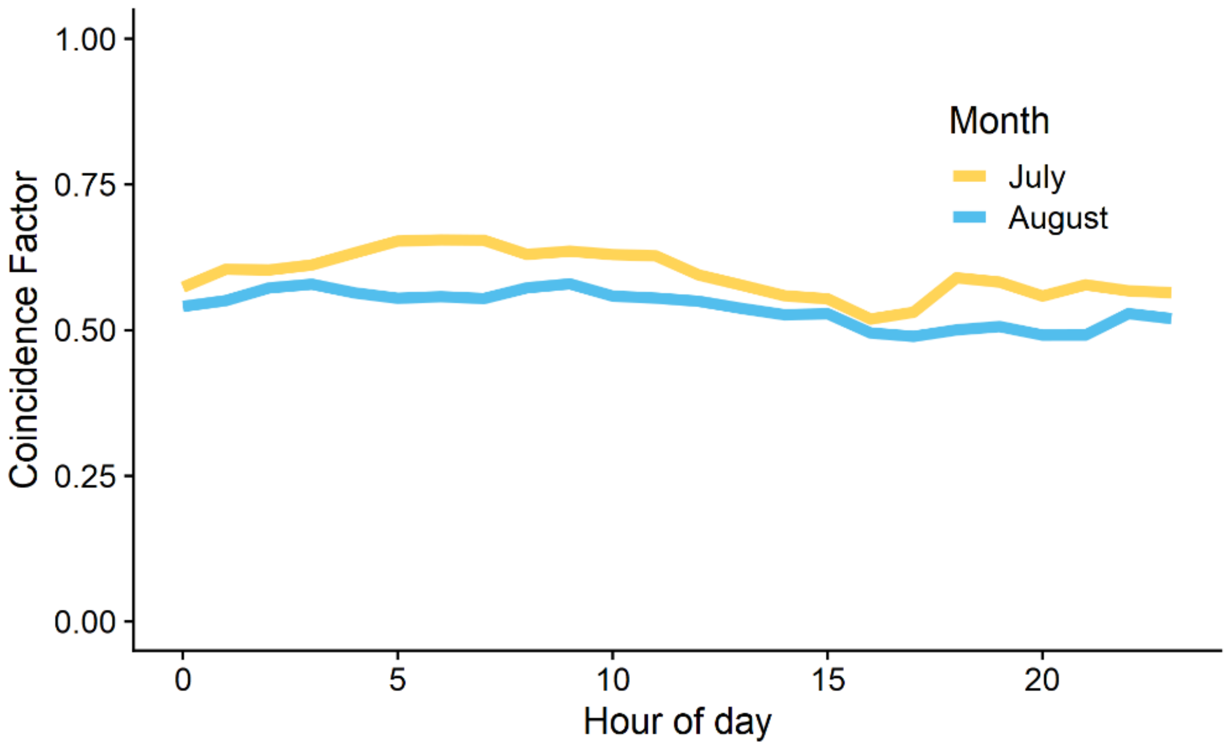

Figure 8: Baseline dehumidification load profile for the average of all sites under normal operation

Peak Event (Type 1 – Load shedding)

Figure 9 shows an example of a type 1 peak event. The temperature (blue), relative humidity (yellow), and power signal (gray) are plotted as functions of time. For the hours before the event, the unit cycles on and off, leading to small fluctuations in temperature and relative humidity. As the event starts, power is cut to the dehumidifier and the relative humidity increases over the next three hours approximately by 5 %. The event ends at 7 pm and the dehumidifier immediately turns on to bring down the relative humidity. The dehumidifier stays on longer than a usual pre-event cycle as it recovers its existing relative humidity setpoint. Once the relative humidity setpoint is met, the dehumidifier continues on with its usual cycling.

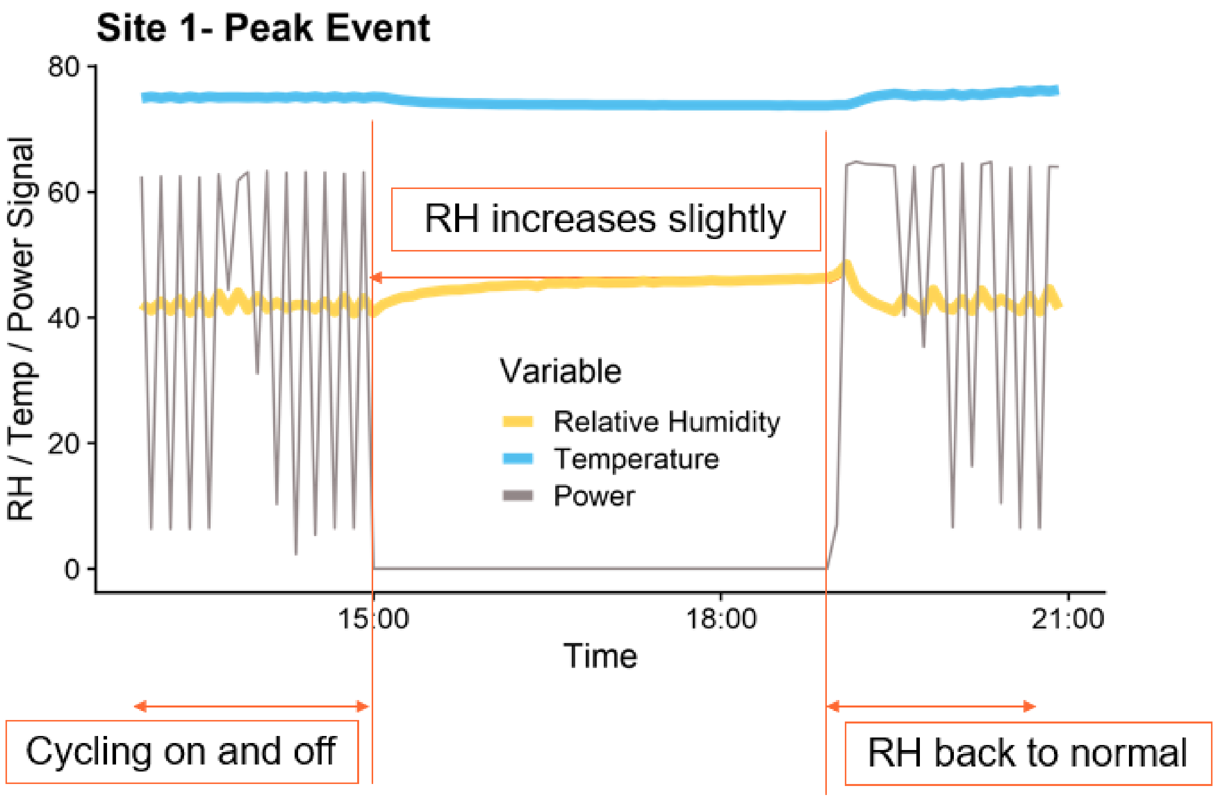

Figure 9: Example of peak event (event type 1)

Peak Event (Type 2 – Pre-dry and coast)

The pre-dry event is the other type of event studied in the project. It was enabled by smart dehumidifiers that can remotely control relative humidity setpoints and hence only attempted at two sites with smart dehumidifiers. During this event, the space is pre-dried by decreasing the relative humidity setpoint during the hour preceding the event period. This pre-dry period is evident in Figure 10, where the power signal increases and the relative humidity level drops. In fact, the data indicate a shorter drying time may have been as nearly as effective. At 3pm the dehumidifier is remotely switched to a high relative humidity setpoint. From about 3pm to 4pm, the unit does cycle somewhat at reduced runtime, likely do to some very local humidity differences caused by the sudden changes in setpoints. Soon however, the unit satisfies the local conditions and remains off as the relative humidity coasts upward over the course of the event.

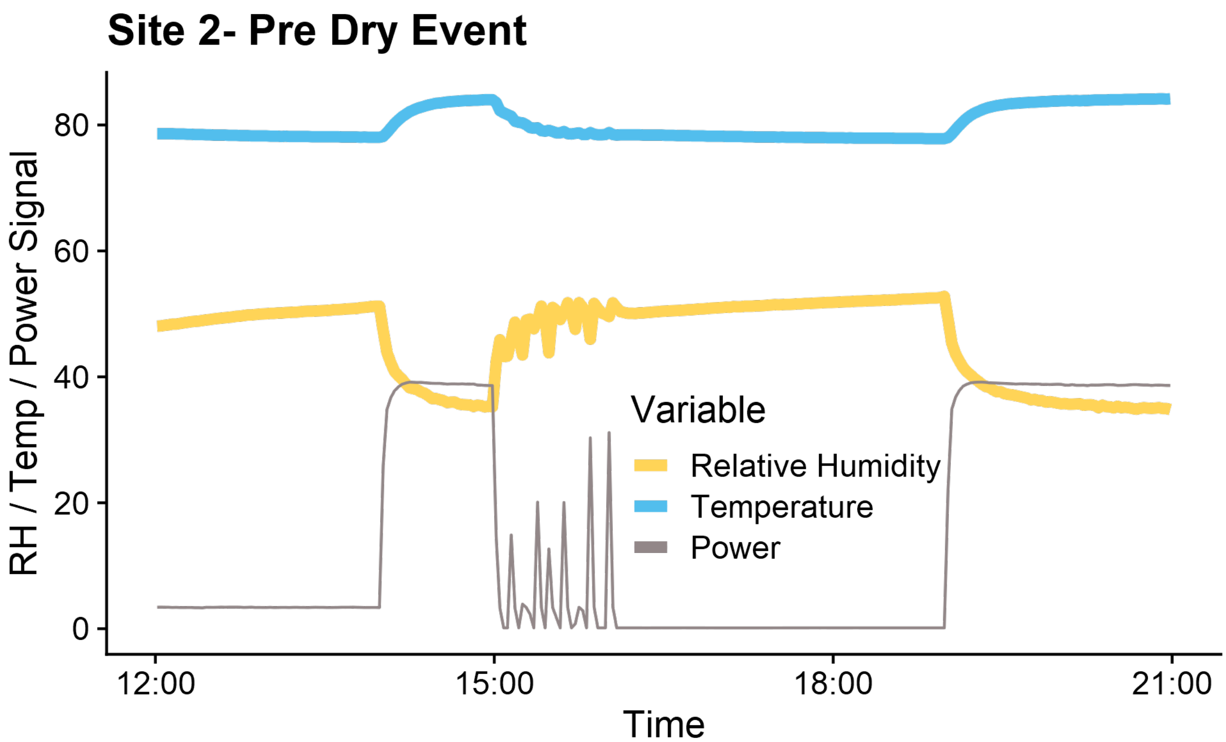

Figure 10: Example of pre-dry event (event type 2)

Average fleet runtime for each event type

Figure 11 shows the average fleet runtime for each hour of the day. The x-axis shows the hour of the day, with the y-axis showing the average runtime of all the dehumidifiers during the testing period of July and August.

The gray line is the standard operation, with no control or scheduling of the dehumidifier. This stays in a range of 49% to 65% throughout the entire day, it is the average of results shown in Figure 8.

The yellow line shows an overall average runtime for all 59 type 1 peak events. These are the events that turn the dehumidifier off from 3pm to 7pm. This fleet runtime value follows the standard operation fairly closely prior to the event period at 3pm. At this time the yellow line falls to nearly 0% until 7pm, when the dehumidifier is allowed to cycle back on. At this time the yellow line peaks to a higher value (77%) for a short time to recover the relative humidity setpoint and over the next few hours decreases until it meets back up with normal operation. The relative humidity is usually returned to its normal setpoint in a few hours.

The blue line shows the average fleet runtime for the pre-dry events. There was only a total of six of these events between two sites, so there is more variability here. This result shows a peak of 94% at 2pm, when the dehumidifiers are set to a lower setpoint. At 3pm this line drops to around 12% until 7pm. This corresponds to the dehumidifiers being set to a higher setpoint. As with type 1 events, there is a substantial recovery period after the event ends at 7pm. Similarly, the runtime continues to decrease after the event.

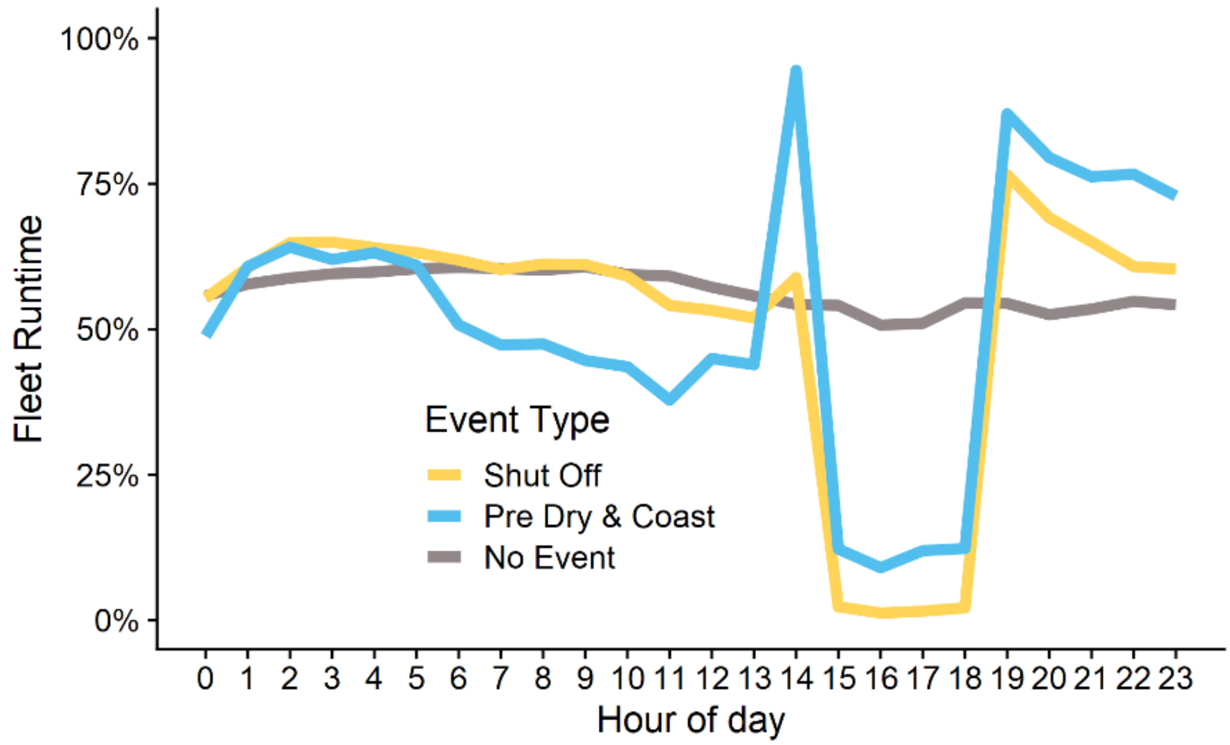

Figure 11: Average fleet runtime throughout the day

Relative Humidity Results and Recovery

Analysis shows that the relative humidity levels did not change drastically during events compared to non-events. Figure 12 shows the daily average relative humidity for each site using box plots. The left box plot for each site shows the distribution of relative humidity during regular operation. The right box plot for each site shows the distribution of relative humidity during days in which an event occurred. For all sites, the relative humidity levels during events is statistically similar to regular operation. Sites one through four have nearly identical median relative humidity levels. Site 5 shows a slightly elevated relative humidity level and site 6 has a noticeably higher relative humidity level; however, it remains within the interquartile range of normal operation.

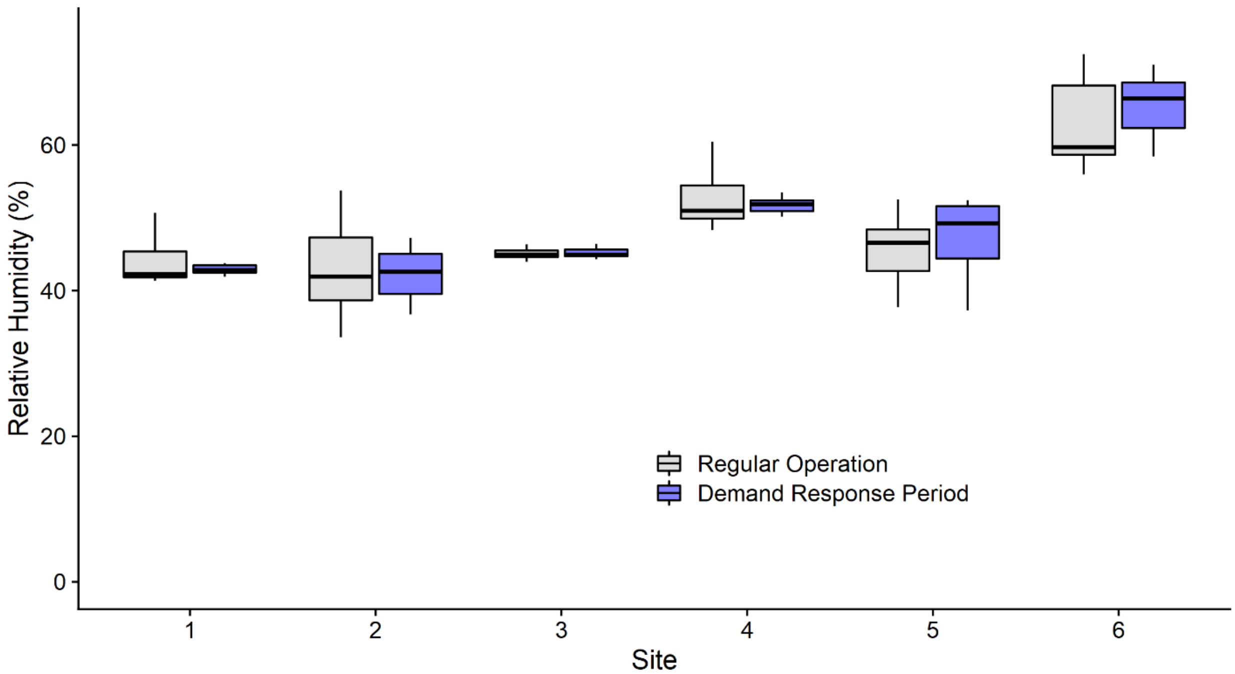

Figure 12: Relative Humidity for each site no event vs peak load event

Table 12 shows an overview of the effects on humidity due to the events as well as the average recovery period. The maximum change in humidity ranged from an increase by 1% RH to 10% RH. This increase is in the basement in the immediate area around the dehumidifier. It can be noted that the sites with the greatest increase in humidity during an event were the ones that had the lowest humidity pre-event. These correspond, as expected, to the sites with the lowest humidity setpoint on their dehumidifiers. These results are visualized for each site in Figure 13. The average recovery period (time it takes for the humidity to return to the pre-event value) is usually less than two hours, with the exception of site 5, consistent with Figure 12.

Table 12: Relative humidity and recovery time for events

Site	Pre event humidity (% RH)	Peak event humidity (% RH)	Max change in humidity (% RH)	Recovery Period (Hours)
1	43	51	8	2
2	43	53	10	1
3	45	51	6	1
4	54	55	1	0
5	46	55	9	5
6	64	67	3	1

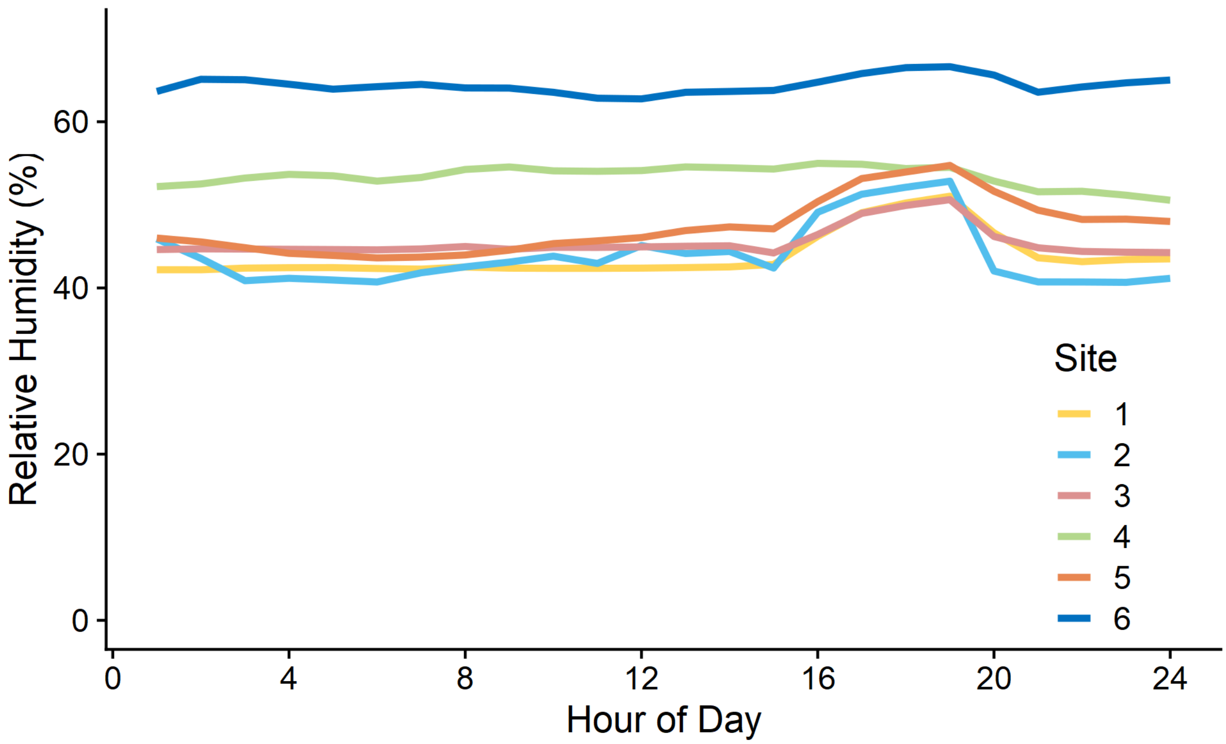

Figure 13: Average relative humidity at each site before, during, and after events

Load Flexibility Conclusions

In this study, it was found that the dehumidifiers could be reliably and unobtrusively controlled via the selected control schemes. While smart plugs were functional, smart dehumidifiers and smart thermostats are the key technologies for enabling load shaping control for dehumidifiers in the future. Smart dehumidifiers offer the ability to verify, reliability, control, and ability to schedule, all at a cost of about $30 more than a non-smart dehumidifier. The smart thermostat is a much more expensive route, but allows verifiable, reliable, and broad control of the dehumidifier as well as the thermostat. Both smart dehumidifiers and smart thermostats could be integrated into existing smart thermostat based peak load control programs with very little effort.

For sites in this study, relative humidity increases during controlled events were minor. Relative humidity increased by a maximum of 10% at one site, but increases were typically much smaller. After events, all sites saw increased energy use for recovery, but also recovered very quickly, typically less than two hours and in one case about 5 hours. These recovery windows and minor increases in relative humidity are temporary and inconsequential with respect to general dehumidification goals.

As many utilities already have a program to control AC during peak demand times, the existence of smart dehumidifier and smart thermostat controls may be a low-effort addition to enhance savings of existing programs.

Key Takeaways

Standalone dehumidifiers represent strong energy efficiency savings potential for Focus

Average savings of 343 kWh or higher can be expected from relatively simple swap outs of existing dehumidifiers for new ENERGY STAR 5 rated units. Caveat: Old units must be retired to guarantee savings.

While program design is challenging due to resource constraints, community-based programs merit consideration

Programs that verify retirement of existing dehumidifier are key to savings; community-based approaches that can accumulate many old dehumidifiers for simultaneous recycling will target cost barriers troubling conventional appliance recycling programs plus they enable additional engagement with customers on energy use and dehumidification best practices. Additionally, community focused efforts are aligned with Focus's strategic interests.

There are added load management benefits to be realized alongside energy efficiency savings

Standalone dehumidifiers are high energy use plug loads. They consume moderate power, but devices run extensively during peak residential load periods. This research has shown dehumidifiers can be reliably interrupted via remote control to affect appreciable demand savings. The effort to integrate smart dehumidifiers into existing load management programs, especially for manufacturers already active in this space, seems especially low. It may be a reliable and unobtrusive way to expand load management programs by activating an additional 180W+ of demand savings per unit on top of anticipated energy savings when replacing old units. While load management benefits primarily accrue to utility partners, these EE/DR partnerships are important to Focus and play an important role in the macro policy decisions in Focus quadrennial planning.

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Appendix A: Dehumidifier Recycling Map and Location Database

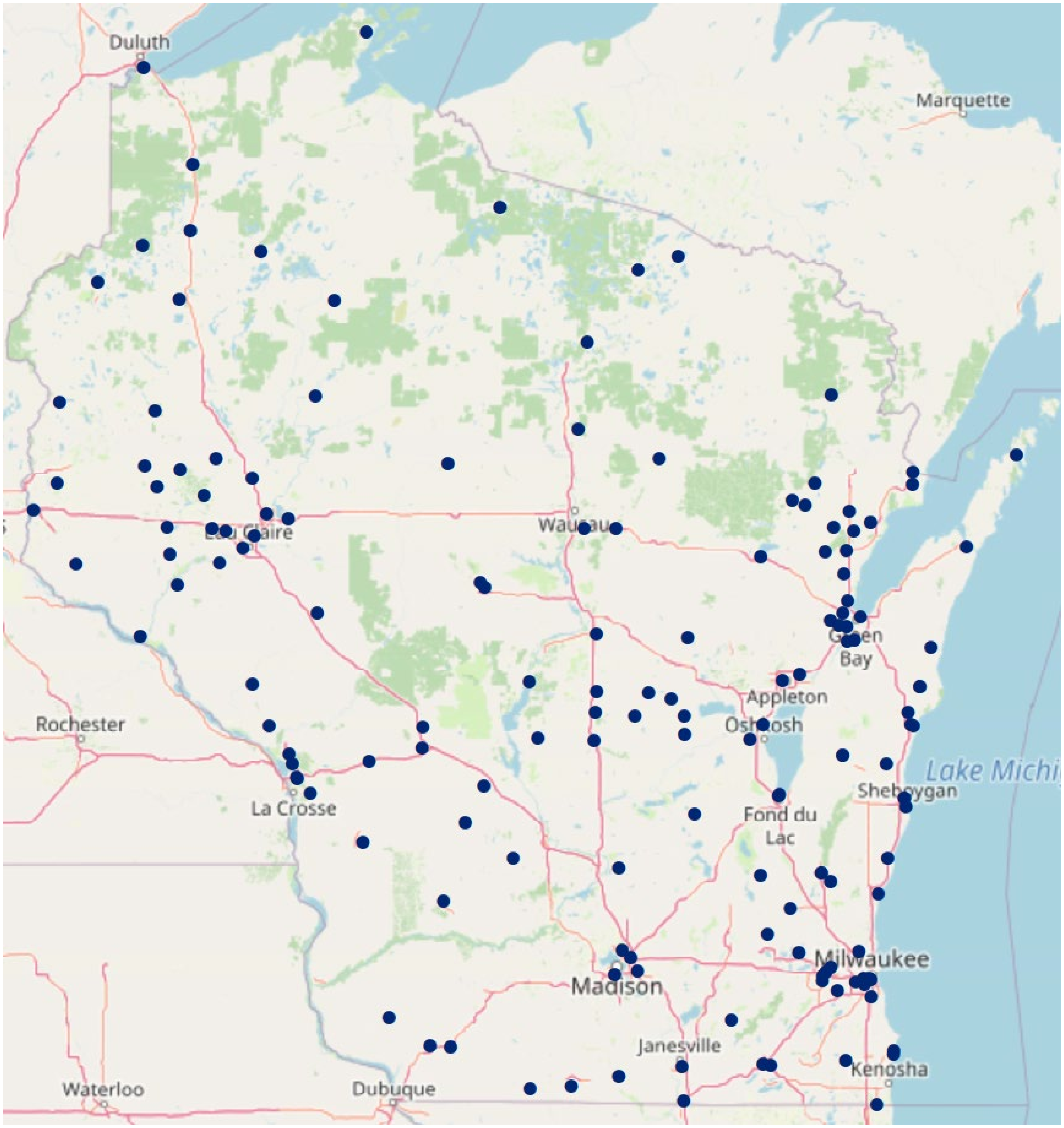

Figure 14: Appliance recycling locations in Wisconsin

Table 13: Appliance recycling locations in Wisconsin

County	Service name	Website	Address	Cost
Adams	Solid Waste & Recycling	https://www.co.adams.wi.us/departments/solid-waste-recycling	1420 State Hwy 21 Friendship, WI 53934	$15.00
Ashland				
Barron	Barron County Waste to Energy and Recycling Facility	https://www.barroncountywi.gov/index.asp?Type=B_BASIC&SEC={A7E66E87-8E68-4A98-B529-C67768AE2615}	585 10 1/2 Ave Almena, WI 54805	$15.00
Bayfield	B.R.B Recycling Authority	http://www.cityofbayfield.com/brb-recycling-authority.html	35945 State Highway 13 Bayfield, WI 54814	$15.00
Brown	Brown County Recycling	https://www.browncountyrecycling.org/refuse-acceptable-material	3734 West Mason Street Hobart, WI 54155	$15.00
Brown	Cyber Green LLC	https://www.cybergreenllc.com/contact	844 Willard Dr Green Bay, WI 54304	$5.00
Brown	Bay Beach Recycling	https://baybeachrecycling.com/services/	1826 N. Irwin Ave. Green Bay WI 54311	
Brown	Sadoff Iron & Metal Company	https://sadoff.com/	1901 Lineville Road Green Bay, WI 54313	$10.00
Brown	Sadoff Iron & Metal Company		3313 N 21st Street Sheboygan, WI 53083	
Brown	Sadoff Iron & Metal Company		240 W. Arndt Street Fond du Lac, WI 54936	
Brown	Town Line Recycling, LLC	https://townlinerecycling.com/	1701 W Paulson Rd Ashwaubenon, WI 54313	$5.00
Brown	Town Line Recycling, LLC		3751 Creamery Rd De Pere, WI 54115	$5.00
Brown	Alter Trading Corporation		2175 Badgerland Drive Green Bay, WI 54303	

Brown	Norsec Coupter Recyclers LLC	http://www.norseccr.com/recyclingfees.html	809 Prosper St DePere, WI 54115	$30.00 fee for pickup
Buffalo				
Burnett				
Burnett	Oakland Collection Center	https://townofoaklandwi.com/oakland-collection-center/	7426 Main St. W Webster, WI 54893	$12
Burnett	Town of Webb Lake Disposal and Recycling Center	https://townofwebblake.com/disposal-and-recycling/	2550 Frog Lake Road Webb Lake, WI 54830	$10
Calumet	Mid-Shores Disposal	http://www.midshoresdisposal.com/index.html	1802 Roosevelt Ave New Holstein, WI 53061	$25
Calumet	Salvage Battery and Lead	https://drive.google.com/file/d/0B10bXDuUxXYiYWlVTXhwOVFYSms/view	175 S Rockway St Mishicot, WI 54228	
Calumet	Advanced Disposal Services	https://townofcalumet.com/garbage-recycling/	1802 Roosevelt Avenue New Holstein, WI 53061	$25
Chippewa		https://www.co.chippewa.wi.us/government/land-conservation-forest-management/recycling/recycling-programs-services	225 Edward St Chippewa Falls, WI 54729	$15
Chippewa	Town of Sampson	http://tn.sampson.wi.gov/recycling/	407 26th Ave Bloomer, WI 54724	$15
Chippewa	Town of Wheaton Recycling Center	https://townofwheaton.com/recycling-center/	2429 20th Street Elk Mound, WI 54739	$20
Chippewa	First Choice Recycling	https://firstchoicerecycling.com/rates/	525 Park Ridge Court Eau Claire, WI 54703	$20
Chippewa	Town of Lafayette	https://lafayettetownship.org/community/recycling-items/	5765 197th St. Chippewa Falls, WI 54729	$15

Clark				
Columbia	County Processing Facility	https://www.co.columbia.wi.us/columbiacounty/solidwaste/RecyclingSolidWaste/PricesPaymentPolicies/tabid/506/Default.aspx	W7465 Hwy 16 Pardeeville, WI 53954	$20.00
Crawford				
Dane	Alter Trading Corporation		4400 Sycamore Avenue Madison, WI 53714	
Dane	Resource Solutions Corp.	http://recyclethatstuff.com/tv-monitor-computer-appliances/	5493 Express Cir Madison, WI 53916	
Dane	All Metals Recycling	https://www.allmetalsrecyclingllc.com/residential_recycling.php#appliance-recycling	1802 S. Park St. Madison, WI 53713	$10
Dane	File 13 E-Waste Solutions, LLC	https://www.file13usa.com/drop-off-rates.html	3460 Meier Rd Unit 2 Madison WI 53718	$0.50/pound + tax
Dodge	The Town of Ashippun Recycle Center	https://townofashippun.org/garbage-and-recycling/	W2522 Oak St Ashippun, WI 53003	$24.00
Dodge	Town of Hartford Recycling Center	https://ci.hartford.wi.us/379/Drop-Off-Disposal-Policies	710 W Sumner Street Hartford, WI 53027	$15.00
Door	Door County Scrap Metal	https://www.doorcountyscrapmetal.com/appliances-computer-recycling	1456 Shiloh Road Sturgeon Bay, WI 54235	$30.00
Door	Going Garbage & Recycling	https://www.goinggarbage.com/drop-off-site/	10564 Old Stage Road Sister Bay, WI 54234	$35.00
Douglas	Village of Solon Springs Solon Springs Recycling	https://villageofsolonsprings.com/recycling-solid-waste/	11523 S Business Hwy 53 Solon Springs, WI 54873	$20.00
Douglas	Afterlife Electronics Graveyard	https://afterlifeelectronicsgraveyard.com/	915 John Avenue Superior, WI 54880	
Dunn	Dunn County Solid Waste & Recycling Transfer Station &	https://www.co.dunn.wi.us/swrfees	e3900 WI-29 Menomonie, WI 54751	$15

	Recycling Center, Menomonie			
Dunn	Dunn County Solid Waste & Recycling Boyceville Area Collection Station & Yard Waste Drop-Off Site	https://www.co.dunn.wi.us/swrfees	1402 Dump Rd Boyceville, WI 54725	$15
Dunn	Dunn County Solid Waste & Recycling Colfax Area Collection Station & Yard Waste Drop-Off Site	https://www.co.dunn.wi.us/swrfees	N9417 810th St Colfax, WI 54730	$15
Dunn	Dunn County Solid Waste & Recycling Connorsville Area Collection Station	https://www.co.dunn.wi.us/swrfees	E1285 1256th Ave Boyceville, WI 54725	$15
Dunn	Dunn County Solid Waste & Recycling Downsville Area Collection Station	https://www.co.dunn.wi.us/swrfees	N2723 440th St Downsville, WI 54735	$15
Dunn	Dunn County Solid Waste & Recycling Elk Mound Area Collection Station & Yard Waste Drop Off Site	https://www.co.dunn.wi.us/swrfees	401 570th Ave Elk Mound, WI 54734	$15
Dunn	Dunn County Solid Waste & Recycling Ridgeland Area Collection Station	https://www.co.dunn.wi.us/swrfees	N12184 Hwy 25 Ridgeland, WI 54763	$15
Dunn	Dunn County Solid Waste & Recycling Rock Creek Area Collection Station	https://www.co.dunn.wi.us/swrfees	N1825 980th St Rock Falls, WI 54764	$15
Dunn	Dunn County Solid Waste & Recycling Sand Creek Area Recycling Drop-Off Site	https://www.co.dunn.wi.us/swrfees	N13425 County Hwy I Sand Creek, WI 54765	$15

Eau Claire	Alter Trading Corporation		3532 White Avenue Eau Claire, WI 54703	
Florence	Florence County Material Drop-off Site	https://www.florencecountywi.com/departments/page_153e272f3a7f/?department=b2d111e3ecff&subdepartment=d4d340fd11ee		$10
Fond du Lac	Municipal Service Center	https://www.fdl.wi.gov/public-works/bulky-waste-disposal/	490 Doty St Fond du Lac, WI 54935	$25
Fond du Lac	American Metal & Paper Recycling Inc	https://www.americanmprwi.com/recycled-items	7651 Otten Dr. Kewaskum, WI 53040	$30
Forest				
Grant	Alternative Recycling, LLC	http://www.altrecycle.net/home.html	1750 Industrial Park Road Lancaster, WI 53813	$5
Grant	Faherty Incorporated	http://www.faherty-inc.com/	1120 Broadway Street Platteville, WI 53818	$15
Green	Green County Landfill	http://www.co.green.wi.gov/localgov_departments_details.asp?deptid=116&locid=148	W2002 CTH SS Brodhead, WI 53520	$25
Green Lake	Town of Green Lake Recycling & Garbage	http://www.townofgreenlake.com/townofgreenlake/recycling-garbage/	N2298 Co Rd A Markesan, WI 53946	$25
Iowa	Iowa County Landfill	http://iowacountylandfill.com/services	3336 Hwy 6 Trail Homestead, IA 52236	$10
Iron	Town of Mercer Transfer/Recycle Site	https://www.townofmercer.com/trash-recycling/	2533 County J Mercer, WI 54547	$10
Jackson	Town of Garfield Recycling Center	https://www.townofgarfieldwi.com/community/recycling-center/	N12915 W Hillcrest Rd Osseo, WI 54758	
Jefferson				
Juneau	Solid Waste & Recycling Department	https://www.co.juneau.wi.gov/solid-waste--recycling.html	W7611 Ceylon Road Mauston, WI 53948	$30
Juneau	Runick Metal Recycling, LLC	http://www.runickmetal.com/what-we-buy.html	W9794 Hwy 33 Wonewoc, WI 53968	$20

Kenosha	City of Kenosha	https://www.kenosha.org/departments/public-works/waste-recycling/drop-off#electronics		$15
Kenosha	Village of Pleasant Prairie	https://www.pleasantprairiewi.gov/cms/One.aspx?portalId=6079616&pageId=10824737	8000 128th St Pleasant Prairie, WI 53158	$25
Kenosha	Johns Disposal Service	http://www.johnsdisposal.com/site/municipalities/salem-town/#1491589778460-8e997bf9-f2238bd0-b28e	107 Hwy U Whitewater, WI 53190	
Kewaunee	Kewaunee Riverview Transfer Station	https://www.kewauneetransferstation.com/residential-services.html	E3726 County Road L Kewaunee, WI 54216	$30
La Crosse	Household Hazardous Materials (HHM) facility	https://www.lacrossecounty.org/solidwaste/hhm.asp#top	3202 Berlin Drive La Crosse, WI 54601	$20
La Crosse	Alter Trading Corporation		2410 Hauser Street La Crosse, WI 54603	
La Crosse	Harters	https://harters.net/recycling-services/	2850 Larson St. La Crosse, WI 54603	$17
La Crosse	Hilltopper Refuse & Recycling	https://www.hilltopperrefuse.com/	W6836 Industrial Blvd Onalaska, WI 54650	$20
La Crosse	Runde Metal Recycling, LLC	http://www.rundemetal.com/accepted-materials/	643 Commerce St Holmen, WI 54636	$20
La Crosse	Hanson Scrap Metal	https://hansonscrapmetal.com/		$25
Lafayette	First Capitol Salvage	http://www.rundemetal.com/locations/	419 W Union St Belmont, WI 53510	$20
Lafayette	South Wayne Recycling	https://villageofsouthwayne.com/garbage-recycling/	Co Rd D South Wayne, WI 53587	$25
Langlade	B & B Containers LLC	https://bandbcontainers.com/trash-drop-off/	380 Rusch Rd Antigo, WI 54409	
Lincoln	Lincoln County Solid Waste/Landfill	https://co.lincoln.wi.us/solid-waste-landfill/page/fees-0	N4750 Landfill Lane Merrill, WI 54452	$20

Manitowoc	Langs Appliance Service	https://www.langsappliance.com/services	3907 Calumet Ave Manitowoc, WI 54220	$25
Manitowoc	Salvage Battery & Lead Inc		175 S Rockway St Mishicot, WI 54228	$21
Manitowoc	Sadoff Iron & Meal Recycling Center	https://sadoff.com/scrap-metal-recycling-center-locations/manitowoc-wi/	1600 S. 26th Street Manitowoc, WI 54220	$15
Marathon	Marathon County Solid Waste Department	http://www.marathoncountysolidwaste.org/appliances	172900 State Hwy 29 Ringle, WI 54471	$10
	Yeager's Salvage Yard	http://www.yaegerauto.com/page/recycling-scrap	8205 Camp Phillips Rd Weston , WI 54476	$15
Marinette	Alter Trading Corporation		N4399 Hwy 180 Marinette, WI 54143	
Marinette	Town of Peshtigo Recycling Center	https://townofpeshtigo.org/index.php?option=com_content&view=article&id=529&Itemid=965	W1945 Old Peshtigo Rd Marinette, WI 54143	
Marinette	Township Of Athelstane Recycling Center	http://athelstanewi.com/recycle.htm	10610 Eagle River Rd Athelstane, WI 54104	$10
Marquette				
Menominee				
Milwaukee	Alter Trading Corporation		1640 W. Bruce Street Milwaukee, WI 53204	
Milwaukee	Refrigerant Depot LLC	https://appliancerecycling.net/appliance-services	5311 South 9th Street Milwaukee, WI 53221	No charge
Milwaukee	Refrigerant Recovery Inc	https://www.refrigerantrecoveryinc.net/appliance-disposal	1125 W. National Avenue Milwaukee, WI 53204	$25 for pickup
Milwaukee	The City of Milwaukee Drop Off Centers	https://city.milwaukee.gov/sanitation/DropOff	3879 W Lincoln Ave Milwaukee, WI 53215	
Milwaukee	The City of Milwaukee Drop Off Centers	https://city.milwaukee.gov/sanitation/DropOff	6660 N Industrial Rd Milwaukee, WI 53223	

Milwaukee	Allied Resource Recovery	https://alliedresourcerecovery.com/customers-recycling-services/residential-recycling-services/	1909 S. 80th Street West Allis, WI 53219	$15
Milwaukee	National Salvage	https://alliedresourcerecovery.com/customers-recycling-services/residential-recycling-services/	600 S. 44th Street Milwaukee, WI 53214	$15
Monroe	Sherwood Recycling, Inc.	https://sherwoodforestrecycling.com/home.html	112 E Washington St, Tomah, WI 54660	No charge
Monroe	Runde Metal Recycling, LLC	http://www.rundemetal.com/accepted-materials/	7296 Division Rd Tomah, WI 54660	$20
Monroe	Modern Disposal Systems	https://modern-disposal-systems.business.site/	200 Hemstock Dr Sparta, WI 54656	$15
Oconto				
Oconto	Abrams Municipality Drop-off Center	https://www.co.oconto.wi.us/departments/forms_and_documents/?department=a67c24bc2735&subdepartment=d9ebc528d086#sthash.oK0mYfV6.dpbs	3394 Nikodem Ln Abrams, WI 54101	
Oconto	Bagley Municipality Drop-off Center	https://www.co.oconto.wi.us/departments/forms_and_documents/?department=a67c24bc2735&subdepartment=d9ebc528d086#sthash.oK0mYfV6.RXOL4jws.dpbs	9812 County Road Z Pound, WI 54161	
Oconto	Doty Municipality Drop-off Center	https://www.co.oconto.wi.us/departments/forms_and_documents/?department=a67c24bc2735&subdepartment=d9ebc528d086#sthash.oK0mYfV6.RXOL4jws.dpbs	16894 National Forest Rd 2117 Mountain, WI 54149	
Oconto	Lena/Village of Lena Municipality Drop-off Center	https://www.co.oconto.wi.us/departments/forms_and_documents/?department=a67c24bc2735&subdepartment=d9ebc528d086#sthash.oK0mYfV6.RXOL4jws.dpbs	301 W Railroad St Lena, WI 54139	
Oconto	Little Suamico Municipality Drop-off Center	https://www.co.oconto.wi.us/departments/forms_and_documents/?department=a67c24bc2735&subdepar	6297 Allen Rd Sobieski, WI 54171	

		tment=d9ebc528d086#sthash.oK0mYfV6.RXOL4jws.dpbs		
Oconto	Maple Valley Municipality Drop-off Center	https://www.co.oconto.wi.us/departments/forms_and_documents/?department=a67c24bc2735&subdepartment=d9ebc528d086#sthash.oK0mYfV6.RXOL4jws.dpbs	8362 Brock Rd Suring, WI 54174	
Oconto	Morgan Municipality Drop-off Center	https://www.co.oconto.wi.us/departments/forms_and_documents/?department=a67c24bc2735&subdepartment=d9ebc528d086#sthash.oK0mYfV6.RXOL4jws.dpbs	3276 County Rd C Oconto Falls, WI 54154	
Oconto	Oconto Municipality Drop-off Center	https://www.co.oconto.wi.us/departments/forms_and_documents/?department=a67c24bc2735&subdepartment=d9ebc528d086#sthash.oK0mYfV6.RXOL4jws.dpbs	6608 Elm Grove School Rd Oconto, WI 54153	
Oconto	Stiles Municipality Drop-off Center	https://www.co.oconto.wi.us/departments/forms_and_documents/?department=a67c24bc2735&subdepartment=d9ebc528d086#sthash.oK0mYfV6.RXOL4jws.dpbs	5718 Watercrest Rd Lena, WI 54139	
Oconto	City of Oconto Falls & Town of Oconto Falls Municipality Drop-off Center	https://www.co.oconto.wi.us/departments/forms_and_documents/?department=a67c24bc2735&subdepartment=d9ebc528d086#sthash.oK0mYfV6.RXOL4jws.dpbs	325 Pioneer Dr Oconto Falls, WI 54154	
Oconto	Village Suring Municipality Drop-off Center	https://www.co.oconto.wi.us/departments/forms_and_documents/?department=a67c24bc2735&subdepartment=d9ebc528d086#sthash.oK0mYfV6.RXOL4jws.dpbs	64 Knapp St Suring, WI 54174	
Oneida	Oneida County Solid Waste	https://www.co.oneida.wi.us/departments/sw/	7450 County Hwy. K Rhinelander, WI 54501	$28
Outagamie	Resource Solutions Corp.	http://recyclethatstuff.com/tv-monitor-computer-appliances/	121 N Linwood Ave Appleton, WI 54914	
Outagamie	Outagamie County Recycling & Solid Waste	https://www.recyclemoreoutagamie.org/material-search/	1919 Holland Road (Gate #3) Appleton, WI 54911	$18

Ozaukee	Ozaukee Iron & Metal LLC.	http://www.ozaukeeironmetal.com/items-we-accept.html	728 Schmitz Dr. Port Washington, WI 53074	$15
Ozaukee	Town of Belgium Transfer Site/Recycling Center	https://www.co.ozaukee.wi.us/DocumentCenter/View/279/Recycling-Brochure?bidId=	837 Jay Rd Cedar Grove, WI 53013	$25
Pepin	Pepin County Recycling and Solid Waste	https://www.co.pepin.wi.us/vertical/sites/%7B379104F9-0DE8-498C-8406-82AD4E352E4A%7D/uploads/2018_Recycling_Brochure_09262018.pdf	N6799 County Rd D Durand, WI 54736	$20
Pepin	Pepin County Recycling and Solid Waste	https://www.co.pepin.wi.us/recycling	W9326 Trail Rd Pepin, WI 54759	$20
Pierce	Pierce County Recycling Center Solid Waste Department	https://www.co.pierce.wi.us/Solid%20Waste/Recycling_Guides.html	707 North Maple Street Ellsworth, WI 54011	$15
Polk	Polk County Recycling Center	https://www.co.polk.wi.us/recycling	1302 208th St St Croix Falls, WI 54024	$18
Portage	Portage County Solid Waste and Recycling	https://www.co.portage.wi.us/department/solid-waste/transfer-facility	650 Moore Rd Plover, WI 54467	$20
Price				
Racine	Alter Trading Corporation		1339 17th Street Racine, WI 53403	
Racine	TEC Recycling	http://tecrecycling.com/	20815 Durand Avenue Union Grove, WI 53182	
Racine	Pearl Street Facility	https://www.cityofracine.org/BulkyWaste/	801 Pearl St Racine, WI 53403	$25
Richland	Richland Center Sanitary Landfill	https://recycling.co.richland.wi.us/landfill/	24147 County Highway AA Richland Center, WI 53581	$10
Rock	Alter Trading Corporation		1753 Beloit Avenue Janesville, WI 53546	

Rock	Beloit Recycling Center	https://townofbeloit.org/appliance-disposal/	2351 Springbrook Court Beloit, WI 53511	$15
Rusk	Grant Recycling	https://ruskcounty.org/index.asp?SEC=EE6C98F4-03F6-4D32-A3D4-9790E0E28DBA&DE=449F3D29-EAB4-4931-B4C7-35038060FF51	W8590 County Road P Ladysmith, WI 54848	$25
Sauk		https://www.co.sauk.wi.us/emergencymanagement/recycling		
Sauk	Helping Hands Recycling LLC	http://helpinghandsrecycling.com/what-we-take/	307 Veterans Drive Reedsburg, WI 53959	$20
Sawyer	Town of Hayward Transfer Site	https://townofhayward.com/garbage-disposal/	14768 W Chippewa Trail Hayward, WI 54843	$20
Sawyer	Town of Winter	https://townofwinter.com/services/	N4680 County W Winter, WI 54896	$15
Shawano	Shawano County Landfill and Recycling Center	https://www.cityofshawano.com/439/Location-Hours-Rates	1099 Rusch Rd Shawano, WI 54166	$15
Sheboygan	Sadoff Iron & Metal Company	https://sadoff.com/scrap-metal-recycling-center-locations/sheboygan-wi/	3313 N 21st Street Sheboygan, WI 53083	$15
Sheboygan	Good as Gold LLC	https://www.goodasgoldappliances.com/recycling/1393368	922 S 15th Street Sheboygan, WI	$15
Sheboygan	B & B Metals Processing	https://www.bandbmetals.com/	14520 Pioneer Rd Newton , WI 53063	$10
St. Croix	eCycling St. Croix Valley	http://www.ecyclingscv.com/index.shtml	900 Industrial St. Hudson, WI 54016	$35-$50
St. Croix	JR's Advanced Recyclers	https://jrsadvancedrecyclers.com/appliances/#appliances	8980 Jefferson Trail Inver Grove Heights, MN 55077	$10
St. Croix	Town of Richmond	https://townofrichmond.com/recycling-center/	1428 100th St. New Richmond, WI 54017	$20
Taylor	Alter Trading Corporation		510 W. Allman Street Medford, WI 54451	
Trempealeau	Hilltopper Refuse & Recycling	https://www.hilltopperrefuse.com/	1420 Wanek Ave Arcadia, WI 54612	$20

Trempealeau	Southern Trempealeau County Solid Waste Commission	http://www.townofgale.com/recyclinggarbage.html	W21488 State Road 54-93 Galesville, WI 54630	
Vernon	Vernon County Solid Waste and Recycling	https://www.vernoncounty.org/departments/solid_waste_and_recycling/residential_drop-off_pricing_and_info.php	S3705 County Highway LF Viroqua, WI 54665	$15
Vilas	Eagle River Recycling Center	http://www.eaglewasteandrecycling.com/dropoff.html	604 Jack Frost St Eagle River, WI 54521	$20
Walworth	Walworth County Recycling & Solid Waste	https://www.co.walworth.wi.us/342/Solid-Waste-Recycling	W4097 County Road NN Elkhorn, WI 53121	
Walworth	Southern Lakes Recycle, INC.	https://southernlakesrecycle.weebly.com/	220 South Broad St Elkhorn, WI 53121	No charge
Washburn	Northwest Regional Planning Commission	http://www.nwrpc.com/872/Recycling-Control-Commission	1400 S River Street Spooner, WI 54801	No charge
Washburn	Minong Transfer Station	https://townofminong.us/minong-transfer-station/	Transfer Station Dr Minong, WI 54859	$15
Washington	American Metal & Paper Recycling Inc	https://www.americanmprwi.com/recycled-items	935 Schoenhaar Dr. West Bend, WI 53090	$30
Washington	A&W Iron & Metal, Inc.	https://awironmetal.com/home-owner-and-small-loads-2/	7588 Otten Ln Kewaskum, WI 53040	$30
Washington	Advanced Disposal	https://www.advanceddisposal.com/	N7296 County Rd V. Horicon, WI 53032	
Waukesha				
Waukesha	Alter Metal Recycling	https://www.waukeshacounty.gov/landandparks/recycling/household/Appliances/	W229 N598 Foster Ct. Waukesha, WI 53189	
Waukesha	Recycle Technologies	https://recycletechnologies.com/e-waste-recycling-2/	1480 North Springdale Road Waukesha, WI 53186	$20
Waukesha	City of New Berlin Recycling Center	https://www.newberlin.org/388/Recycling-Center-and-Trash-Information	3711 S Casper Dr New Berlin, WI 53151	

Waukesha	City of Brookfield Recycle Center	https://www.ci.brookfield.wi.us/314/City-Recycle-Center	19700 Riverview Dr Brookfield, WI 53045	
Waukesha	Town of Merton Recycle Center	https://www.townofmerton.com/publicworks/page/what-they-take-town-merton-residents-only	32101 Petersen Rd Hartland, WI 53029	$25
Waukesha	Allied Resource Recovery, Inc.	https://alliedresourcerecovery.com/customers-recycling-services/residential-recycling-services/	1001 Tesch Court Waukesha, WI 53186	$15
Waupaca	Waupaca County Processing & Transfer Facility	https://www.waupacacounty-wi.gov/departments/solid_waste_and_recycling/Appliances.php#:~:text=In%20Waupaca%20County%20you%20can,is%20through%20Focus%20on%20Energy.	E4981 Swan Rd Manawa, WI 54949	$15
Waushara	Waushara County Parks & Solid Waste Department	https://townaurora.com/recycling.php	W2321 Hwy. 21 Berlin, WI 54923	No charge
Waushara	Waushara County Parks & Solid Waste Department	https://www.co.waushara.wi.us/pview.aspx?id=12728&catid=636	N1098 5th Rd. Coloma, WI 54930	No charge
Waushara	Waushara County Parks & Solid Waste Department	https://www.co.waushara.wi.us/pview.aspx?id=12728&catid=636	W12606 Cty Rd. V Hancock, WI 54943	No charge
Waushara	Waushara County Parks & Solid Waste Department	https://www.co.waushara.wi.us/pview.aspx?id=12728&catid=636	750 N. Pine St. Plainfield, WI 54966	No charge
Waushara	Waushara County Parks & Solid Waste Department	https://www.co.waushara.wi.us/pview.aspx?id=12728&catid=636	N3901 31st Drive Poy Sippi, WI 54967	No charge
Waushara	Waushara County Parks & Solid Waste Department	https://www.co.waushara.wi.us/pview.aspx?id=12728&catid=636	W3802 Archer Ave Pine River, WI 54965	No charge

Waushara	Waushara County Parks & Solid Waste Department	https://www.co.waushara.wi.us/pview.aspx?id=12728&catid=636	W6345 County Rd K Wild Rose, WI 54984	No charge
Waushara	Waushara County Parks & Solid Waste Department	https://www.co.waushara.wi.us/pview.aspx?id=12728&catid=636	N3830 17th Dr Wautoma, WI 54982	No charge
Winnebago	Winnebago Solid Waste Management	https://www.winnebagocountysolidwaste.com/brochures	100 West County Road Y Oshkosh, WI 54901	$13
Wood	Alter Trading Corporation		406 East Depot Street Marshfield, WI 54449	
Wood	Marshfield Scrap Company	https://www.marshfieldscrap.com/appliances.html	2304 S Galvin Ave, Marshfield, WI, 54449	$20
Wood	Fox Valley Iron Metal & Auto Salvage	http://foxvalleyiron.com/locations/oshkosh/	3446 Witzel Ave. Oshkosh, WI 54904	No charge
Wood	Nekoosa Auto Iron & Metal	https://www.nekoosaautoiron.com/services	369 Ten Mile Ave Nekoosa, WI 54457	$10

Appendix B: Consumer Recommendations

Does my dehumidifier work?

- Dehumidifiers should make noise, produce condensate, and generally hold the relative humidity level in the room to the unit's setpoint.
- Most units less than 12 years old have a display that indicates the current relative humidity level. When the setpoint is changed by the user, the display will briefly show the current setpoint before reverting to the room's measured relative humidity. Other units may just have a dial, which can be harder to relate to a relative humidity level without measurement.
- Most dehumidifiers older than 10 years ***can be*** cost-effectively replaced by new Energy Star units and dehumidifiers over 15 years old ***should be*** replaced by a new Energy Star units for better performance, lower operating cost, and less noise.

When should I dehumidify?

- A dehumidifier should ***usually*** operate when relative humidity levels exceed 50% and should ***definitely*** operate to keep relative humidity levels below 60%.
- In basement applications, dehumidification season usually runs from April – October, peaking between June and September. In typical basement applications, peak loads yield less than 8 pints/day of condensate on average.
- Standby losses for newer units (<5 years) are very low so leaving a dehumidifier 'always on' is a convenient solution.
- Dehumidification loads are very small or non-existent in winter months so units can also be powered off / unplugged / or stowed in November – March as convenient.

How should I dehumidify?

- A dehumidifier relative humidity set point of 50% is a good starting point to promote comfort, indoor air quality, and health of building materials. Dehumidifier setpoints should not exceed 60%. Setpoints can be adjusted up or down as necessary; however, energy use (and cost) increases for lower setpoints.
    - Every 5% decrease in relative humidity will increase energy use and operating cost by about 12%
- Dehumidifiers should be set up to drain automatically to maintain better humidity control and improve quality of life.
    - Units that fill a reservoir provide less humidity control and require user intervention (possibly more than once per day) to achieve their nameplate capacity. Automatic units operate continuously without intervention.
    - Typically, new units are configured to collect condensate into their reservoir, but can be setup to drain automatically by connecting a garden hose (GHT) to a fitting on the back of the unit. If the hose becomes blocked, the unit will revert to filling its reservoir.
    - Humidity control is not sensitive to dehumidifier placement so there is flexibility in placing the unit to facilitate automatic draining as long as air movement is not restricted (e.g. by closed doors or large furniture/property).
    - A typical location is in a mechanical/laundry area where the unit can drain directly to a floor drain or utility sink.
    - If the unit can't be moved to facilitate an automatic gravity drain, consider tying into an existing condensate pump (from Furnace/AC) or using a new condensate pump to

    - drain the unit. Most condensate pumps installed for condensing furnaces and central air conditioners can accept additional connections.
- Measure and display relative humidity levels in a more convenient way. Inexpensive wireless sensors are available from big box retailers which can transmit temperature and relative humidity to a display.
    - A display can be located at the main thermostat or another frequently accessed location to get a more frequent update on basement conditions.
    - These measurements relate our intuitive understanding of relative humidity to values that can facilitate better relative humidity control.
    - These sensors can relate the (higher) basement humidity levels to humidity levels in the main living area.
    - Multiple sensors can show how humidity levels vary throughout a large basement area or between isolated basement spaces, providing feedback on how or where to operate the dehumidifier to maintain desired relative humidity levels.

What dehumidifier should I buy?

- Most single-family homes with basements less than 1000 sqft can use small capacity units.
    - A 30 pints/day unit (Energy Star 4) or 20-22 pints/day unit (Energy Star 5) is sufficient. These units have the same capacity and efficiency in practice.
    - High dehumidification loads caused by very old foundations, dirt slabs, large basement spaces, periodic liquid water infiltration, high water tables, or very high infiltration may need additional capacity (30-50 pints/day).
    - In rare cases, large capacity units (70+ pints/day) may be needed. Capacity over 90 pints/day is usually reserved for whole house dehumidifiers and commercial drying equipment.
    - While larger dehumidifiers often have better efficiency, oversized units can lead to short cycling (consistently turn on and off in short intervals, typically less than 10 minutes) which can lead to higher operating cost and reduced performance.
    - While they may help ameliorate the situation, residential dehumidifiers are typically not a good solution for frequent liquid water entry or standing water; however, they are an essential component to dry out air and building materials after large water intrusion events.
- Buy an Energy Star rated unit; there are no cost savings or meaningful benefits (brand choice, reliability) to purchasing minimum efficiency units.
- Old dehumidifiers should be removed from service when replaced. Like refrigerators, very old dehumidifiers use a lot of energy compared to new units. After they are replaced, dehumidifiers are often passed along as hand-me-downs to friends/family/new occupants or used as 2nd dehumidifiers. In most cases, buying a new unit will pay off its purchase price in energy savings after only a few years.
- Dehumidifiers need to be recycled to collect their refrigerant before disposal.
- For most applications, a new dehumidifier will cost about $30/year to $100/year to operate or about $62/year on average, which is a little bit over half the cost of older units.

Appendix C: TRM Workpapers

Standalone Dehumidifier – Replace-on-Fail Measure

	Measure Details
Measure Master ID	TBD
Workpaper ID	TBD
Measure Unit	Per dehumidifier
Measure Type	Prescriptive
Measure Group	HVAC or Vending & Plug Loads
Measure Category	Dehumidifier
Sector(s)	Residential-single family
Annual Electricity Savings (kWh)	Varies by baseline, size, efficiency
Peak Demand Reduction (kW)	Varies by baseline, size, efficiency
Annual Natural Gas Savings (therms)	0
Lifecycle Electricity Savings (kWh)	Varies by measure
Lifecycle Natural Gas Savings (therms)	0
Annual Water Savings (gallons)	0
Effective Useful Life (years)	Varies by measure
Incremental Cost ($/unit)	$-2.0 / HE Cost Varies by measure

Measure Description

This measure describes the installation of a new ENERGY STAR 4.0, ENERGY STAR 5.0, or higher efficiency dehumidifier as a replace-on-fail of an existing dehumidifier or instead of a new, baseline efficiency dehumidifier in a new application. ENERGY STAR 4.0, ENERGY STAR 5.0, and high efficiency dehumidifiers save energy through higher moisture removal efficiency compared to older units (including earlier ENERGY STAR standards) and new, standard baseline efficiency units. The dehumidifier efficiency metric is called the Energy Factor (EF) for the 2012 baseline efficiency and Energy Star 4.0 standard and the Integrated Energy Factor (IEF) for the 2019 efficiency and ENERGY STAR 5.0 standard. These metrics describe how much moisture (Liters) is removed from the air per unit energy (kWh) at specified temperature and relative humidity (rating) conditions. There are two methods to estimate savings presented here. The recommended method is to lookup deemed savings based on the annual energy values given in baseline and efficiency measure annual energy tables. These recommended annual energy values were obtained from detailed dehumidifier monitoring across representative cold climate applications [1]. The second method is to use the algorithm to calculate annual energy savings based on estimated or measured parameters from a specific use case. The algorithm is based on measured values and a generic normalization curve fit obtained from laboratory data [1, 2]. Baseline and efficiency measure tables are available to provide parameter estimates for unknown values.

Description of Baseline Condition

The baseline condition is a new, minimum efficiency dehumidifier from one of three size categories. Annual energy values for baseline cold-climate basement dehumidification use cases are given in the table below. These values are used to *determine deemed savings. For more specific savings calculations, the rated performance of baseline units and their appropriate standard are given in the table as well.*

Baseline Annual Energy and Rated Performance

Baseline	Size (Pints/day)	Energy (kWh/yr)	Efficiency Standard	Rated Energy Factor (L/kWh)
New – Small	≤ 25	512	2019	1.3
New – Medium	> 25 & ≤ 50	416	2019	1.6
New – Large	>50	238	2019	2.8

Description of Efficient Condition

The efficiency condition is an ENERGY STAR 4.0, ENERGY STAR 5.0, or other higher efficiency dehumidifier. Both standards are currently available in the market as of December 2020. High efficiency dehumidifiers are those units that *exceed* minimum required Energy Star performance. Annual energy values for efficient cold-climate basement dehumidification use cases are given in the table below. These values are used to determine deemed savings depending on the baseline condition.

Efficiency Measure Annual Energy and Rated Performance

Measure	Size (Pints/day)	Energy (kWh/yr)	Efficiency Standard	Rated Energy Factor (L/kWh)
New ENERGY STAR4.0	<75	424	2012	2
New ENERGY STAR5.0 – Small	≤ 25	424	2019	1.57
New ENERGY STAR 5.0 – Medium	> 25 & ≤ 50	370	2019	1.8
New ENERGY STAR5.0 – Large	>50	201	2019	3.3
New –High Efficiency	ALL	352	2012	2.4

Annual Energy-Savings Algorithm

The deemed savings depend on the selected baseline and efficiency measure. Deemed annual energy savings using this method are given in the Deemed Savings Table below. Empty cells have negative savings. Negative savings occur when a smaller and less efficient dehumidifier replaces a larger more efficient dehumidifier. These cases are unlikely to occur frequently. The bold value represents the most common overall deemed savings; those for small capacity ENERGY STAR 5.0 unit over a small minimum efficiency unit.

Deemed Savings Table

	Baseline		
Efficiency Measure	New Small	New Medium	New Large
New Energy Star 4.0	88		
New ENERGY STAR 5.0 – Small	**88**		
New ENERGY STAR 5.0 – Medium	142	46	
New ENERGY STAR 5.0 – Large	311	215	37
New – High Efficiency	88		

The second method to estimate annual energy savings is a calculation based on the rated performance of the baseline and energy efficient measures, the temperature and relative humidity of the operating environment, and the relevant efficiency standard. The rated performance and efficiency standards are given for the most common scenarios in the baseline and efficiency tables above. Operating conditions for the efficiency standards as well as representative conditions are given in the table below. The algorithm uses a normalization curve fit developed by Winkler et al. to estimate dehumidifier performance across a range of operating conditions [2]. This process is necessary because dehumidifier performance depends strongly on the operating condition and prior work has shown that dehumidifiers are not typically operated at the rated performance conditions [1,2,6].

Operating Conditions

Measure	T (°F)	RH (%)
2012 Federal & ≤ ENERGY STAR 4.0 Standard	80	60
2019 Federal & ENERGY STAR 5.0 Standard	65	60
2018-2019 Field Measurements	67	50

Normalization Curve Fit Parameters [2]

Parameter	Value
a	-1.9022
b	0.063467
c	-0.00062
d	0.03954
e	-0.00013
f	-0.00018

If the representative operating condition is constant and baseline energy data are available at that operating condition, energy savings can be calculated using the formula below.

$kWhSAVED = Eb(1- EFb/STDB * STDe) / EFe$

If measured energy data are used at other operating conditions or energy values measured at the recommended operating conditions must be translated to different operating conditions then energy savings can be calculated using the formulas below, where both baseline and efficiency measures can have different operating conditions or the field energy factor from either or both can be calculated at different operating conditions.

$FEFb = (a + b * T + c * T^2 + d * RH + e * RH^2 + f * T * RH) / STD\_fb*EF\_Rb$

$FEFe = (a + b * T + c * T^2 + d * RH + e * RH^2 + f * T * RH) / STD\_fe*EF\_Re$

$kWHsaved = FEFb / FEFc *Eb$

Where:

a – f	=	Curve fit coefficients for translating rated performance to performance at other operating conditions [2].
T	=	Ambient temperature in dehumidified space. This can be given by user or taken from representative field measurements in the Operating Conditions Table.
RH	=	Ambient relative humidity in dehumidified space; typically it is the dehumidifier setpoint. This can be given by user or taken from representative field measurements in the Operating Conditions Table.
EF_	=	The rated energy factor (2012 efficiency standard) or the rated integrated energy factor (2019 efficiency standard) for the baseline and energy efficiency units.
STD_	=	The efficiency standard of the baseline (b) and energy efficient (e) dehumidifiers. This parameter is 1 for the 2012 efficiency standard and 0.79 for the 2019 efficiency standard, reflecting the difference in operating conditions between the two standards.
FEF_	=	The field energy factor (FEF) is the anticipated performance of a dehumidifier under field conditions (ambient temperature and relative humidity) that vary from rated operating conditions (efficiency standards). It is an intermediate quantity, which is only necessary to calculate if there will be a change in operating condition or if performance must be translated from either rated condition or the recommended field condition.
E_mb	=	Annual energy used by the baseline unit. This can be a measured value or taken from the Baseline Annual Energy and Rated Performance Table.

kWhSAVED = Annual energy savings

Summer Coincident Peak Savings Algorithm

$$Peak\ Savings\ (kW) = \frac{Savings\left(\frac{kWh}{yr}\right)}{runtime\left(\frac{hrs}{yr}\right)} * Coincidence\ Factor\ (0.55)$$

Where:

CF = Coincidence factor (= 0.55)[2]

Lifecycle Energy-Savings Algorithm

$kWh_{LIFECYCLE} = kWh_{SAVED} * EUL$

Where:

EUL = Effective useful life (= 10 for baseline ENERGY STAR dehumidifiers; = 15 years for high efficiency dehumidifiers)

Assumptions

Both the deemed savings and calculated savings approaches are based on measurements conducted in 20 homes in 2018-2019, which aimed to represent dehumidifier use characteristics developed from

[2] This was the average value obtained for July and August during the 3pm – 7pm peak load window for the 6 units studied

statewide surveys and site visits conducted in Minnesota [1]. This study measured annual energy from 15 existing, pre- ENERGY STAR 4.0 dehumidifiers, 18 ENERGY STAR 4.0 rated dehumidifiers, and four high performance dehumidifiers in single-family homes over two dehumidification seasons. A critical assumption is that these Minnesota dehumidification use cases are also representative of typical use cases in Wisconsin. This assumption was deemed reasonable due to similar findings between these measurements and prior work [2, 5, and 6] as well as similar climates, housing stock, and applications.

The calculated savings approach assumes that dehumidifier performance at any operating condition can be estimated by performance at a known condition. Winkler et al. found that generic performance curve fit could predict dehumidifier performance over an operating range from 59 °F and 40% relative humidity to 86 °F and 80% relative humidity to within 5.9% under laboratory conditions [2]. This relationship between operating conditions and performance was found to hold in the field as well [1]. This same assumption can be used to develop the STD factor, which enables a single formula to be used for dehumidifier units with performance rated at either the 2012 or 2019 efficiency standards.

Sources

Quinnell, J., 2020, Portable Dehumidification in Minnesota Single-Family Homes, Conservation Applied Research & Development, Minnesota Department of Commerce. (TBP)

A sampling of 1,497 geographically diverse occupants of single-family homes in Minnesota were polled on dehumidifier ownership. Follow up surveys and site visits were conducted on 197 53 occupants to characterize dehumidification in climate zones 6 and 7. A sample of 20 sites were selected from these data to match the representative characteristics of dehumidifier applications. These units were monitored through a full dehumidification season, including detailed measurements of energy use, condensate production, and ambient conditions. These units were replaced by ENERGY STAR4.0 and high efficiency dehumidifiers alongside operational and behavior based strategies to improve dehumidification outcomes.

Winkler, J., Christensen, D., and Tomerlin, J., 2011, Laboratory Test Report for Six ENERGY STAR Dehumidifiers, Technical Report. National Renewable Energy Laboratory, NREL/TP-5500-52791, Golden, CO. December 2011.

Laboratory measurements verified the rated performance of six different ENERGY STAR and high efficiency dehumidifiers at the rated conditions. The performance was also measured over a range of operating conditions resulting in performance curves for each unit as a function of inlet temperature and relative humidity. A generic performance curve was created for all six units with an error in predicted energy factors of less than 5.9%. Curve fit parameters from this curve are used to scale energy consumption across operating conditions or between rating conditions.

ENERGY STAR

DOE Federal Registrar

Energy Center of Wisconsin, 2010, Dehumidification and Subslab ventilation in Wisconsin Homes, A Field Study. Madison, WI.

https://www.focusonenergy.com/sites/default/files/dehumidificationsubslabventialation_evaluationreport.pdf

Mattison, L. and Korn, D., 2012, Dehumidifiers: A Major Consumer of Residential Electricity, ACEEE Summer Study on Energy Efficiency in Buildings, August 2012.

Revision History

Version Number	Date	Description of Change
01	12/05/2020	Initial TRM workpaper DRAFT
011	12/29/2020	Edits based on staff feedback
012	12/31/2020	Split measure in 2; retrofit and replace on fail
013	10/31/2021	Updated coincidence factors with those measured in fieldwork

Standalone Dehumidifier – Retrofit Measure

	Measure Details
Measure Master ID	TBD
Workpaper ID	TBD
Measure Unit	Per dehumidifier
Measure Type	Prescriptive
Measure Group	HVAC or Vending & Plug Loads
Measure Category	Dehumidifier
Sector(s)	Residential- single family
Annual Electricity Savings (kWh)	Varies by size and efficiency
Peak Demand Reduction (kW)	Varies by size and efficiency
Annual Natural Gas Savings (therms)	0
Lifecycle Electricity Savings (kWh)	Varies by measure
Lifecycle Natural Gas Savings (therms)	0
Annual Water Savings (gallons)	0
Effective Useful Life (years)	Varies by measure
Incremental Cost ($/unit)	$-2.0 / HE Cost Varies by measure

Measure Description

This measure describes the installation of a new ENERGY STAR r 4.0, ENERGY STAR r 5.0, or higher efficiency dehumidifier as a retrofit for an existing dehumidifier. Energy Star 4.0, ENERGY STAR 5.0, and high efficiency dehumidifiers save energy through higher moisture removal efficiency compared to older units (including earlier ENERGY STAR standards) and new, standard baseline efficiency units. The dehumidifier efficiency metric is called the Energy Factor (EF) for the 2012 baseline efficiency and ENERGY STAR 4.0 standard and the Integrated Energy Factor (IEF) for the 2019 efficiency and ENERGY STAR 5.0 standard. These metrics describe how much moisture (Liters) is removed from the air per unit energy (kWh) at specified temperature and relative humidity (rating) conditions. There are two methods to estimate savings presented here. The recommended method is to lookup deemed savings based on the annual energy values given in baseline and efficiency measure annual energy tables. These recommended annual energy values were obtained from detailed dehumidifier monitoring across representative cold climate applications [1]. The second method is to use the algorithm to calculate annual energy savings based on estimated or measured parameters from a specific use case. The algorithm is based on measured values and a generic normalization curve fit obtained from laboratory data [1, 2]. Baseline and efficiency measure tables are available to provide parameter estimates for unknown values. A spreadsheet is available to simplify the calculation.

Description of Baseline Condition

The baseline condition is any existing dehumidifier rated ENERGY STAR 3.0 or lower in performance, including unrated units. Annual energy values for baseline cold-climate basement dehumidification use cases are given in the table below. These values are used to determine deemed savings. For more specific savings calculations, the rated performance of baseline units and their appropriate standard are given in the table as well.

Baseline Annual Energy and Rated Performance

Baseline	Size (Pints/day)	Energy (kWh/yr)	Efficiency Standard	Rated Energy Factor (L/kWh)
Existing ENERGY STAR 3.0 or lower	ALL	767	2012	1.1

Description of Efficient Condition

The efficiency condition is an ENERGY STAR 4.0, ENERGY STAR 5.0, or other higher efficiency dehumidifier. Both standards are currently available in the market as of December 2020. High efficiency dehumidifiers are those units that *exceed* minimum required Energy Star performance. Annual energy values for efficient cold-climate basement dehumidification use cases are given in the table below. These values are used to determine deemed savings depending on the baseline condition.

Efficiency Measure Annual Energy and Rated Performance

Measure	Size (Pints/day)	Energy (kWh/yr)	Efficiency Standard	Rated Energy Factor (L/kWh)
New ENERGY STAR 4.0	<75	424	2012	2
New ENERGY STAR 5.0 – Small	> 25 & ≤ 50	424	2019	1.57
New ENERGY STAR 5.0 – Medium	≤ 50	370	2019	1.8
New ENERGY STAR5.0 – Large	>50	201	2019	3.3
New –High Efficiency	ALL	352	2012	2.4

Annual Energy-Savings Algorithm

The deemed savings depend on the selected baseline and efficiency measure. Deemed annual energy savings using this method are given in the Deemed Savings Table below. Empty cells have negative savings. Negative savings occur when a smaller and less efficient dehumidifier replaces a larger more efficient dehumidifier. These cases are unlikely to occur frequently. The bold value represent the most common overall deemed savings; those for small capacity ENERGY STAR 5.0 units over generic existing unit.

Deemed Savings Table

	Baseline
Efficiency Measure	Existing Unit
New ENERGY STAR 4.0	343
New ENERGY STAR 5.0 – Small	**343**
New ENERGY STAR 5.0 – Medium	397
New ENERYG STAR 5.0 – Large	566
New – High Efficiency	415

The second method to estimate annual energy savings is a calculation based on the rated performance of the baseline and energy efficient measures, the temperature and relative humidity of the operating environment, and the relevant efficiency standard. The rated performance and efficiency standards are given for the most common scenarios in the baseline and efficiency tables above. Operating conditions for the efficiency standards as well as representative conditions are given in the table below. The algorithm uses a normalization curve fit developed by Winkler et al. to estimate dehumidifier performance across a range of operating conditions [2]. This process is necessary because dehumidifier performance depends strongly on the operating condition and prior work has shown that dehumidifiers are not typically operated at the rated performance conditions [1,2,6].

Operating Conditions

Measure	T (°F)	RH (%)
2012 Federal & ≤ Energy Star 4.0 Standard	80	60
2019 Federal & Energy Star 5.0 Standard	65	60
2018-2019 Field Measurements	67	50

Normalization Curve Fit Parameters [2]

Parameter	Value
a	-1.9022
b	0.063467
c	-0.00062
d	0.03954
e	-0.00013
f	-0.00018

If the representative operating condition is constant and baseline energy data are available at that operating condition, energy savings can be calculated using the formula below.

*kWhSAVED = Eb(1- EFb/STDB * STDe) / EFe*

If measured energy data are used at other operating conditions or energy values measured at the recommended operating conditions must be translated to different operating conditions then energy savings can be calculated using the formulas below, where both baseline and efficiency measures can have different operating conditions or the field energy factor from either or both can be calculated at different operating conditions.

*FEFb = (a + b * T + c * T^2 + d * RH + e * RH^2 + f * T * RH) / STD_fb*EF_Rb*

*FEFe = (a + b * T + c * T^2 + d * RH + e * RH^2 + f * T * RH) / STD_fe*EF_Re*

*kWHsaved = FEFb / FEFc *Eb*

Where:

a – f = Curve fit coefficients for translating rated performance to performance at other operating conditions [2].

T = Ambient temperature in dehumidified space. This can be given by user or taken from representative field measurements in the Operating Conditions Table.

RH = Ambient relative humidity in dehumidified space; typically it is the dehumidifier setpoint. This can be given by user or taken from representative field measurements in the Operating Conditions Table.

EF_ = The rated energy factor (2012 efficiency standard) or the rated integrated energy factor (2019 efficiency standard) for the baseline and energy efficiency units.

STD_ = The efficiency standard of the baseline (b) and energy efficient (e) dehumidifiers. This parameter is 1 for the 2012 efficiency standard and 0.79 for the 2019 efficiency standard, reflecting the difference in operating conditions between the two standards.

FEF_ = The field energy factor (FEF) is the anticipated performance of a dehumidifier under field conditions (ambient temperature and relative humidity) that vary from rated operating conditions (efficiency standards). It is an intermediate quantity, which is only necessary to calculate if there will be a change in operating condition or if performance must be translated from either rated condition or the recommended field condition.

E_mb = Annual energy used by the baseline unit. This can be a measured value or taken from the Baseline Annual Energy and Rated Performance Table.

kWhSAVED = Annual energy savings

Summer Coincident Peak Savings Algorithm

$$Peak\ Savings\ (kW) = \frac{Savings\left(\frac{kWh}{yr}\right)}{runtime\left(\frac{hrs}{yr}\right)} * Coincidence\ Factor\ (0.55)$$

Where:

CF = Coincidence factor (= 0.55)[3]

Lifecycle Energy-Savings Algorithm

$kWh_{LIFECYCLE} = kWh_{SAVED} * EUL$

Where:

EUL = Effective useful life (= 10 for baseline and ENERGY STAR dehumidifiers; = 15 years for high efficiency dehumidifiers)

Assumptions

Both the deemed savings and calculated savings approaches are based on measurements conducted in 20 homes in 2018-2019, which aimed to represent dehumidifier use characteristics developed from

[3] This was the average value obtained for July and August during the 3pm – 7pm peak load window for the 6 units studied

statewide surveys and site visits conducted in Minnesota [1]. This study measured annual energy from 15 existing, pre- ENERGY STAR 4.0 dehumidifiers, 18 ENERGY STAR 4.0 rated dehumidifiers, and four high performance dehumidifiers in single-family homes over two dehumidification seasons. A critical assumption is that these Minnesota dehumidification use cases are also representative of typical use cases in Wisconsin. This assumption was deemed reasonable due to similar findings between these measurements and prior work [2, 5, and 6] as well as similar climates, housing stock, and applications.

The calculated savings approach assumes that dehumidifier performance at any operating condition can be estimated by performance at a known condition. Winkler et al. found that generic performance curve fit could predict dehumidifier performance over an operating range from 59 °F and 40% relative humidity to 86 °F and 80% relative humidity to within 5.9% under laboratory conditions [2]. This relationship between operating conditions and performance was found to hold in the field as well [1]. This same assumption can be used to develop the STD factor, which enables a single formula to be used for dehumidifier units with performance rated at either the 2012 or 2019 efficiency standards.

Sources

Quinnell, J., 2020, Portable Dehumidification in Minnesota Single-Family Homes, Conservation Applied Research & Development, Minnesota Department of Commerce. (TBP)

A sampling of 1,497 geographically diverse occupants of single-family homes in Minnesota were polled on dehumidifier ownership. Follow up surveys and site visits were conducted on 197 53 occupants to characterize dehumidification in climate zones 6 and 7. A sample of 20 sites were selected from these data to match the representative characteristics of dehumidifier applications. These units were monitored through a full dehumidification season, including detailed measurements of energy use, condensate production, and ambient conditions. These units were replaced by ENERGY STAR4.0 and high efficiency dehumidifiers alongside operational and behavior based strategies to improve dehumidification outcomes.

Winkler, J., Christensen, D., and Tomerlin, J., 2011, Laboratory Test Report for Six ENERGY STAR Dehumidifiers, Technical Report. National Renewable Energy Laboratory, NREL/TP-5500-52791, Golden, CO. December 2011.

Laboratory measurements verified the rated performance of six different Energy Star and high efficiency dehumidifiers at the rated conditions. The performance was also measured over a range of operating conditions resulting in performance curves for each unit as a function of inlet temperature and relative humidity. A generic performance curve was created for all six units with an error in predicted energy factors of less than 5.9%. Curve fit parameters from this curve are used to scale energy consumption across operating conditions or between rating conditions.

Energy Star

DOE Federal Registrar

Energy Center of Wisconsin, 2010, Dehumidification and Subslab ventilation in Wisconsin Homes, A Field Study. Madison, WI.

https://www.focusonenergy.com/sites/default/files/dehumidificationsubslabventialation_evaluationreport.pdf

Mattison, L. and Korn, D., 2012, Dehumidifiers: A Major Consumer of Residential Electricity, ACEEE Summer Study on Energy Efficiency in Buildings, August 2012.

Revision History

Version Number	Date	Description of Change
01	12/05/2020	Initial TRM workpaper DRAFT
011	12/29/2020	Edits based on staff feedback
012	12/31/2020	Split measure in 2; retrofit and replace on fail
013	10/31/2021	Updated coincidence factors with those measured in fieldwork

Appendix D: Load Flexible Dehumidifier Equipment

Table 14: Potential smart thermostats for dehumidifier control

Brand and Model	Cost	Works With	Works with	Product Link
Nest Learning	$130	Google Home app		https://store.google.com/us/magazine/compare_thermostats?hl=en-US
Nest Learning	$249	Nest app	Nest temp sensor	https://store.google.com/us/magazine/compare_thermostats?hl=en-US
SmartThermostat w voice control	$250	Ecobee app		https://www.ecobee.com/en-us/smart-thermostats/
Ecobee3 Lite	$170	Ecobee app		https://www.ecobee.com/en-us/smart-thermostats/
Smart thermostat with whole house sensors	$220	Ecobee app		https://www.ecobee.com/en-us/smart-thermostats/
T9 Smart			Alexa, Google Assistant, IFTTT	https://www.honeywellhome.com/us/en/products/air/thermostats/wifi-thermostats/
Sensi Touch smart	$169			https://sensi.emerson.com/en-us/shop/sensi/products/sensi-sensi-touch-smart-thermostat-white?fetchFacets=true#facet:&partsFacet:&facetLimit:&productBeginIndex:0&partsBeginIndex:0&orderBy:2&partsOrderBy:&pageView:list&minPrice:&maxPrice:&pageSize:&
ST55 Sensi smart	$129		Alexa, Google Assistant, Apple Homekit, Smart Things	https://sensi.emerson.com/en-us/products/wifi-thermostat

Table 15: Potential smart plugs for dehumidifier control

Brand	Cost	Remote on/off	Hub Required?	Schedule/ Timer?	App	Works with	Product Link
Belkin Wemo	$25	y		y	Wemo app	Alexa, Google Assistant, Apple Homekit, Smart Things, IFFFT	https://www.belkin.com/us/smart-home/wemo/wemo-wifi-smart-plug/p/p-wsp080/
TP-Link Kasa/Kasa Smart Wifi plug	$30	y		y	Kasa Smart app		https://www.kasasmart.com/us/products/smart-plugs/kasa-smart-wifi-power-outlet-kp200
Wyze	$15		No hub required			Alexa, Google assistant,	https://wyze.com/wyze-plug.html
Amazon	$25					Alexa app	https://www.amazon.com/Amazon-Smart-Plug-works-Alexa/dp/B01MZEEFNX
Eve	$40			y			https://www.evehome.com/en-us/eve-energy

Table 16: Potential apps for dehumidifier control

App Type	Brand	Model	App name	App Link
Smart Dehumidifier	Honeywell	TP50AWKN	HonewellAir-Comfort	https://play.google.com/store/apps/details?id=com.jmateks.smart&hl=en_US&gl=US
Smart Dehumidifier	Emerson	EAD50SE1H	ConnectLife	https://play.google.com/store/apps/details?id=com.hisense.juconnect.connectlife&hl=en_US&gl=US

App Type	Brand	Model	App name	App Link
Smart Plug	Wemo	na	Wemo	https://play.google.com/store/apps/details?id=com.belkin.wemoandroid&hl=en_US&gl=US
Smart Plug	Kasa		Kasa	https://play.google.com/store/apps/details?id=com.tplink.kasa_android
Whole House Dehumidifier	Honeywell		TCC	https://play.google.com/store/apps/details?id=com.honeywell.mobile.android.totalComfort

Table 17: Potential smart (and non smart) dehumidifiers

Smart/ Wifi	Brand	Model	Cost	Watts	Capacity (Pint)	Bucket Size	Coverage (sq ft)	Energy Star	Timer	Auto Restart	continuous drain option	Pump?	Wifi?	Alexa control	Link to Product
No	LG	UD501KOG5	$300	545	50			y	y	y	y	y			https://www.lg.com/us/air-care-solutions/lg-ud501kog5-dehumidifier
Yes	LG	UD501KOJ5	$329	545	50			y	y	y	y	y	y		https://www.lg.com/us/air-care-solutions/lg-ud501koj5
Yes	TCL	30D91	$200		30		2500	y	y	y	n			y	https://www.tcl.com/us/en/products/appliances/dehumidifiers/30-pint-dehumidifier-30d91
Yes	TCL	50D91	$240		50		4500	y	y	y	n			y	https://www.tcl.com/us/en/products/appliances/dehumidifiers/50-pint-dehumidifier-50d91
No	TCL	TDW50EP20-B	$230		50		4500	y	y	y					https://www.tcl.com/us/en/products/appliances/dehumidifiers/50-pint-dehumidifier-tdw50ep20-b
Yes	Hisense	DH7021W1WG	$299	564	50		2000	y	y	?	y	n	y	y	https://www.hisense-usa.com/air-products/all-air-products/DH7021W1WG_hisense-connectlife-smart-control-50-pint-3-speeds-dehumidifier
No	Hisense	DH7021K1W	$249	564	50		2000	y	y	?	y	n			https://www.hisense-usa.com/air-products/all-air-products/DH7021K1W_hisense-energy-star-50-pint-3-speeds-dehumidifier
	Hisense	DH70W1WG Dehumidifier												app	https://assets.hisense-usa.com/assets/ProductDownloads/68/62c1736693/2-User-Manual-for-Hi-Smart-v2.pdf
Yes	Emerson	DEH-EA-WIFI-EAD30SE1T	$250		30	7.4 pints		y	y	?	?	n	y	y	https://www.emersonquietkool.com/collections/dehumidifier/products/eqk-dehumidifier-2?variant=39995664040088
Yes	Emerson	DEH-EA-WIFI-EAD50SEP1T	$350		50	13.7 pints		y	y	?	?	y	y	y	no longer available on their website
Yes	Emerson	DEH-EA-WIFI-EAD50SE1T	$310		50	13.7 pints		y	y	?	?	n	y	y	https://www.amazon.com/Emerson-Quiet-Kool-Efficiency-Dehumidifier/dp/B0868QPHLP
No	Emerson	DEH-EA-EAD30SE1T	$220		30	7.4 pints		y				n			-
No	Emerson	DEH-EA-EAD50SEP1T	$270		50	13.7 pints		y				y			
No	Emerson	DEH-EA-EAD50SE1T	$270		50	13.7 pints		y				n			
Yes	Emerson	EAD50E1H	$230		50						n				https://www.emersonquietkool.com/collections/dehumidifier/products/eqk-dehumidifier-2?variant=39995663974552
Yes	Emerson	EAD50SEP1H	$260		50						y				https://www.emersonquietkool.com/collections/dehumidifier/products/eqk-dehumidifier-2?variant=39995664007320

Smart/ Wifi	Brand	Model	Cost	Watts	Capacity (Pint)	Bucket Size	Coverage (sq ft)	Energy Star	Timer	Auto Restart	continuous drain option	Pump?	Wifi?	Alexa control	Link to Product
Yes	Emerson	EAD50SE1H	$250		50						n				https://www.emersonquietkool.com/collections/dehumidifier/products/eqk-dehumidifier-2?variant=39995664040088
Yes	Frigidaire	FGAC5044W1	$379		50			y	y	y	y		y		https://www.frigidaire.com/Home-Comfort/Dehumidifiers/FGAC5044W1/
No	Frigidaire	FFAD5033W1	$299		50	16.9 pints		y	y	y	y	n			https://www.frigidaire.com/Home-Comfort/Dehumidifiers/FFAD5033W1/
No	Frigidaire	FFAP5033W1	$370		50			y	y	y	y	y			https://www.frigidaire.com/Home-Comfort/Dehumidifiers/FFAP5033W1/
Yes	Honeywell	TP30AWKN	$270	298	30/20 DOE	7 pints	2000	y	y	y	y	n	y	y	https://www.honeywellstore.com/store/products/honeywell-smart-wifi-30-pint-energy-star-dehumidifier-tp30awkn.htm
Yes	Honeywell	TP50AWKN	$345	490	50/30 DOE	7 pints	3000	y	y	y	y	n	y	y	https://www.honeywellstore.com/store/products/honeywell-smart-wifi-50-pint-energy-star-dehumidifier-tp50awkn.htm
No	Honeywell	TP30AWKN	$240	298	30/20 DOE	7 pints	2000	y	y	y	y	n			https://www.honeywellstore.com/store/products/honeywell-30-pint-energy-star-dehumidifier-for-small-rooms-tp30wkn.htm
No	Honeywell	TP50AWKN	$315	490	50/30 DOE	7 pints	3000	y	y	y	y	n			https://www.honeywellstore.com/store/products/honeywell-50-pint-energy-star-dehumidifier-for-medium-sized-rooms-tp50wkn.htm
Yes	Ivation	IVADUWIFI50WP	$300		50/70	2.25 gal	4500		y	y	y	y	y	y	Amazon.com - Ivation 4, 500 Sq Ft Smart Wi-Fi Energy Star Dehumidifier with App, Continuous Drain Hose Connector, Programmable Humidity, 2.25 Gal Reservoir for Medium and Large Rooms (4, 500 Sq Ft) -
No	Ivation	IVADH30PW	$230	345	30	1.3 gal	2000	y	y	y	y	n			https://www.ivationproducts.com/collections/dehumidifiers/products/ivadh30pw-30-pint-energy-star-dehumidifier
No	Ivation	IVADH50PW	$266	345	50	1.3 gal	3000	y	y	y	y	n			https://www.ivationproducts.com/collections/dehumidifiers/products/ivaldh50pw-50-pint-energy-star-dehumidifier

Appendix E: Site-Specific Notes and Results

All the houses in the study were single-family residences with continuous draining dehumidifiers placed in the basement. All houses used the dehumidifiers during the humid months from late spring to early fall. The houses that used smart plugs were the only ones that had technical issues. The inability to verify any more than the fact that the power was on or off when using smart plugs did decrease their reliability compared to the other methods. The smart dehumidifiers both worked the entire research period without issues, as did the whole-house dehumidifier connected to a smart dehumidifier.

1. Site 1 was a single-family house with four occupants. They had a dehumidifier with a smart plug in their unfinished basement. The house had central air that worked intermittently throughout the project timeframe. This household did have two events that needed to be dismissed due to the dehumidifier being turned off. It is unclear if this was due to occupant control or the smart plug. Otherwise the smart plug was worked as intended.

2. Site 2 was a single-family house without central air and two occupants. This house had a smart dehumidifier in their unfinished basement. They used a portable air conditioning unit (that outlets exhaust air through a vent to a window) on extremely hot days but had limited air conditioning in the house. The testing at this house had no technical issues, and we were able to log every event that was scheduled.

3. Site 3 was also a single-family house, with one occupant and without central air. This house had a smart dehumidifier in their basement. This house did not have any form of air conditioning. Like site 2, there were no technical issues, and we were able to log every event that was scheduled.

4. Site 4 was a single-family house with two occupants and central air. The dehumidifier was in their finished basement. The first smart plug had issues connecting with the Wi-Fi in this house. The plug would disconnect and would only reconnect if the home-owner power cycled the plug. The plug would then disconnect again within 24 hours. Because of the connectivity issues, a second smart plug replaced it after the first week of testing. Once the smart plug was replaced there were no more technical issues with this house. The testing originally meant for the first week (when there were Wi-Fi issues with the first smart plug) was redone during the final week of the testing period. This household did have one event that was not logged due to technical issues. In this case, the dehumidifier restarted 15 minutes earlier than it should have. It is not clear if this was an issue with the smart plug or occupant behavior.

5. Site 5 was a single-family house with 4 occupants and central air. This is the only house that had a whole-house dehumidifier (in an unfinished basement), which was connected to a smart thermostat. The testing at this house had no technical issues, and we were able to log every event that was scheduled.

6. Site 6 was a single-family house with 2 occupants. The dehumidifier was in the finished basement and they used a smart plug for testing. This house was used as a back-up for the project and did not get started until the second week of testing. They experienced flooding in their basement in the final week, so the dehumidifier was not plugged in for the whole testing period. That said, there were no technical issues with testing.

Site 3

Figure 15 shows a typical type 1 peak event at site 3. We see the cycling of the dehumidifier power before the event. At 3 pm the power goes to zero as the relative humidity increases slightly until the event end at 7 pm. At this time the dehumidifier stays on for longer than its normal cycle in order to recover the relative humidity setpoint. Once this is met the dehumidifier returns to its normal cycling.

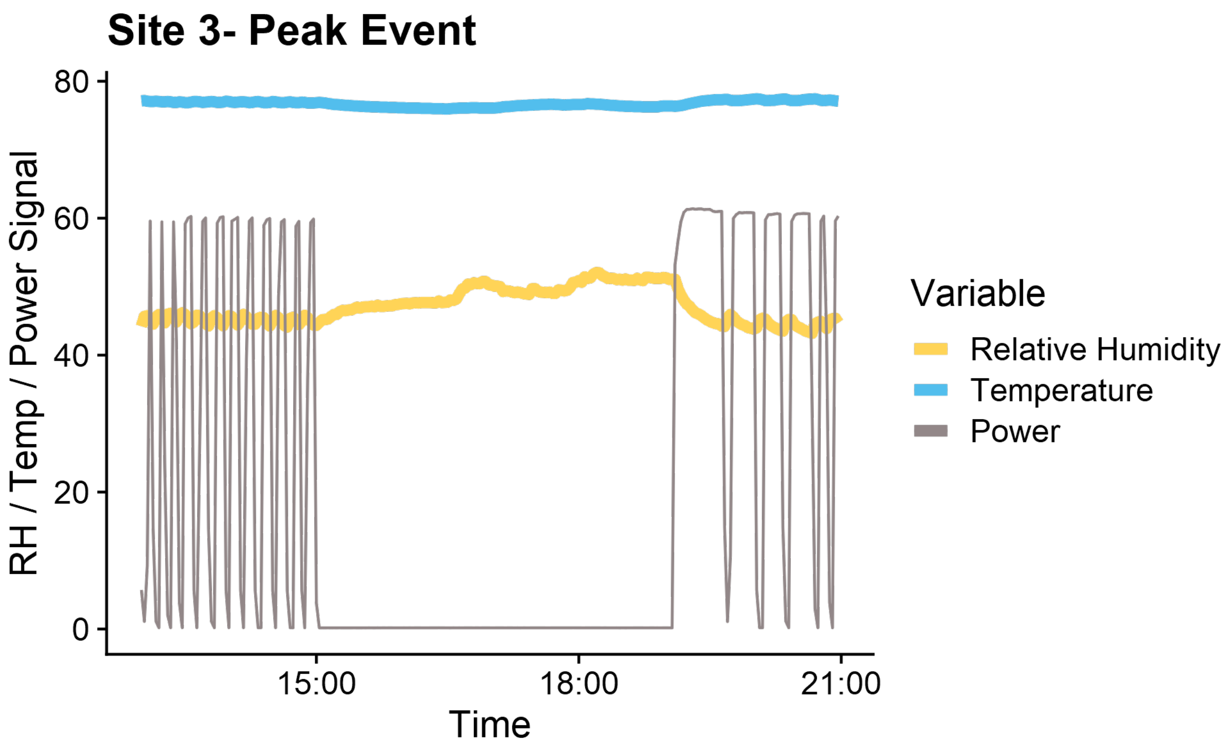

Figure 15:Type 1 peak event at site 3

Site 4

Figure 12 shows a type 1 peak event at site 4. We see power to the dehumidifier is essentially zero as the relative humidity is already satisfied. At 3 pm the power stays at zero as the relative humidity increases slightly until the event end at 7 pm. At this time the dehumidifier turns on and returns to its normal cycling. Whereas this unit wasn't operating at the start of the cycle, the event successfully prevented the unit from running during the event as evidenced by the recovery beginning at the end of the event.

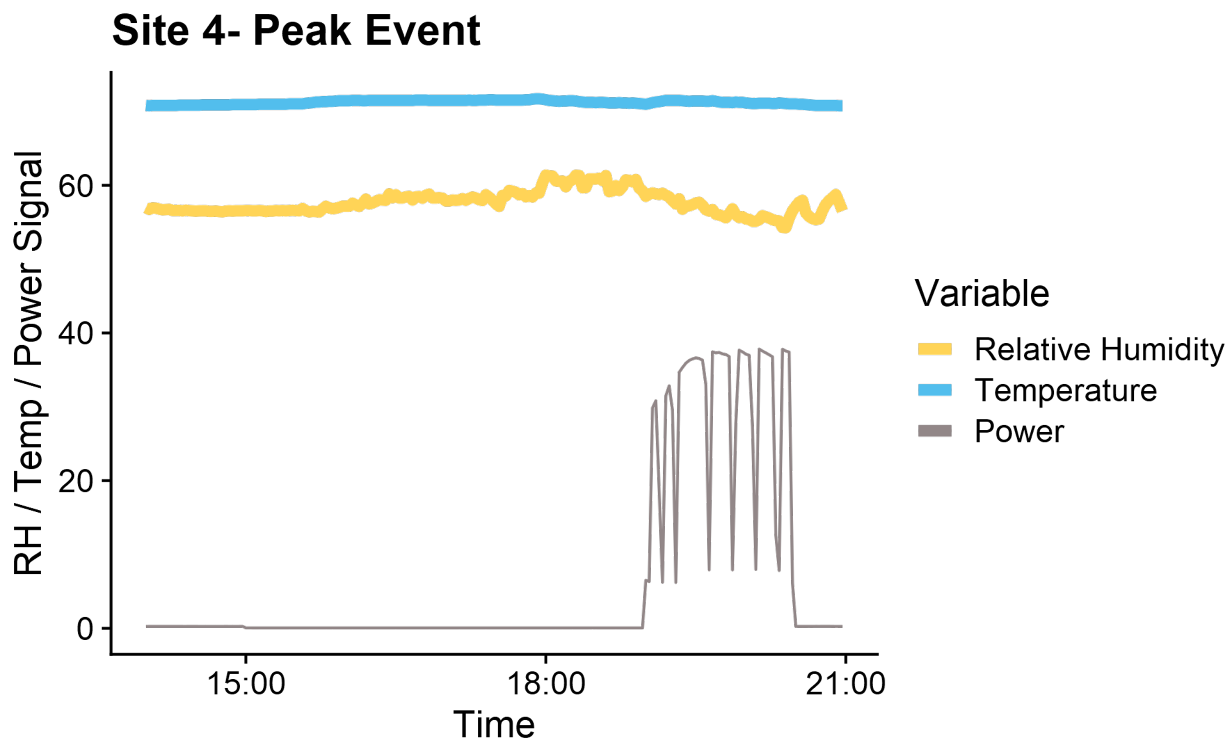

Figure 16: Type 1 peak event at site 4

Site 5

Figure 17 shows a type 1 peak event at site 5. In this case dehumidifier is operating at full power before the event. At 3 pm the power goes to zero and the relative humidity increases slightly until the event end at 7 pm. At this time the dehumidifier stays on in order to recover the relative humidity setpoint.

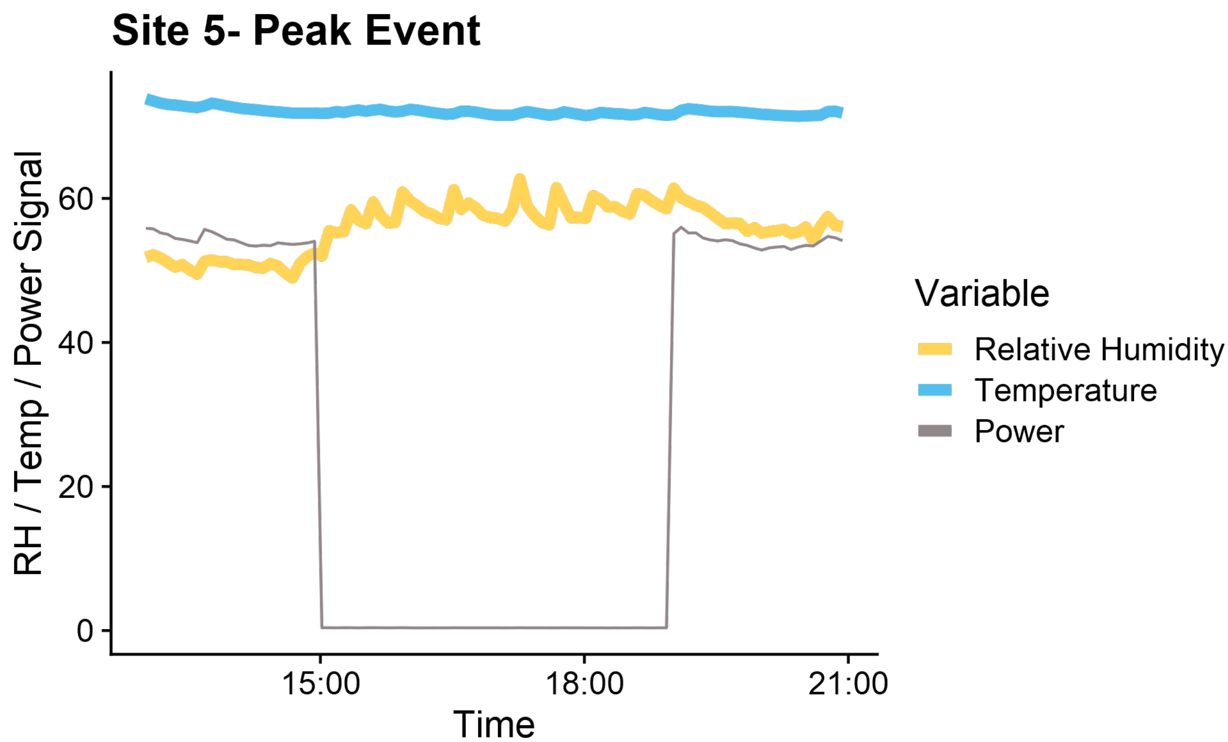

Figure 17: Type 1 peak event at site 5

Site 6

Figure 18 shows a type 1 peak event at site 6. We see the long cycling of the dehumidifier power before the event indicating a fairly high dehumidification load. At 3 pm the power goes to zero as the relative humidity increases slightly until the event end at 7 pm. At this time the dehumidifier resumes at full power to recover the relative humidity setpoint.

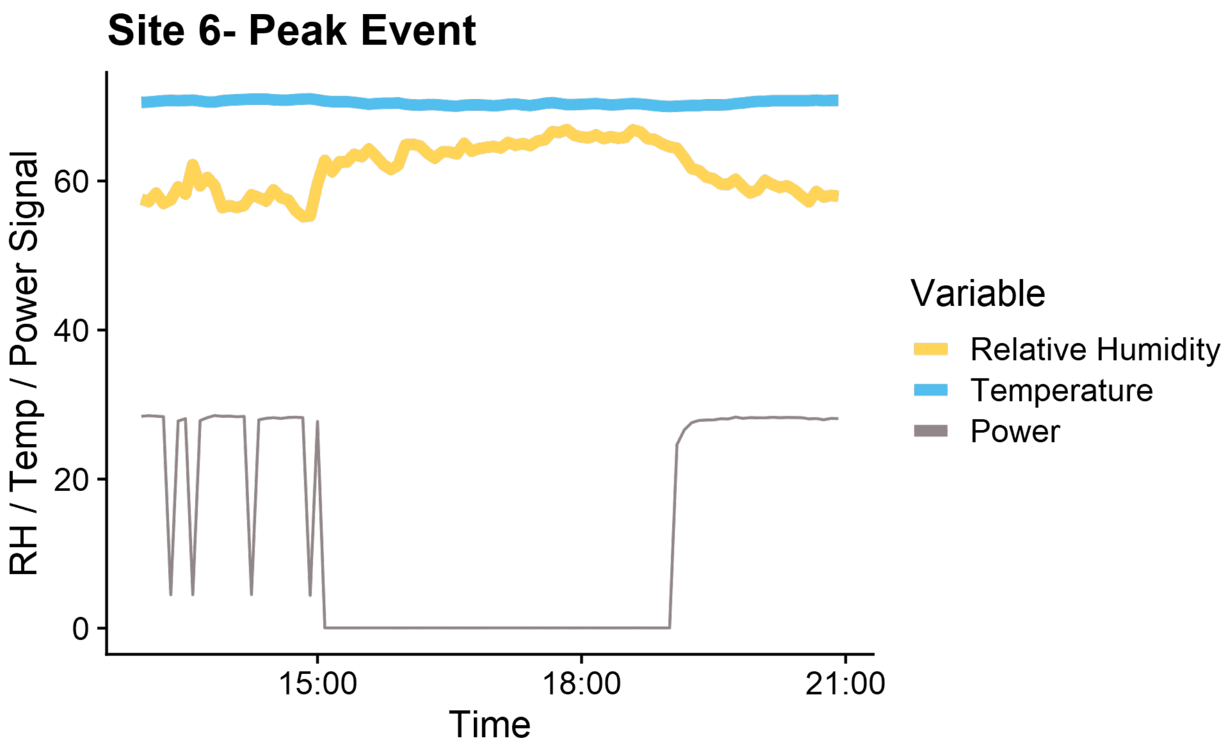

Figure 18: Type 1 peak event at site 6