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Dehumidifier Use in the U.S. Residential Sector: Results from an Amazon Mechanical Turk Survey

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DISCLAIMER

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1 INTRODUCTION

The energy consumed by dehumidifiers differs among households depending on user settings, frequency and duration of product operation, and the ambient conditions under which the product operates. In the United States, dehumidifiers are used most commonly in basements during humid summer days in northern climates. Although there have been past efforts to obtain information that describes dehumidifier ownership and usage patterns in the United States, there remains a lack of real-world data collected from individual households. This lack of data severely limits Lawrence Berkeley National Laboratory's (LBNL's) ability to quantify current usage patterns and thus energy consumption, and ultimately to predict the effects energy efficiency standards might have. Data that more precisely characterize dehumidifier use in real-world applications will facilitate a more accurate estimate of their range in energy use.

To define a more precise range in annual dehumidifier energy use, LBNL initiated an online consumer survey through Amazon Mechanical Turk (AMT). The survey was designed to collect nationally representative data on dehumidifier ownership and frequency of use by product type, selected product characteristics, and household demographics. The results of the consumer survey will enable LBNL to improve past estimates of annual energy use by incorporating more detailed and recent data. This report describes earlier sources that have attempted to define dehumidifier ownership and usage in the United States, the dehumidifier product and technology types on the market, and the methodology and findings of the dehumidifier consumer survey.

2 DEHUMIDIFIER DATA OVERVIEW

Lawrence Berkeley National Laboratory's past efforts to calculate dehumidifier energy consumption encountered a lack of data on household-level ownership and usage. Furthermore, sources that collect such data often do not present information at a level of resolution sufficient to inform our calculations of product energy usage. More detailed knowledge of dehumidifier characteristics and ownership demographics (particularly the regions of highest use) will enable us to account for implications those variables may have on day-to-day operation, and thus energy usage. The following sections describe sources that provide relevant dehumidifier ownership and usage data, their limitations, and (if applicable) their usefulness for LBNL's energy use calculation.

2.1 2009 Residential Energy Consumption Survey

The Energy Information Administration's (EIA's) 2009 Residential Energy Consumption Survey (RECS) was designed to be a representative sample of U.S. household energy consumption. The survey collected information regarding the energy characteristics of each surveyed housing unit,

appliance usage patterns, and household demographics. It collected data from 12,083 households divided into the four census regions, the ten census divisions, and 27 geographical areas[1].

The 2009 RECS provides data on dehumidifier ownership and operation—specifically the saturation rate of dehumidifiers, demographics of households owning at least one dehumidifier, and consumers' use of dehumidifiers. In the 2009 RECS, approximately 13 percent of households throughout the United States reported that they used dehumidifiers. The four census divisions that showed the highest percentage of dehumidifier use were the East North Central, Middle Atlantic, South Atlantic, and West North Central (29.9 percent, 23.8 percent, 13.5 percent, and 13.2 percent, respectively). The 2009 RECS data provide insight into dehumidifier ownership and frequency of use, but most notably provides a robust account of household demographics, which we used to benchmark our survey results. RECS, however, does not disaggregate dehumidifier units beyond general product type (whole-home or portable) and capacity, thus limiting the precision of any calculation of annual energy use.

2.2 The Association of Home Appliance Manufacturers

In consultation with manufacturers and others familiar with dehumidifiers, the Association of Home Appliance Manufacturers (AHAM) developed estimates of the annual operating hours typically associated with dehumidifier usage. The association estimated average annual operating hours of 1,095, with a low of 875 and a high of 1,315 hours per year.

The AHAM data and research reports also provide ranges in dehumidifier energy consumption. However, all the estimates were based on numerous assumptions regarding the months when dehumidifiers are used, daily hours of usage, and mode of operation, so the household-specific energy use data are not precise enough to be used for LBNL's analysis.

2.3 California Energy Commission, ENERGY STAR®, and NPD Group

Appliance model and energy use data from the California Energy Commission (CEC) and ENERGY STAR, combined with sales figures from the NPD Group, can help LBNL estimate the capacity of dehumidifiers currently in use and their annual energy use for each U.S. household that owns a dehumidifier.

3 CHARACTERISTICS OF DEHUMIDIFIERS

Although consumer usage and operation strongly affect dehumidifier energy consumption, so do the products' specific characteristics. The following sections describe the range of product and technology options for dehumidifiers intended for residential applications. We describe the two

[1] RECS originally divided the household into nine census division, including New England, Middle Atlantic, East North Central, West North Central, South Atlantic, East South Central, West South Central, Mountain and Pacific. In the 2009 RECS, the Mountain division was subdivided into Mountain North and Mountain South, so we also divided our sample to ten census division in the following analysis.

major types of residential dehumidifier products, how various technologies operate, and some energy-related considerations for portable mechanical/refrigerative dehumidifiers, which represent the most prevalent technology type.

The U.S. Department of Energy (DOE) defines a dehumidifier as "a self-contained, electrically operated, and mechanically encased assembly consisting of—

1. a refrigerated surface (evaporator) that condenses moisture from the atmosphere;
2. a refrigerating system, including an electric motor;
3. an air-circulating fan; and
4. a means for collecting or disposing of the condensate." (42 U.S.C. 6291–6309)

Dehumidifier products can be distinguished by their general type (whole-home or portable units); moisture removal capacity; moisture removal mechanism (tub or drain line); and technology type (mechanical/refrigerative, desiccant, electronic, or heat pump). Although both whole-home and portable dehumidifier units may utilize any of the first four technology types, the overwhelming majority of both product types represent mechanical/refrigerative units.

3.1 Dehumidifier Product Types

The two general types of dehumidifier are *portable units*, designed to dehumidify a room or contained space, and *whole-home units*, designed to dehumidify an entire home.

3.1.1 Portable dehumidifiers

The most common type of residential dehumidifier is a portable unit that removes moisture in one area of a home. The primary components of both portable and whole-home dehumidifiers are the compressor, cooling coils, reheater, and fan. Control usually is provided by a built-in humidistat that enables the user to set the desired humidity level for a room. After the room reaches the set humidity level, the dehumidifier automatically cycles on and off to maintain that level. Other systems use a timer to operate the dehumidifier.

3.1.2 Whole-home dehumidifiers

Whole-home dehumidifiers (WHDs) are designed to either be ducted directly into a home's heating, ventilating, and air-conditioning (HVAC) system or be installed with a separate ducting system. They have a large moisture-removing capacity that provides increased air movement. Technologically WHDs are almost identical to portable mechanical/refrigerative dehumidifiers. The most noticeable difference is the absence of a drainage bucket, because WHDs use a dedicated drain line to dispose of condensate. Although most drain lines rely on gravity to dispose of condensate, supplemental pumps can be used when necessary.

3.2 Dehumidifier Technology Types

Although the *mechanical/refrigerative* technology is the most common, others are *desiccant,* and *electronic/heat pump* dehumidifiers.

3.2.1 Mechanical/Refrigerative

When moist air is drawn into a mechanical/refrigerative dehumidifier, it passes over wet cooling coils (an evaporator), then over a set of heating coils (the condenser) before being returned to the interior space. The air returned to the space is drier and at a slightly higher temperature than the ambient air. The moisture that condenses out of the air drops either into a receptacle (tub or bucket) that is emptied manually or goes directly into a drain line. Some dehumidifiers also incorporate a condensate pump to remove excess water from the drainage area.

3.2.2 Desiccant

A desiccant dehumidifier draws moist air over desiccant materials, such as silica gel. Desiccant materials naturally attract moisture from the air by creating an area of low vapor pressure at the surface of the desiccant. The higher vapor pressure of the moist air causes water molecules in the air to move to the desiccant material. Desiccant dehumidifiers eliminate the need to cool the air prior to dehumidification, making the technology especially suited for cooler climates. Desiccant dehumidifiers comprise the following components:

1. a desiccant holder to contain the silica gel,
2. a fan that draws in air to be passed over the desiccant,
3. a heater to warm the air inside the unit, and
4. a fan to remove the water vapor from the gel so that it can once again absorb moisture.

Desiccant dehumidifiers are made in many configurations, including liquid spray-towers, solid packed towers, rotating horizontal beds, multiple vertical beds, and rotating honeycombs. The most widely used configuration for a home-sized application is the solid packed tower.

3.2.3 Electronic dehumidifier/heat pump

Electronic dehumidifiers utilize a peltier heat pump (named after the French physicist Jean-Charles Peltier) to create a cool surface for water vapor to condense from air. The operation of a heat pump is similar to that of an air conditioner. Moisture is removed from the air as a fan draws indoor air over a heat exchange coil that is at near-freezing temperatures. Water in the air condenses on the coil and is drained into a tank below. The air is reheated and returned to the room.

Because they have no mechanical converters and thus are extremely quiet, heat pump dehumidifiers are well suited to an environment where noise is a concern. Such dehumidifiers

represent a very small percentage of the total market share, however, and were not included as a technology option in our survey.

3.3 Energy Use Considerations for Portable Mechanical/Refrigerative Dehumidifiers

Two considerations for portable mechanical/refrigerative dehumidifiers are the *moisture removal mechanism* and *potential ice buildup,* both of which can affect product energy use.

3.3.1 Moisture removal mechanism

Portable mechanical/refrigerative dehumidifiers utilize one of two moisture removal mechanisms. Most include a receptacle—a tub or bucket—for collecting the condensate produced through dehumidification. The receptacle typically is equipped with a float sensor that detects when the collection vessel is full. The float sensor then sends a signal to shut off the dehumidifier and prevent an overflow of collected water. The receptacle may need to be emptied manually several times a day for continued operation. Portable units designed around a desiccant gel or heat pump also may have collection tubs. Because units having moisture removal tubs tend to experience periods when the unit is shut off, they may have lower energy use.

Most portable dehumidifiers have a fitting that enables the user to attach an ordinary garden hose directly to the collection tub. Although not as common as manual emptying, an attached hose enables users to direct the condensate into a floor drain or sump pump. If gravity does not provide for easy drainage, a dedicated condensate pump can be used to move collected water to a disposal location. Some models can drain into the plumbing system of a house or use a built-in water pump to self-empty as they collect moisture. Because of their large moisture removal capacity, all whole-home dehumidifiers use such drainage devices.

3.3.2 Ice buildup

Frost can form on a dehumidifier's condensing coils if the room air temperature drops below 65 °F. Under certain conditions of temperature and humidity, ice can form in a mechanical dehumidifier. The ice buildup can impede airflow and eventually form a solid block of ice that encases the cooling coils. Ice formation negatively affects performance by causing the compressor to cycle on and off repeatedly without removing moisture from the air. The buildup also can cause water damage if condensed water drips off the accumulated ice but not into the collection tray.

Many higher-end dehumidifiers have a so-called frost or ice sensor that turns off the unit when frost is detected, allowing the icy coils to warm and defrost before automatically restarting. Most ice sensors are simple thermal switches that do not directly sense the presence or absence of ice buildup. An alternative design senses the impeded airflow and shuts off the cooling coils in a similar manner.

4 SURVEY METHODOLOGIES

Lawrence Berkeley National Laboratory conducted its online consumer survey through Amazon Mechanical Turk (AMT), an online survey platform supported by Amazon.com. Our dehumidifier survey targeted anyone in the general U.S. residential population who owns at least one dehumidifier. Based on past experience, we set a goal of 2,000 respondents. The survey, launched on January 17, 2014, and closed on January 31, 2014, collected 2,104 responses in two weeks. The sections below discuss the AMT survey platform, as well as the survey design, parameters, data-cleaning process, and data weighting.

4.1 Survey Platform

As internet availability and use have expanded, online surveys offer the ability to collect data from a wider geographic distribution and in a less costly and time-consuming manner than traditional survey methods. In recent years, a crowd-sourcing online survey platform administered by Amazon.com, Amazon Mechanical Turk, has been used as a cost-effective tool to collect a large amount of data for many social behavioral research projects (Gosling et al. 2004) (Mason and Suri 2012). Because AMT surveys are accessible only to (self-selecting) internet users, certain demographic groups are likely to be underrepresented and others overrepresented in the raw survey response data. For example, households having individuals 20–29 years old are overrepresented, and those who identify themselves as having no college education, being of low income, and being Black/African American are disproportionately underrepresented in the raw survey data. Hence, we applied a weighting method to adjust inherent biases in our raw survey results to ensure that they are representative of the population of U.S. dehumidifier-owning households (see Section 4.4). For more information about the post-stratification method used to mitigate potential biases, see LBNL's report (Greenblatt et al. 2013).

4.2 Survey Design

Our survey first screened potential respondents by informing them that participants had to own and use at least one portable or whole-home dehumidifier in their primary residence. The survey initially asked respondents to identify the number of portable and/or whole-home dehumidifiers in their primary home, then directed respondents to answer a set of questions on product characteristics, product costs, usage, and household demographics. Table 4.1 lists the survey parameters evaluated and the associated survey questions.

Table 4.1 Parameters Evaluated and Associated Survey Questions

Parameter	Query
Saturation of each product class	Number of portable and/or whole-home dehumidifiers in the home Types of dehumidifiers (mechanical or desiccant) Moisture removal capacities Locations of dehumidifiers Brands and models
Usage patterns	Number of months dehumidifiers operating per year Operating hours per day; operating days per week Relative humidity setpoint and operational control Purpose of using dehumidifier
Costs associated with dehumidifier	Purchase price Repair costs/amount of rebate
Connection to other surveys	Demographics of the respondent and household

The demographic questions were structured to be consistent with the 2009 RECS survey so that we could benchmark our survey data directly to the 2009 RECS data. The demographic questions in the survey requested information on geographic region, gender, race, education, age distribution, size of household and annual household income.

To increase data quality for the survey, we also included a "cheater" question (a non-topical question that attempts to identify frivolous respondents) in each product section. The cheater question in the section on portable dehumidifiers asked respondents to identify what ice cubes typically are made of, and the cheater question in the section on WHDs asked respondents to choose the correct number of hours in a day.

The full survey is available in the Appendix.

4.3 Data-Cleaning Schemes

To obtain high-quality survey data, LBNL employed several data-cleaning schemes. We first discarded records from respondents who failed to provide the cheater question or provided the wrong answer to a cheater question, assuming those respondents were distracted or deliberately gave untruthful answers. Other data-cleaning schemes included removing duplicate respondents and respondents who skipped seven or more questions from both product-related and demographic questions combined. During the preliminary data analysis, we found that 8 percent of total respondents claimed to own both portable and whole-home dehumidifiers. Most of those respondents, however, failed to provide a model number for their WHD, or the model number they provided was either unverifiable or not actually a WHD. Thus, we believe those respondents may have mistakenly interpreted the ownership question or do not own a whole-home

dehumidifier. We further repeated this model number verification exercise to all the models provided, and removed those potentially mistaken responses from our analysis. After applying the data-cleaning schemes to the original data set, we generated a set of raw clean AMT survey data. Table 4.2 shows the data cleaning statistics, including the total number of record exclusions by basis for elimination.

Table 4.2 Data Cleaning Statistics

Responses	**Number**
Raw responses	2,104
Eliminated responses	482
Rationale for Elimination	**Number of Exclusions**
- Duplicate	14
- Failed to answer cheater questions or answered incorrectly	239
- 7 or more skipped questions	41
- Inconsistent answers*	188
Remaining clean responses	1,622

Note: *Inconsistent answers include those who provided inconsistent responses to related product characteristics questions and those who provided unverifiable dehumidifier model numbers.

4.4 Data Weighting Methods

Below we describe the purpose for weighting the data obtained and the method we applied to weigh the data.

4.4.1 Purpose

As mentioned above, we observed some demographic biases in our raw AMT survey results compared to the 2009 RECS dehumidifier owners subsample. We corrected those demographic biases to represent U.S. dehumidifier owners by using the cell weighting method, a post-stratification method commonly used in survey analysis (Kalton and Flores-Cervantes 2003). Weighting the raw AMT survey data enabled us to make robust inferences from the data and use them to study dehumidifier saturation by product type, hours of usage, operation mode, location, and costs.

4.4.2 Method

We applied our cell weighting method by directly comparing a subset of our survey respondent demographics to the corresponding demographic variables in the 2009 RECS subsample of dehumidifier owners. Applying that weight to our data adjusted the sum of all survey responses for a given demographic combination to be equal to the sum of corresponding RECS responses.

Given the size of both the AMT and RECS 2009 samples, there was a practical limit to the total number of demographic variables we could use if we wanted to avoid excessive "non-responses" (Greenblatt et al., 2013). The final demographic variables included in our weighting method were census division, number of occupants, race, number of 20–29 year olds, and educational level.

First we divided the AMT survey data and 2009 RECS data into several demographic categories by the first demographic variable (census division). Each record was assigned a weight based on the ratio of population shares in AMT versus RECS. We then added the second demographic variable (number of occupants) while retaining the first to further subdivide the sample, and calculated a new weight for each demographic subcategory. We continued this process for each of the five demographic variables listed above. If there was no corresponding combination of demographics in 2009 RECS as in our survey sample, or a null response such as "don't know" or "decline to state," the response was assigned a weight based on the previous combination of (fewer) demographics.

5 SURVEY RESULTS

The following sections present the results of weighting the AMT survey demographic data, calculating ownership by product type and product characteristics, identifying trends in regional ownership, and estimating frequency of dehumidifier use.

5.1 Demographic Weighting Comparison

Table 5.1 shows the raw demographic distributions from AMT survey data and the final weighted AMT data compared to the subsample of dehumidifier owners in the 2009 RECS survey data. The table shows how biases in the raw AMT ownership data were improved by adjusting them via the cell weighting method. The demographic distribution of the weighted AMT survey data became more consistent with 2009 RECS data.[2]

[2] Respondents who answered "Don't know" to certain demographic questions in AMT survey were dropped when calculating the demographic distribution of that particular variable.

Table 5.1 Demographics of Dehumidifier Ownership for Raw and Weighted Data

	2009 RECS Dehumidifier Owners (%)	AMT Dehumidifier Owners	
		Raw Data (%)	Weighted Data (%)
Race			
White	87.92	84.85	86.16
Black	6.88	5.81	6.04
Asian	2.96	4.58	4.49
Other	2.24	4.76	3.30
Annual Household income (in $1,000)			
0–20	8.77	9.75	11.78
20–40	17.42	20.33	21.67
40–60	19.45	24.25	24.31
60–80	15.33	19.63	18.28
80–100	12.15	10.46	10.02
100+	26.88	15.59	13.95
Gender			
Female	50.75	42.88	42.01
Male	49.25	57.12	57.99
Census division			
New England	10.14	8.12	9.90
Middle Atlantic	23.83	17.75	23.87
East North Central	29.90	21.46	30.02
West North Central	13.17	7.68	13.19
South Atlantic	13.48	21.40	13.73
East South Central	3.46	5.16	3.49
West South Central	2.19	6.48	2.19
Mountain North	0.57	2.27	0.58
Mountain South	0.23	0.00	0.00
Pacific	3.01	9.69	3.04
Educational level of head of household			
No school	4.20	0.68	0.77
High school diploma or GED	20.30	8.89	16.86
Some college, no degree	22.69	27.53	25.65
Associate’s degree	11.18	11.19	10.87
Bachelor’s degree	24.89	38.04	31.72
Master’s degree	11.78	10.32	11.66
Professional + Doctorate	4.95	3.36	2.46

Table 5.1 (continued)

	2009 RECS Dehumidifier Owners (%)	AMT Dehumidifier Owners	
		Raw Data (%)	Weighted Data (%)
Number of people in household			
1	19.50	10.84	19.74
2	36.32	29.39	36.02
3	17.23	24.81	17.42
4	16.58	19.55	16.79
5	7.28	9.46	6.45
6+	3.08	5.95	3.58

5.2. Dehumidifier Ownership

As discussed previously, a primary purpose of our survey was to develop a more detailed and accurate portrayal of dehumidifier market ownership in the United States, including specific product types and characteristics. This section presents the results of our AMT survey by product and technology type, census division, and product moisture removal and capacity. We augment our discussion with RECS data and compare where appropriate.

5.2.1 Ownership by product and technology type

As described previously, we classified dehumidifiers into two major product types (portable and whole-home) and into three major technology types (mechanical/refrigerative, desiccant, and electronic). We included questions about product and technology type to acquire data on the saturation of each dehumidifier type and corresponding household demographics. We did not include electronic dehumidifiers as a technology type in the survey because they represent only a tiny fraction of the dehumidifier market.

According to 2009 RECS, the penetration of dehumidifier ownership throughout the nation is 13.2 percent. Because our survey targeted only those households owning one or more dehumidifiers, we did not obtain data on dehumidifier ownership as a total percentage of the population. We therefore relied on the national dehumidifier penetration rate on the 2009 RECS estimate. Our survey captured more detailed data on ownership by dehumidifier type (portable or whole-home) than did the RECS 2009, however. In Figure 5.1, we found that most U.S. dehumidifier-owning households use portable dehumidifiers (98.66 percent); very few use WHDs (1.34 percent). Moreover, we found that the majority of both product types use mechanical/refrigerative technologies (about 84.5 percent for portable dehumidifiers and 78.7 percent for WHDs) (Figure 5.2).

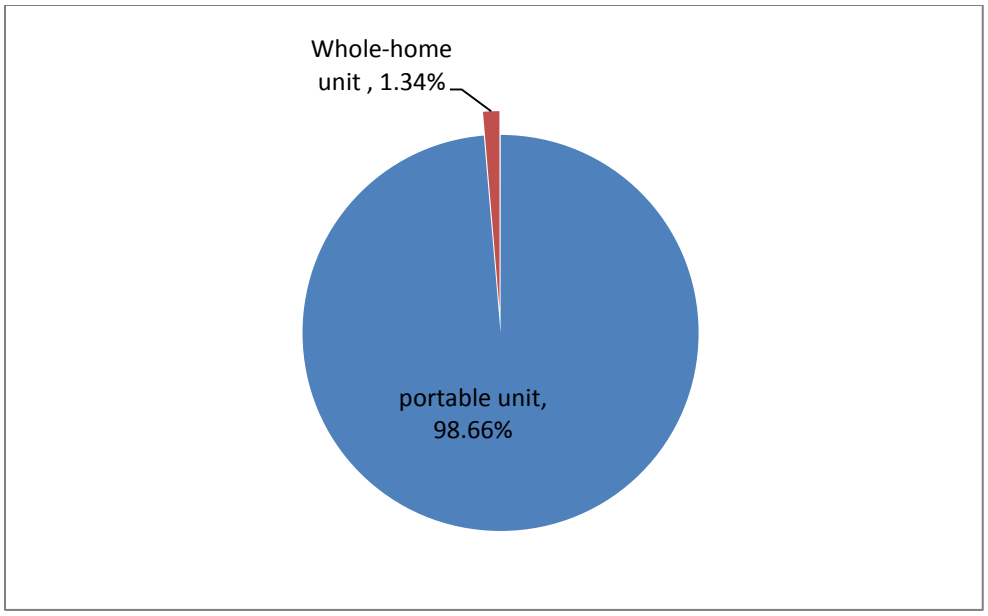

Figure 5.1 Dehumidifier Product Type (n = 1,622)

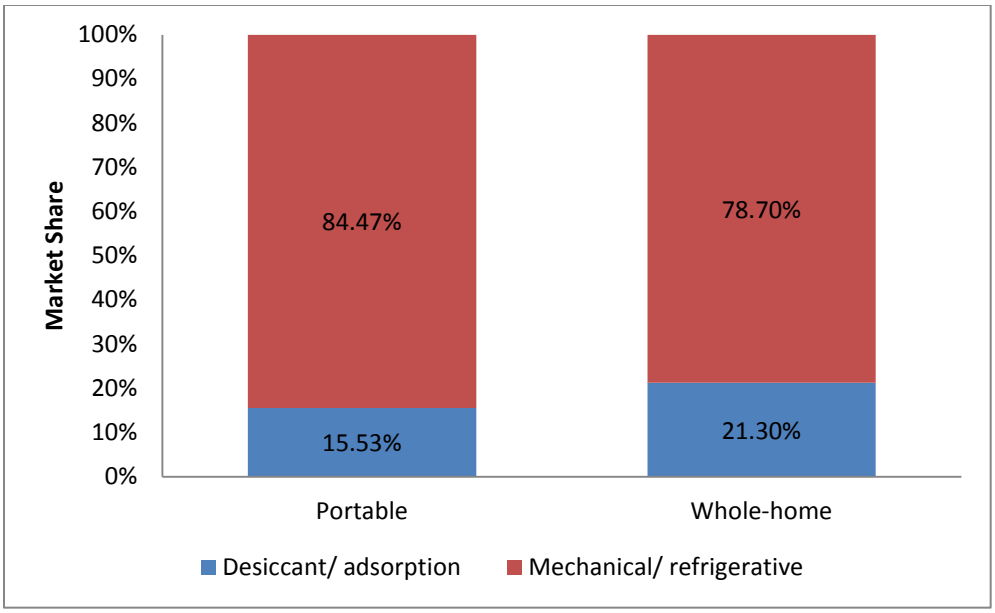

Figure 5.2 Technology Type by Product Type

5.2.2 Ownership by product type and region

Dehumidifier ownership in the United States depends greatly on climate; in particular, humidity levels. Regions that experience more humid weather have higher rates of dehumidifier penetration. According to the 2009 RECS, the four census divisions that account for the highest dehumidifier market shares are the East North Central, Middle Atlantic, South Atlantic, and West North Central, which total 80 percent of the national dehumidifier ownership (Figure 5.3).

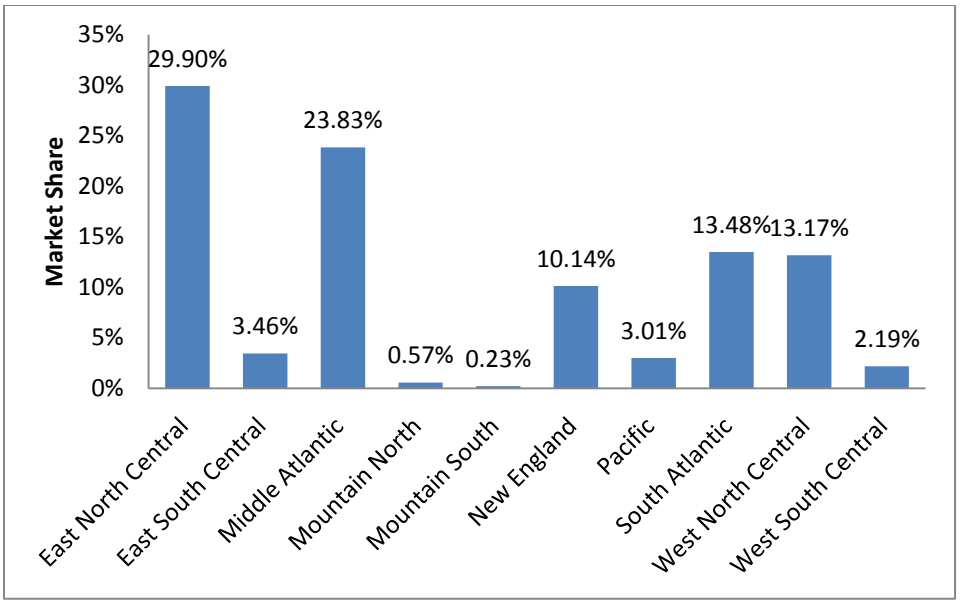

Figure 5.3 Dehumidifier Ownership Distribution by Census Division in 2009 RECS

RECS, however, did not further break down ownership by dehumidifier type. Our AMT survey obtained ownership data based on dehumidifier product type, as well as region. Figure 5.4 presents AMT survey results regarding the market shares of portable and whole-home dehumidifiers in dehumidifier-owning households across region. The data show that among portable and whole-home unit owners, East North Central, Middle Atlantic, and South Atlantic have relatively higher market shares compared to other regions, presumably because of their higher humidity levels. This finding is consistent with what we concluded in our analysis of the 2009 RECS data.

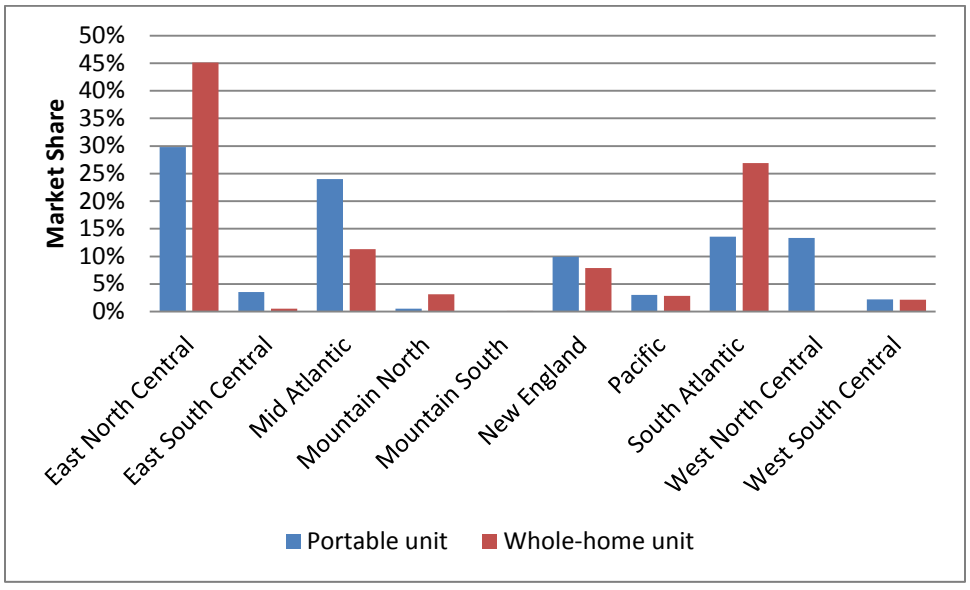

Figure 5.4 Dehumidifier Product Type Distribution by Census Division

Because portable dehumidifiers are the most prevalent type in use, we gathered more detailed ownership information on them, specifically regarding the distribution of number of units per household and average number of units per region. Table 5.2 shows the distribution of portable dehumidifier ownership by number of units per household.

Table 5.2 Weighted Count of Portable Dehumidifiers

Number of Portable Dehumidifiers	Weighted Count	Percent of Total (%)
1	1,499.19	93.76
2	93.87	5.87
3	5.60	0.35
4	0.30	0.02
Grand Total	1,598.96	100

Almost 94 percent of households that reported owning a portable dehumidifier owned one unit, nearly 6 percent owned two, and the few remaining respondents owned three or four. Those totals average 1.066 units per household. Assuming 13.2 percent of U.S. households own a dehumidifier (per RECS 2009), and based on the market breakdown by product type shown in Figure 5.1, we can conclude that approximately 13 percent of U.S. households own a portable dehumidifier. Since the average household ownership of portable dehumidifiers is 1.066, the estimated saturation of portable dehumidifiers in U.S. households is around 13.9 percent.[3]

Figure 5.5 illustrates the distribution of the number of portable dehumidifiers owned, by region. Again, households in regions having more humid climates account for higher market shares within each distribution; namely the East North Central, Middle Atlantic, New England, and South Atlantic divisions.

[3] *Penetration* is the percentage of households that own a product; *saturation* is the total number of products divided by all households.

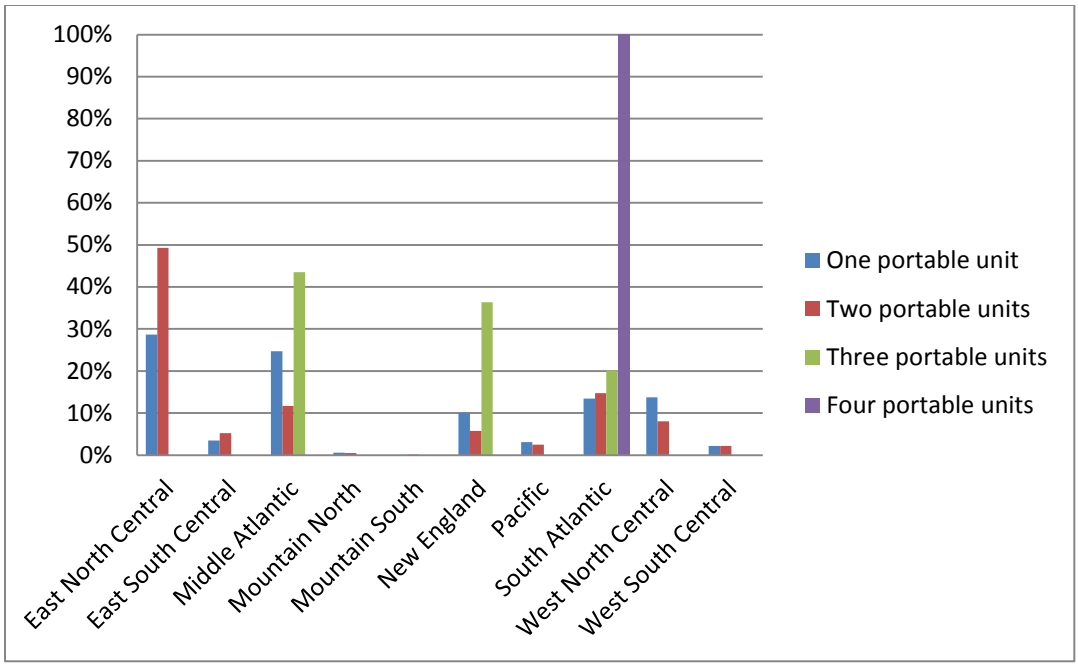

Figure 5.5 Distribution of the Number of Portable Dehumidifiers by Census Division

5.2.3 Moisture removal capacities

The moisture removal capacity of a dehumidifier (the maximum amount of moisture collected and removed by bucket per day) is a characteristic with strong implications for the unit's energy use. The retail market offers dehumidifiers having a wide range of moisture removal capacities to meet individual consumer needs as determined by the size of the room in which the dehumidifier is located, the room's humidity level, and the desired humidity level. Our survey provided a list of moisture removal capacity options, as well as the option to fill in the capacity if the appropriate one was not in our list.

Figure 5.6 shows the distribution of portable dehumidifier ownership by moisture removal capacity. In our survey data, the moisture removal capacity of portable dehumidifiers ranged from less than 35 pints per day to more than 75 pints per day, with an approximate weighted average capacity of 47 pints per day.

Figure 5.7 shows the distribution of whole-home dehumidifiers by capacity bin. Most WHDs (63.9 percent) can remove 50 to 99 pints of moisture per day, with a weighted average capacity of 88 pints per day. Whole-home dehumidifiers are likely to have greater moisture removal capacities than portable units because they are designed to remove moisture from a large space.

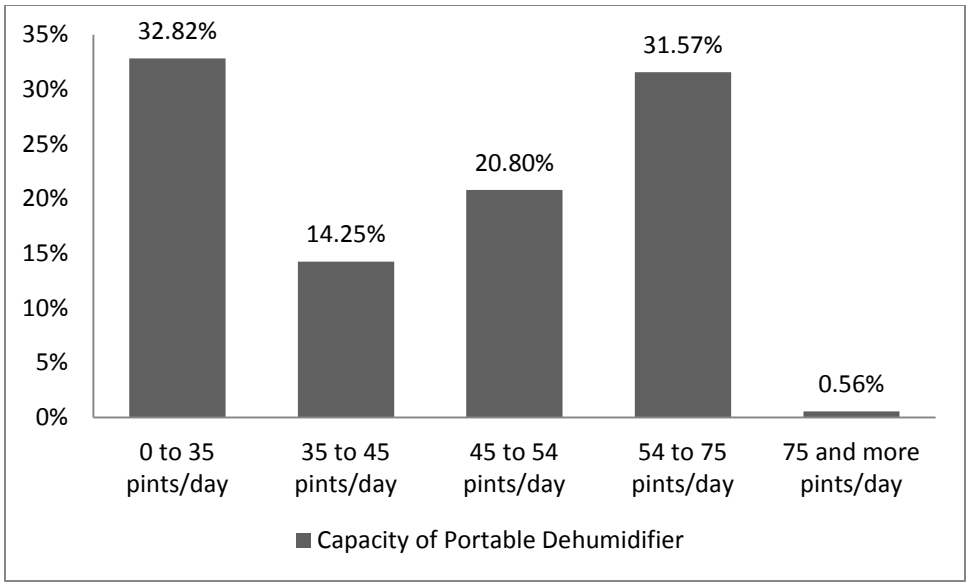

Figure 5.6 Capacity Distribution for Portable Dehumidifiers

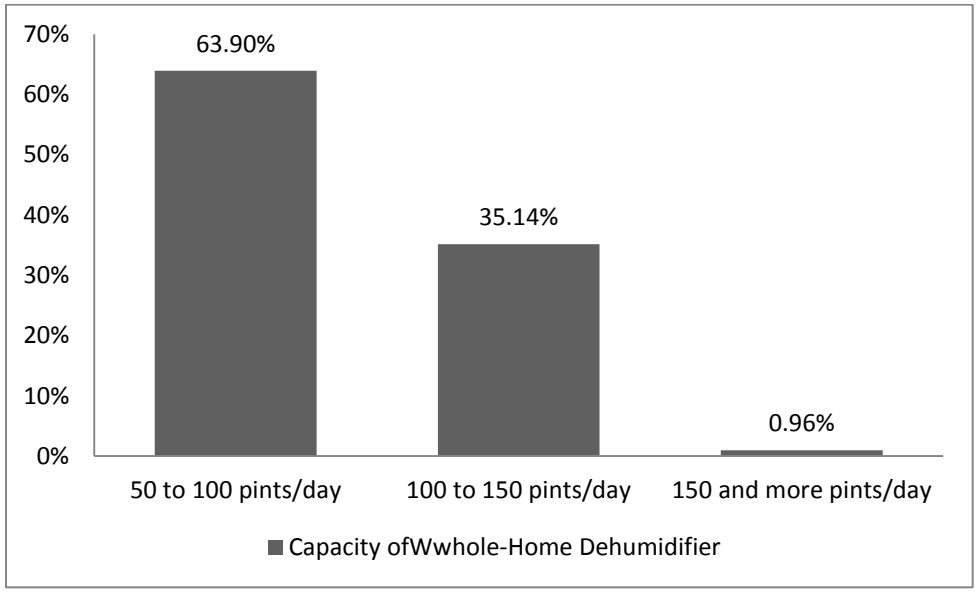

Figure 5.7 Capacity Distribution for Whole-Home Dehumidifiers

5.2.4 Moisture Removal Mechanism

When portable dehumidifiers reach their maximum moisture removal capacity, the units stop operating. Unless a hose has been connected directly from the unit to a drain, the owner must empty the unit's bucket manually before the dehumidifier will resume running. Given the same operating hours and humidity levels, portable dehumidifiers that require users to empty a bucket manually probably use less energy than those with a hose. There tends to be a period when the dehumidifier is not running, between the time the bucket reaches maximum capacity and when it

is emptied. Dehumidifiers that have direct drainage systems, on the other hand, can operate continuously. Based on survey responses, about 85 percent of portable dehumidifier owners have units with a bucket that must be emptied manually. Figure 5.8 displays the percentages of portable dehumidifiers having the two moisture removal mechanisms.

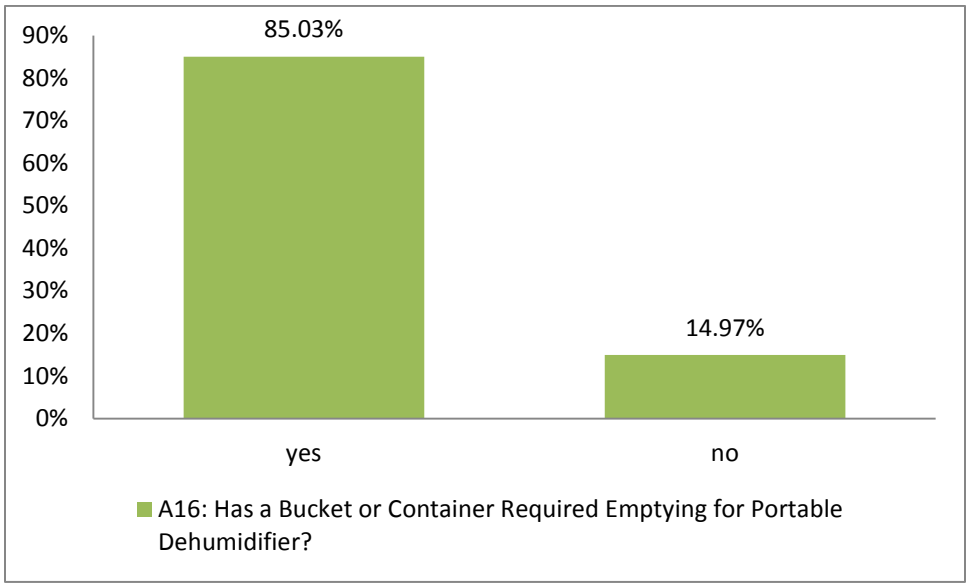

Figure 5.8 Portable Dehumidifiers by Moisture Removal Mechanism

5.3 Dehumidifier Usage

Our dehumidifier survey collected annual frequency of use information by asking respondents to report the number of hours they operate their dehumidifier(s) in a day, the number of operating days in a week, and which months they typically operate their dehumidifiers. This information enabled us to derive annual operating hours for each dehumidifier type—an input required for calculating annual energy consumption. The survey options for number of operating hours per day and days per week were given in ranges, so we took the median as the representative value for each group. Based on our survey results, the average annual usage for portable units is around 1,580 operating hours per year, and for whole-home units is around 1,038 operating hours per year. Figure 5.9 shows the distribution of frequency of use (in month range bins) for both portable and whole-home dehumidifiers. Even though whole-home dehumidifiers have higher shares than portable dehumidifiers in the first three frequency bins, 20 percent of portable units are turned on all year, while none of the whole-home units are. Hence, on average portable dehumidifiers were used more frequently (6.7 months per year) than whole-home dehumidifiers (5 months per year).

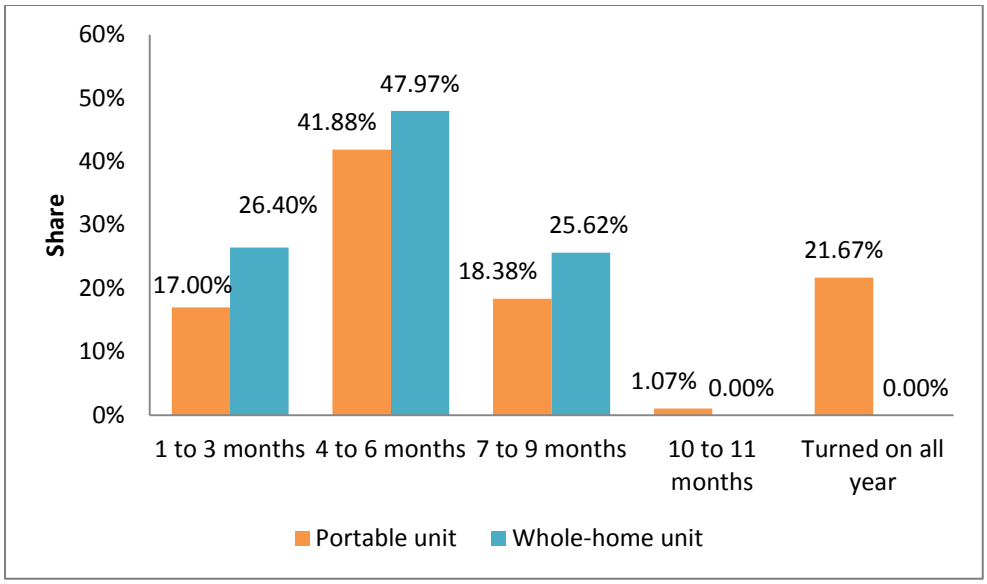

Figure 5.9 Frequency of Dehumidifier Use in a Year Based on the AMT Survey

As we compared the frequency distribution derived from the survey data to the 2009 RECS, the usage pattern is pretty different (Figure 5.10). In the 2009 RECS data, the dehumidifiers were mostly used from one to three months a year, but in the survey results, the highest frequency of usage of both portable and whole-home dehumidifiers is from four to six months a year. One plausible reason resulting in this discrepancy might be that these two data sets were deployed in different years and the frequency of dehumidifier usage has increased over time due to a warmer climate in certain regions.

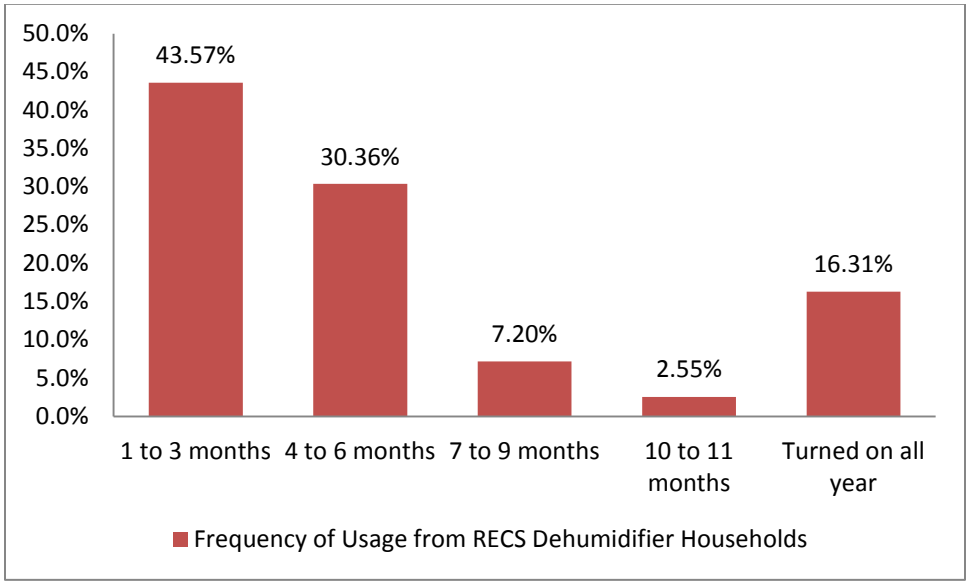

Figure 5.10 Frequency of Dehumidifier Use in a Year Based on 2009 RECS

In addition, we examined the correlation between frequency of dehumidifier use and geographic location. Figure 5.11 demonstrates the strong correlation between the average number of operating months for portable dehumidifiers and geographic location. Households located in more humid climates would be expected to use their dehumidifiers more often than those located in drier regions, like the Mountain South. The average number of months that portable dehumidifiers were in use is relatively more consistent across regions, except for the Mountain North and Mountain South census divisions. The frequency of usage of whole-home dehumidifiers, on the other hand, varies substantially between regions, with the East South Central region using them the most frequently and the Mountain South using them the least frequently.

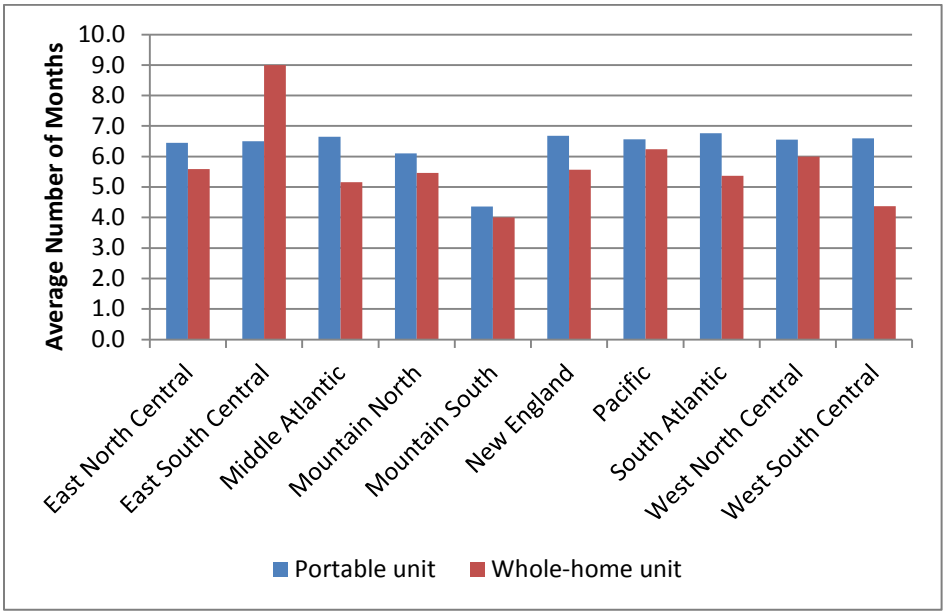

Figure 5.11 Average Number of Operating Months by Census Division and Product Type, from the AMT Survey

6 CONCLUSIONS

The goal of this study was to expand the available information regarding dehumidifier ownership and usage patterns in the United States to more accurately estimate annual energy use. We obtained real-world data for dehumidifier ownership and usage through an online survey platform, Amazon Mechanical Turk (AMT). Those data will enhance our currently limited understanding of dehumidifier ownership and energy consumption. To achieve our goal, we obtained survey data that would enable us to:

1. differentiate dehumidifier ownership by product type—specifically portable versus whole-home dehumidifiers—among households owning at least one dehumidifier;
2. differentiate dehumidifier ownership by owners' household characteristics;

3. for both types of dehumidifiers, estimate the moisture removal capacity, a feature that indirectly determines the energy consumption of the unit; and
4. estimate the frequency of use in operating hours per year for both dehumidifier product types and in relation to the geographical location of the household.

Our AMT survey collected detailed data on product ownership and usage for both portable and whole-home dehumidifiers (WHDs), as well as on household demographics. Because AMT is an online survey platform, some demographics are over- or under-represented in the survey results compared to all U.S. dehumidifier-owning households. We applied a cell weighting method to correct possible biases in demographic groups and assigned a weight to each response in the survey. After aligning the demographic distribution of our survey data with that of the 2009 RECS data on dehumidifier owners, the weighted AMT data showed an overall improvement in representing demographic variables compared to the unweighted raw AMT data.

Our weighted data enabled us to estimate the rate of market penetration of portable and whole-home dehumidifiers among dehumidifier owners. Our data on the units' moisture removal capacities and frequencies of usage enabled us to estimate the average capacity and operating hours per year for each dehumidifier type—information that enables estimating how much energy each type consumes. We found an average capacity of portable dehumidifiers of about 47 pints per day. The average capacity of WHDs was found to be about 88 pints per day. Based on our survey data, the average annual usage is 1,580 operating hours per year for portable units and 1,038 operating hours per year for whole-home units. We also found that the frequency of usage is correlated to the geographical region where a household resides. Households located in more humid regions tend to use dehumidifiers more frequently than households located in drier regions.

Although we developed results that help us achieve our overall goal, we faced some challenges in analyzing the data. First, we did not inform participants of all the characteristics of the two dehumidifier types, which could have resulted in false positive responses on product ownership. For example, an unreasonably large number of respondents claimed to have both portable and whole-home dehumidifiers. Those participants may mistakenly think a central air conditioner system is the same as a WHD. Second, we found more skipped questions in this survey than in other surveys we have previously conducted. One explanation may be that this survey contained more technical questions that owners could not answer. Third, we derived the average operating hours per year based on three stages of questions: (1) number of hours per day the dehumidifier is in use, (2) number of days in a week the dehumidifier is in use, and (3) number of months in a year the dehumidifier is turned on. We assumed that those frequencies of use could be applied to any typical day, week, and year; however, that may not be the case. We should also have provided a more precise definition of what was considered a dehumidifier in use. For portable dehumidifiers that require users to empty a bucket manually, the operating hours should only account for the period that the unit is actually running, excluding the idle period between the time the bucket reaches maximum capacity and when it is emptied. A more accurate way to

collect the annual operating hours of a given dehumidifier would be through on-site metering, but the downside is that field metering is relatively more time consuming and costly as compared to online survey. Additionally, if respondents failed to answer any of the three frequency of use questions, we were unable to estimate the unit's total operating hours per year and thus lost a critical input for calculating annual energy use.

The challenges we encountered analyzing the results of the AMT survey will help us improve future survey efforts. In the future we should be able to apply refinements of survey design and data processing learned from this project. First, more accurate market penetration and saturation data for the two product types could be obtained by providing more specific descriptions of the products in the survey or by requesting that respondents provide their product model number to verify they own a given type of product. Second, using software that provides programmed skip patterns and answer checks would avoid some of the data cleaning and verification issues we encountered. Such software would be especially helpful in handling missing responses to frequency of usage questions and would provide better data quality.

Despite areas of potential improvement, surveys offer the flexibility to craft the survey design and questions to achieve specific research goals. Online product-specific surveys appear to be a viable means to collect data to help us better understand ownership and usage patterns for various product types and their correlation with household demographics. We will use this study to evaluate the advantages and disadvantages of conducting online surveys in the field of appliance energy use. We also will continue to search for more representative dehumidifier ownership and usage data to inform our estimates of annual energy consumption.

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Appendix: Dehumidifier – General Population Survey

Survey title: Dehumidifier Research Study

The Energy Efficiency Standards Group at Lawrence Berkeley National Laboratory is conducting research on dehumidifier systems in the United States.

Before taking this survey, please ensure that you fulfill all of the following qualifications:

1. **You must reside in the U.S.**
2. **You must be at least 18 years old.**
3. **You must own and use at least one dehumidifier in your home. A dehumidifier removes moisture from the air. It is a self-contained and electrically-operated device. Air conditioners and air purifiers are NOT dehumidifiers. Example of residential dehumidifiers:**

<u>Portable</u> model:  **OR <u>Whole-home</u> model:** 

Financial considerations and risk matters:

- **Within 7 days of the survey being closed, we will review your responses and make a decision to accept or reject your work.**
- **You will NOT be paid and your work will NOT be accepted if you do not fulfill the qualifications stated above.**
- **Please do NOT leave any questions unanswered. Doing so may cause rejection of your work. If applicable, you may choose options such "I don't know" and "I decline to state."**
- ***Please be informed that if your work is rejected, a negative rating will be applied to your Amazon Mechanical Turk (AMT) account, which will affect your overall rating andmay prevent you from taking other works with high rating requirements.***

Please note:

- **You may need direct access to your dehumidifier as some questions require information such as model number and capacity.**
- **This survey is broken into 3 sections. Please respond to all sections applicable to you.**

- **All data collected from this survey will be password-protected and only accessible to the research team.**
- **Participation in this research is voluntary. You have the right to not take part in this survey. If you decide to take this survey, please click "Accept" HIT at the end of this page.**

Should you have any questions related to this survey, you may contact Camilla Whitehead at 207- 228-3573, Henry Willem at 510-486-7138, or you may contact us via e-mail: EES.Surveys@dante.lbl.gov. Any questions you have about your rights as a research subject will be answered by: Berkeley Lab Human Subjects Committee at 510-486-5399. A copy of this study information can be obtained from the following webpage: fsp.lbl.gov.

****

If you have or live in more than one home, please provide your answer based on the home where you spend the most time.

1. **How many portable dehumidifiers are currently plugged in and powered on in your home?**
   0
   1
   2
   3
   4
   5
   More than 5
   Don't know

2. **Do you use a whole-home dehumidifier in your home?**
   Yes
   No
   Don't know

If your answers for: Question number 1 is "0" or "Don't Know" and your answer to Question number 2 is "No" or "Don't know", you do NOT qualify to take this survey. Please stop and do not submit your responses because your submission will be rejected!

****

SECTION A: PORTABLE DEHUMIDIFIER

(Please complete SECTION A only if you own and use a portable dehumidifier, otherwise please skip to SECTION B)

If you have two or more portable dehumidifiers, please provide your answers based on the biggest (largest-capacity) unit.

A1. What type of portable dehumidifier do you have in your house?

Mechanical/ refrigerative (condense moisture on a cold surface, uses a compressor and fan to operate)
Desiccant/ adsorption (moisture adsorbed in a porous material, uses a heater and fan to recharge material and does not use a compressor)
I don't know

A2. Please enter the brand name of your portable dehumidifier:
_____

A3. Please enter the model number of your portable dehumidifier:
_____

A4. Is your portable dehumidifier an Energy Star labeled unit?

Yes
No
I don't know

A5. What is the moisture removal capacity in terms of <u>pints per day</u> of your portable dehumidifier? You may find this information near the model number information on the front or back panel of the unit.

32 pints/day
40 pints/day
45 pints/day
50 pints/day
60 pints/day
65 pints/day
70 pints/day
101 pints/day
107 pints/day
Other: _____
I don't know

A6. In which area or room is this portable dehumidifier located?

Basement
Crawl space
Living room
Family room
Bedroom
Closet
Garage
Storage space
Other area or room, please specify:
_____

A7. What is the approximate size of the area or room in which this portable dehumidifier is located?

200 to 500 sq ft
501 to 800 sq ft
801 to 1,000 sq ft
1,001 to 1,500 sq ft
1,501 to 2,000 sq ft
2,001 to 2,500 sq ft
2,501 to 3,000 sq ft
3,001 to 3,500 sq ft
More than 3,500 sq ft
I don't know

A8. If you have more than one portable dehumidifier, please indicate where the other unit(s) are located in your home: (you can select more than one)

Basement
Crawl space
Living room
Family room
Bedroom
Closet
Garage
Storage space
Other area or room, please specify: _____
Not applicable I only have one portable dehumidifier

A9. In which of the following months do you usually turn on your dehumidifier? Please select all that apply

January
February
March
April
May
June
July
August
September
October
November
December
I don't know

A10. Do you unplug your portable dehumidifier when you are not using it?
Yes
No
Sometimes
I don't know

A11. What is the relative humidity set point for your largest capacity dehumidifier when in use?

Between 41% and 45%RHRH
Between 46% and 50%RHRH
Between 51% and 55%RHRH
Between 56% and 60%RHRH

Between 61% and 65%RHRH
Between 66% and 70%RHRH
Between 71% and 75%RHRH
Low
Medium
High
Other: please specify_____

A12. For what reasons do you turn on this dehumidifier?
The room or house smells musty
To lower the humidity
To dry clothes
Other: please specify_____
I don't know

A13. How do you control the operation of this portable dehumidifier? Please select all that apply.

I keep the unit on all the time (the machine itself can cycle off and on)
I turn it on and off manually
I only use the dehumidifier in fan-only mode
Other settings (please explain briefly): _____
I don't know

A14. If you use manual control, how many days per week (only during the season when the dehumidifier is used) would you estimate that the dehumidifier is in operation?
1
2
3
4
5
6
7
I don't know
Not applicable (I don't use manual control)

A15. If you use manual control, how many hours in a typical day is the dehumidifier operating?
1-5 hours
6-10 hours
11-15 hours
16-24 hours
I don't know
Not applicable (I don't use manual control)

A16. Does this portable dehumidifier have a container or bucket that requires emptying?
Yes
No

A17. How often do you empty the bucket or container of this portable dehumidifier?

I empty the bucket more than once per day
I empty the bucket once per day
I empty the bucket 2-6 times per week
I empty the bucket once per week
I empty the bucket 2-3 times per month
I empty the bucket once per month or less
I don't know
Not applicable (My dehumidifier does not have a container or bucket)

A18. Is this portable dehumidifier hooked directly into a drain by hose and therefore does not require having its container manually emptied?

Yes
No
I don't know
Not applicable (My dehumidifier does not have a container or bucket)

A19. Did you purchase or receive this portable dehumidifier new?

Yes, it was brand new.
No, it was bought or received in used condition.
No, it was part of the house when we moved in.
I don't know

A20. If you purchased your portable dehumidifier as a new unit, how much did you pay for your dehumidifier?

Up to $100
Between $101 and $125
Between $126 and $150
Between $151 and $200
Between $201 and $250
Between $251 and $300
Between $301 and $350
Between $351 and $400
Between $401 and $500
Between $501 and $600
Between $601 and $700
Between $701 and $800
Between $801 and $1000
$1001 or more
I don't know the amount of purchase
Not applicable (I didn't purchase it as new unit or I don't know if it was new)

A21. If you purchased this unit new, how much was the rebate?

No rebate
Up to $10
Between $11 and $20
Between $21 and $30
Between $31 and $40
Between $41 and $50
Between $51 and $60
Between $61 and $80
Between $81 and $100
Between $101 and $125
Between $126 and $150
Between $151 and $200
$201 or more
I don't know the amount of rebate
Not applicable (I didn't purchase it as new unit or I don't know if it was new)

A22. If you purchased this unit as new, what is the age of this portable dehumidifier right now?

Less than 6 months old
At least 6 months but less than 1 year old
At least 1 but less than 2 years old
At least 2 but less than 3 years old
At least 3 but less than 4 years old
At least 4 but less than 5 years old
At least 5 but less than 6 years old
At least 6 but less than 8 years old
At least 8 but less than 10 years old
At least 10 years old
I don't know
Not applicable (I didn't purchase it as new unit or I don't know if it was new)

A23. Have you had your portable dehumidifier repaired?

Yes
No
I don't know

A24. If your portable dehumidifier had been repaired, what was the cost of the repair?

Free (under warranty period)
Below $25
$25 to 50
$51 to 100
Greater than $101
I don't know
Not applicable (The unit had never been repaired or I don't know if it has been repaired)

****

SECTION B: WHOLE-HOME DEHUMIDIFIER

(Please complete SECTION B only if you own and use a whole-home dehumidifier, otherwise skip to SECTION C)

B1. What type of whole-home dehumidifier do you have in your house?

Mechanical/ refrigerative (condense moisture on a cold surface, uses a compressor and fan to operate)

Desiccant/ adsorption (moisture adsorbed in a porous material, uses a heater and fan to recharge material and does not use a compressor)

I don't know

B2. Please enter the brand name of your whole-home dehumidifier:

_____

B3. Please enter the model number of your whole-home dehumidifier:

_____

B4. Where is the location of your whole-home dehumidifier?

Attic
Basement
Crawl space
Garage
Storage space
Other area or room, please specify: _____

B5. Is your whole-home dehumidifier an Energy Star labeled unit?
Yes
No
I don't know

B6. Is your whole-home dehumidifier connected to the air handler of the house?

Yes
No
I don't know
Not applicable (I don't use air handler system)

B7. How is your whole-home dehumidifier connected to the air handler?

It is fully-connected, both return and supply air streams
Only partially-connected, only return air stream is connected
Only partially-connected, only supply air stream is connected
Not connected at all
I don't know
Not applicable (I don't have or use air handler system)

B8. What is the square footage of the area in your house served by the dehumidifier?
Less than 801 sq ft
801 to 1,000 sq ft
1,001 to 1,500 sq ft
1,501 to 2,000 sq ft
2,001 to 2,500 sq ft
2,501 to 3,000 sq ft
3,001 to 3,500 sq ft
More than 3,500 sq ft
I don't know

B9. What is the moisture removal capacity in terms of <u>pints per day</u> of your whole-home dehumidifier?

50-59 pints/day
60-69 pints/day
70-79 pints/day
80-89 pints/day
90-99 pints/day
100-109 pints/day
Other: please specify _____
I don't know

B10. In which of the following months does your whole-home dehumidifier usually turn on? Please select all that apply.

January
February
March
April
May
June
July
August
September
October
November
December
I don't know

B11. What is the humidity set point or setting of this whole-home dehumidifier when in use?
Between 41% and 45%RHRH
Between 46% and 50%RHRH
Between 51% and 55%RHRH
Between 56% and 60%RHRH
Between 61% and 65%RHRH
Between 66% and 70%RHRH

Between 71% and 75%RHRH
Low
Medium
High
Other: please specify_____

B12. For what reasons do you turn on this whole-home dehumidifier? Select all that apply.
The room or house smells musty
To lower the humidity
To dry clothes
Other: please specify_____
I don't know

B13. How do you control the operation of your whole-home dehumidifier?
Humidistat control, separate from air handler control
Humidistat control, integrated with air handler control
I turn it on and off manually
Other: please specify_____
I don't know

B14. If you turn it on and off manually, how many days per week would you estimate that the whole-home dehumidifier is in operation?
1
2
3
4
5
6
7
I don't know
Not applicable (I don't use manual control)

B15. If you turn it on and off manually, how many hours in a typical day is the whole-home dehumidifier in operation?
1-5 hours
6-10 hours
11-15 hours
16-24 hours
I don't know
Not applicable (I don't use manual control)

B16. Do you keep one or more windows open most of the day during one or more seasons? Choose all that apply.

Winter
Spring
Summer
Fall
I don't know

B17. Did you purchase or receive this whole-home dehumidifier new?

Yes, it was brand new.
No, it was bought or given in used condition.
No, it was part of the house when we moved in.
I don't know

B18. If you purchased your dehumidifier as a new unit, how much did you pay for your dehumidifier?

Under $500
Between $501 and $600
Between $601 and $700
Between $701 and $800
Between $801 and $1000
Between $1001 and $1200
Between $1201 and $1400
Between $1401 and $1600
Between $1601 and $1800
Between $1801 and $2000
Between $2001 and $2500
Between $2501 and $3000
$3001 or more
I don't know the amount of purchase
Not applicable (I didn't purchase it as new unit or I don't know if it was new)

B19. If you purchased this whole-home dehumidifier as new, how much was the rebate?

No rebate
Up to $10
Between $11 and $20
Between $21 and $30
Between $31 and $40
Between $41 and $50
Between $51 and $60
Between $61 and $80
Between $81 and $100
$101 or more
I don't know the amount of rebate
Not applicable (I didn't purchase it as new unit or I don't know if it was new)

B20. If you purchased this unit as new, what is the age of this whole-home dehumidifier right now?

Less than 6 months old

At least 6 months but less than 1 year old
At least 1 but less than 2 years old
At least 2 but less than 3 years old
At least 3 but less than 4 years old
At least 4 but less than 5 years old
At least 5 but less than 6 years old
At least 6 but less than 8 years old
At least 8 but less than 10 years old
At least 10 years old
I don't know
Not applicable (I didn't purchase it as new unit or I don't know if it was new)

B21. Have you had your whole-home dehumidifier repaired?

Yes
No
I don't know

B22. If your whole-home dehumidifier had been repaired, what was the cost of the repair?

Free (under warranty period)
Below $25
$25 to 50
$51 to 100
Greater than $101
I don't know
Not applicable (The unit had never been repaired or I don't know if it had been repaired)

****

SECTION C: DEMOGRAPHIC AND HOUSE INFORMATION

You must respond to all questions presented in Section C

The following information is needed so that we can adjust the results to the rest of the country. Please provide us with your most accurate responses.

C1. What is your gender?

Female
Male

C2. Are you Hispanic or Latino?

Yes
No

C3. What is your race? Please check all that apply.

American Indian or Alaska Native
Asian
Black or African American
Native Hawaiian or Other Pacific Islander
White or Caucasian
Other: please state_____

C4. What is your highest education level?

No schooling completed
Kindergarten to grade 12 (No Diploma)
High school diploma or GED
Some college, no degree
Associate's degree
Bachelor's degree
Master's degree
Professional degree
Doctorate degree

C5. Please indicate the number of people in your household in the following age groups. Please provide your answers to all groups that apply.

Age 9 or less :_____
Age 10 to 19:_____
Age 20 to 29:_____
Age 30 to 39:_____
Age 40 to 49:_____
Age 50 to 59:_____
Age 60 to 64:_____
Age 65 or above:_____

C6. What is your combined annual household income?

$0-$19,999 per year
$20,000-$39,999 per year
$40,000-$59,999 per year
$60,000-$79,999 per year
$80,000-$99,999 per year
$100,000-$119,999 per year
$120,000 or more per year
I decline to state

C7. Do you own or rent the home where the dehumidifier is used?

Yes
No
I decline to state

C8. Please select which State your dehumidifier is used in? (insert a pull down menu for States)

C9. What are the first three digits of the zip code where this home is located?

_____

I decline to state

C10. What is the type of your home?

Single-Family Detached
Single-Family Attached
Multi-Family (duplex or apartment)
Mobile Home
Other: please specify_____
I decline to state

C11. What is your home's square footage?

_____

I decline to state

C12. Please check all the features that apply to your home:
Concrete basement floor
Presence of central air handler
Presence of sump
I decline to state

****