Analyzing Factors that Affect a Portable Vapor Compression Dehumidifier's Efficiency (Measured in L/kWh)

Abstract

Analyzing Factors that Affect a Portable Vapor Compression Dehumidifier's Efficiency (Measured in L/kWh). This research paper is sponsored by the National Institute of Standards and Technology. The purpose of this study is to determine factors that affect portable vapor compression dehumidifier efficiency. This research aims to discover to what extent does exterior weather influence the efficiency and cycling of portable dehumidification systems. In this quantitative case study analysis we looked at a dehumidifier and used sensors to measure weather conditions and the dehumidifier energy usage. We used ambient weather sensors and put the data into a CSV and then used Python and Matplotlib and Pandas to do the analysis. In conclusion the study found a positive correlation between absolute and relative humidity and efficiency. More tests would need to occur with multiple dehumidifiers in the same weather conditions but in different houses to validate the data.

Keywords: Portable vapor compression dehumidifier, Efficiency, Absolute humidity, Portable dehumidifiers, Basements, Energy usage, Compressor, Power efficiency, Relative humidity (RH), Dehumidifier behavior, Dehumidifier runtime, Dehumidifier control settings, Absolute humidity, Internal and external humidity sensors, Data annotation

Introduction

Due to a change in climate and a rise in temperatures, humidity levels have been on the rise for the past 10 years (Brown & DeGaetano, 2013). With rising humidity we can expect to see more dehumidification systems in greenhouses to facilitate plant growth, in residential and commercial buildings to maintain comfort levels, and throughout the world to prevent mold and fungal infections. The rising need for dehumidifiers alongside the immense percentage of energy residential and commercial buildings use (41% of total United States energy as of 2010) increases the need for energy efficient dehumidification methods (Payne 2016).

This study focuses on portable dehumidification modules that are commonly used in basements. The purpose of this study is to determine factors that affect portable vapor compression dehumidifier efficiency. This research aims to discover to what extent does exterior weather, specifically humidity, influence the efficiency and cycling of portable dehumidification systems.

Literature Review

I. Introduction

The purpose of this literature review is to determine the preexisting knowledge on dehumidifiers and discover gaps that will guide further research. Dehumidifiers have seen heavy use in greenhouses due to the high humidity caused by plant transpiration. Recently as greenhouses develop better insulation, old ventilation techniques have proven to not be as effective and need for dedicated dehumidification techniques are needed (Campen, Bot, & de Zwart, 2003). Building onto this, the need to explore dehumidifiers extends beyond agriculture as dehumidifiers not only prevent fungal growth and plant disease but also mixtures of organic chemicals that have been correlated with allergies, respiratory, and dermal diseases (Cobo-Golpe et al., 2020). Cobo-Glope discussed dehumidifiers as a way to screen semi-volatile compounds and found that dehumidifiers have the ability to filter out air pollutants as shown by the finding of these pollutants in the water extracted from the air. Building onto this, dehumidifiers not only screen the air for semi-volatile compounds but also find use cases in indoor pools where excess humidity is inevitable and will cause bacteria growth and other pathogens (Santos et al., 2023).

Finally, as the humidity levels are set to rise due to a rising climate (Barreca, 2012) human work capacity is set to decrease as humid environments limit work capacity (Willem, 2013) and building energy usage is set to increase as inefficient dehumidifier modules are used in humid environments (Li, Lu, & Yang, 2010). The use of more efficient dehumidifier modules will lower energy consumption and increase human work capacity.

II. Advances in the field

The field of dehumidification has primarily focused on the use of liquid desiccant and refrigeration/vapor compression modules. However, in light of new research microwave dehumidification systems have risen in popularity. Ybyraiymkul et.al. (2023) examined the potential of using distributed microwaves as a means of dehumidification in AC modules. They noted that because AC chillers have reached their asymptotic limit, decoupling the dehumidification system from the cooling system will allow for the incorporation of new innovative methods of dehumidification (Ybyraiymkul et al., 2023). This study looked into new methods because conventional methods consume immense amounts of energy (Islam et al., 2023). As this study was dedicated to increasing efficiency, microwave dehumidification systems were the perfect solution as they have been branded as an environmentally-friendly method of dehumidification that had potential. The factors Ybyraiymkul et.al. (2023) attributed as potential microwave dehumidification limitations were internal entropy generation due to unheated areas, enormous energy-wasting, and excess microwave irradiation time. They demonstrated that "97–99.5%" of power could be efficiently used.

III. Optimal Relative Humidity Levels for Human Comfort and Prevention of Fungi, Bacterial, and Viruses

It is agreed that humidity is a factor of human comfort and a general estimation of what levels of humidity provide that comfort. Scientists at NIST set the RH percentage (relative humidity) to 50% (Payne, 2016). Supporting this the Lawrence Berkeley National Laboratory indicated that a range of 45-55% was ideal (Willem, 2013).

Other applications of dehumidifiers, such as in pools, have different standards. Somewhere in the range of 40-80% would be ideal for airspeed where levels between 50-60% prevent the growth of fungi, bacteria, and viruses. Santos et.al. (2023) also showcased the ideal growth humidity needed for certain organisms. For example, mites are seen to grow in large quantities above 70% with 50-60% as the ideal setting for most.

However, with these ideal conditions, it is important to consider that human comfort and maximum heat pump SEER (Seasonal Energy Efficiency Ratio) are at a trade-off. (Payne, 2016) While the heat pump is just one component of a house and any air conditioning dehumidification system it speaks out towards a larger idea of difficulties balancing energy efficiency and comfort, highlighting a greater need for research in the dehumidification field.

IV. Uniform humidity

Common use cases for dehumidification systems are in greenhouses to facilitate plant growth. In such places large dehumidification modules are used, however, a recent study developed a need for uniform levels of humidity which in turn created a use for portable dehumidifiers in greenhouses. The need for uniform levels of humidity was introduced because in greenhouses every plant needs to be within their most optimal range of humidity to facilitate plant growth and prevent unwanted growth. Islam and colleagues found that there were differing levels of humidity within the greenhouse. Islam et al. (2023) noted that the use of portable dehumidifiers in larger quantities can offer better overall humidity levels and higher seasonal yields.

V. Operational Modes and Behavior of Dehumidifiers

Interest in how dehumidifiers operate daily has sparked the Lawrence Berkeley National Laboratory's research on field-metered data from portable dehumidifiers. While initially it was thought that dehumidifiers were consistent and operated in a similar fashion everywhere, Willem uncovers the opposite. Amongst a variety of dehumidifiers, it was found that some remained idle for a majority of the year while others were continuously running, hinting at the idea of two categories of dehumidifiers. Standby power was found to be either between 0.4-1.9 watts in the more active modules and next to nothing in the inactive modules (Willem, 2013).

Other studies that aim to increase uniform humidity urge the importance of understanding dehumidifier behavior before trying to solve any sort of problem. (Islam et al., 2023) Islam et al., (2023) goes on to say that low-power dehumidifiers have already been made but the important thing to look at is dehumidifier operation.

The attention given to accessing dehumidifier functionality has shed light on some important takeaways. For starters, dehumidifier runtime was found to be anywhere as high as 9 hours per day. On Top of this, we have learned how relative humidity control settings dictate dehumidifiers. Once the indoor RH reaches the set control level, the dehumidifier cycles on and off to maintain it, with some modules using timers to cycle back on. We also have learned that the more we cycle on and off the less efficient a dehumidifier is, due to the energy loss from cooling down and heating the coils in mechanical/refrigeration portable dehumidifiers (Willem, 2013). In Henry Willem's "Field-Metered Data…" paper he demonstrated a relationship between dehumidifier compressor's run time and outdoor humidity. Indicating that the higher the outdoor humidity the longer the compressor's run time. This study indicated that the compressor is the primary energy consumer. We can start to see new beneficial aspects of research that analyzing behavior can open up. (Willem, 2013) Willem (2023) also reveals that dehumidifiers are not used in fall, winter, or early spring and peak usage is in July and August.

VI. Gaps in the Literature

A. Portable dehumidifiers

Currently, research regarding dehumidifiers focuses primarily on large-scale industrial dehumidifiers that are used for greenhouses. However, limited data exists on the efficiency of portable dehumidifiers, which are significant in settings such as basements for human comfort and greenhouses to ensure uniform levels of humidity (Islam et al., 2023). Additionally, most research looks into metered mechanical/refrigerative dehumidifiers. While this paper will also look into this type, looking into other modules would be significant to add to the current literature. (Willem, 2013)

B. Individual Case Studies

Current literature addresses large generalizations about groups of portable dehumidifiers but does not record conclusions about individual portable dehumidifiers. Willem (2013) makes the clear distinction that individual dehumidifiers vary in energy usage, with many operating on opposite spectrums between 0.4-1.9 kWh and as little as 0 kWh due to inactivity. Our research aims to address the gap of knowledge that is the limited understanding of an individual portable dehumidifier's behavior as opposed to the many studies that have been conducted on individual large-scale dehumidifiers.

C. Ambient Conditions

To effectively design solutions to improve dehumidifier efficiency and behavior, more research is necessary delving into ambient conditions and their effect on dehumidifier behavior. Studies have gone into places like Hong Kong where the effect of ambient conditions would greatly help their work. Li and colleagues state that humid areas like Hong Kong need to be further researched (Li, Lu, & Yang, 2010). This study also looks into cloudy days and concludes that they may yield different dehumidification effects, however general conclusions about ambient conditions are yet to be found. (Li, Lu, & Yang, 2010)

VII. Synthesis of Findings and Conclusion

After examining the current literature database on dehumidifiers, in relation to my project, the important conclusions are that portable dehumidifiers are needed in greenhouses to ensure uniform humidity and in homes to remove volatile compounds.

Research into this literature has demonstrated the importance of understanding portable dehumidifier behavior in ambient weather conditions and the lack of research in portable dehumidifiers, individual dehumidifier behavior, and the effect of ambient conditions. My research is focused on addressing these gaps and finding correlations between an individual portable dehumidifier and the effects of ambient conditions.

Methodology

This paper follows an experimental design which allows for dehumidifier observations during different weather conditions. This design with quantitative research tests the impact of weather conditions on the outcome which is dehumidifier efficiency (Creswell, 2021). This justifies the use of experimental design to see the impact of weather on the efficiency of dehumidifiers for this research.

Data Collection

To analyze the weather conditions we utilized ambient weather sensors to detect relative humidity, temperature, dewpoint, heat index. These small sensors were placed throughout the house as indicated by table 1, however the notable sensors that were used are indicated by the yellow highlight. The sensor used to determine outdoor ambient conditions was the "Out_FR_door" sensor that is located outside by the front door. The "Base(guest)" sensor is located in the basement guest room where the dehumidifier is located and tells us how the humidity of the room is affected by the dehumidifier and the ambient conditions in the location with the dehumidifier. The "Deh(out)" is the ambient weather sensor located next to the outlet of the dehumidifier that is pumping out hot dry air. We can use this sensor to correct data where we did not record times for when the dehumidifier bucket was emptied. As the temperature charts for this sensor lower and reach levels close to the room temperature we can safely conclude that the dehumidifier is not running. These are the methods we used to collect the data to determine the relationship between weather conditions and dehumidifier efficiency.

The use of sensors similar to these was found in the evaluation of a 0.7 kW suspension-type dehumidifier module in a closed chamber and in a small greenhouse (Islam et al., 2023) as well as in the field-metered data collection from portable unit dehumidifiers in the U.S. residential sector as part of an initial pilot study (2013). This displays how these are valid methods for measuring the weather conditions and power outage.

Code Name	Location

Out_FR_door	Outside by Front Door
Attic(house)	Attic, over house
Attic(gar)	Attic, over garage
Garage	Inside garage by door to house
MasterBR	On a bureau in the master bedroom
Office	1st four office, on a shelf
Base(guest)	Basement guest room
Base(pong)	Basement ping-pong room

I. NetZero Data Collection Program

We utilized Robbie Morrison's NetZero data collection tool to get airport temperature data, Pepco energy usage, and SolarEdge data. Robbie Morrison's NetZero program uses NOAA's NCDC API service to get temperature data on the Baltimore Washington International Airport, MD US and the Washington Dulles International Airport, VA US. While not utilized in this study, the code also obtains solaredge data and Pepco energy data. This data was used to validate the temperature sensors and ensure data was accurate.

Other studies utilize similar weather data acquisition methods. For instance, in their modeling study on the performance evaluation of a commercial greenhouse in Canada, Nauta et al. (2023) also used TMY data from nearby Vineland, Ontario, to get external weather data. Similarly, Li, Lu, and Yang (2010) also utilized TMY data in their dehumidifier studies. And closest to the methods in our research Willem's study about Field-Metered data from portable unit dehumidifiers (2013) employed NOAA's temperature and absolute humidity data. This demonstrates that this method is reliable and widely used.

II. Dehumidifier Model

This study we took a look at the Frigidaire's model FFAD5033W1 portable vapor compression dehumidifier. This specifically has been rated for 1.80 kWh, comes with a bucket capacity 2.1 gallons, a dehumidification of 50 pints per day, and a relative humidity minimum of 35 % and a maximum of 85 %. This is important because future studies can compare this study's results with different models or compare them against the conditions used in this experiment.

III. Energy Measuring

To measure the daily energy used we used a Fayleeko made watt meter to figure out the daily energy consumption. The wattmeter used added the total energy consumption and to figure out how much energy was used we subtracted the total energy from the total energy of the day before. It is important to use similar models during other tests to maintain constants and lower room for error.

IV. Efficiency Definition

This research measured efficiency in terms of liters of water removed per kilowatt hour. (L/kWh) The Energy Star Dehumidifier Efficiency Rates in L/kWh states that for portable dehumidifiers their efficiency is rated in a manner described in table 2. They rate a dehumidifier by the amount of pints it can extract under the ambient conditions of 80 F and 60% RH ("Dehumidifiers Key Efficiency Criteria," n.d.).

Pints Extractable	Efficiency (L/kWh)
≤ 25.00	≥ 1.57
25.01 to 50	≥ 1.80
≥ 50	≥ 3.30

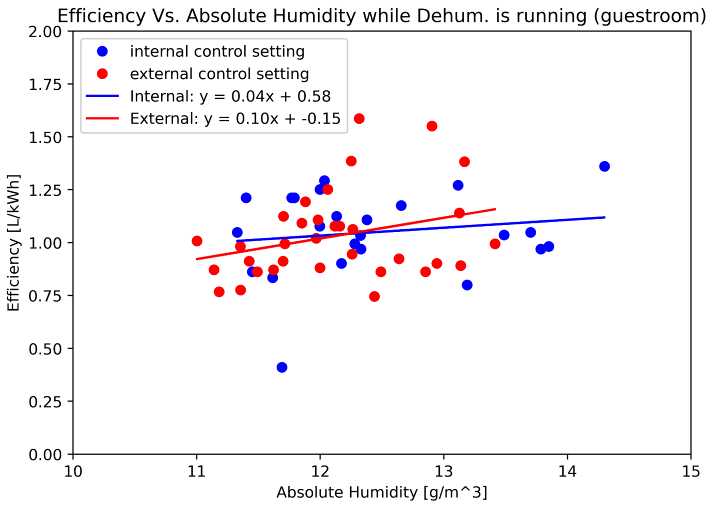
V. Python Program

In this study we used the ambient weather data and netzero code data in combination with Python to plot points together as well as interpolate for missing data.

MatPlotLib was utilized to plot the data. Through these plots we were able to plot up the dehumidifier outlet temperature charts and see when the dehumidifier was on and off. On Top of this all the plots in this paper were obtained from this code. This code also takes the Relative Humidity and Temperature to calculate Absolute Humidity as this is what we used in analysis of this dehumidifier. This allowed for a visualization of the data.

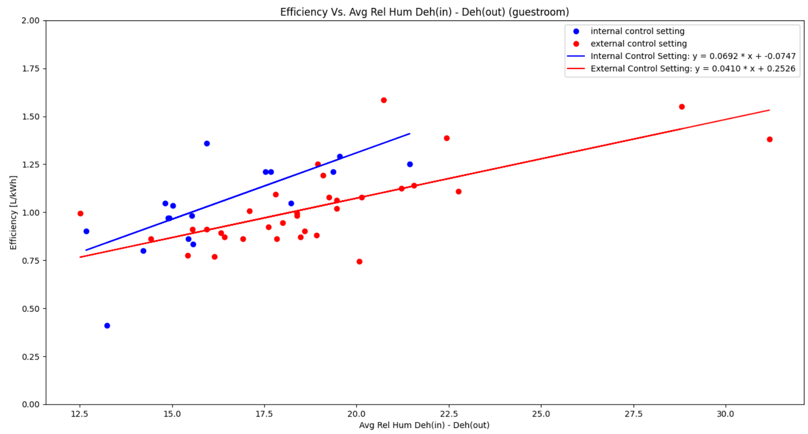
Results

I. Efficiency vs. Absolute Humidity while the Dehumidifier is running



The data in this plot showcases the efficiency of the dehumidifier in L/kWh against the absolute humidity of the room while the dehumidifier was running. Most of the data points cluster between an efficiency of 0.75 and 1.25 L/kWh and an absolute humidity of 11 to 14 g/m^3. The difference between blue and red in this graph is whether the dehumidifier was using the internal humidity sensor or the external humidity sensor. The internal control setting has a P-value (Prob F-statistic) of 0.456516 and the external control sensor has a P-value of 0.088353. In summary, for the external control setting, the p-value for Avg Abs Hum is less than 0.05, indicating statistical significance. However, for the internal control setting the Avg Abs Hum variable is not statistically significant based on the p-values. The external humidity slope is 1.5 times larger which could suggest that dehumidifier efficiency could be linked to the signal point averaging of an external sensor as opposed to the internal sensor which isn't affected as much by the entire room's humidity.

II. Efficiency vs. Relative Humidity of the Dehumidifier Inlet - Relative Humidity of the Dehumidifier Outlet while the Dehumidifier is running



The data in this plot showcases the efficiency of the dehumidifier in L/kWh against relative humidity of the dehumidifier inlet minus the relative humidity of the dehumidifier outlet while the dehumidifier was running. The external control setting has a P-value of 3.46e−06 and the internal control setting has a P-value of 0.000295. Both of these are below the required 0.05, rendering these data points statistically significant and the equations listed below valid for dehumidifier efficiency predictions.

- Internal Line Equation: Efficiency = 0.0692 × (Avg Rel Hum Deh(in) - Deh(out)) − 0.0747
- External Line Equation: Efficiency = 0.0410 × (Avg Rel Hum Deh(in) - Deh(out)) + 0.2526

These suggest that the larger the relative humidity difference the larger the efficiency. The outlet humidity tends to remain at the same level which would imply that the inlet relative humidity could be an indication of the efficiency.

Discussion, Analysis, or Evaluation Final

The current research on portable dehumidifiers is quite limited with very few papers conducted on the weather conditions that affect efficiency. Our study has found that there is a link between higher humidity and efficiency. With our final data in the table below.

Variable	Averaged During Runtime	Sensor Location	Control Setting	P-Value	Equation for Efficiency	Statistically Significant (by P-Value)
Absolute Humidity [g/m^3]	Yes	Guestroom	Internal Control Sensor	0.456516	= 0.04(Avg Abs Hum) + 0.58	No
Absolute Humidity [g/m^3]	Yes	Guestroom	External Control Sensor	0.088353	= 0.10 × (Avg Abs Hum) + -0.15	Yes
Rel Hum(Deh(in) - Deh(out))	Yes	Dehum. Inlet & Dehum. Outlet	Internal Control Sensor	0.000295	= 0.0692 × (Avg Rel Hum Deh(in) - Deh(out)) − 0.0747	Yes
Rel Hum(Deh(in) - Deh(out))	Yes	Dehum. Inlet & Dehum. Outlet	External Control Sensor	3.46e−06	= 0.0410 × (Avg Rel Hum Deh(in) - Deh(out)) + 0.2526	Yes

The data has aspects that were to be expected with some wild cards in the mix. The higher humidity suggests a shorter runtime as the tank will fill up faster, which would mean that the dehumidifier will have to lower efficiency by starting up the coils for a small runtime. While this would indicate that the efficiency is lower the data suggests otherwise, which means that the tank is not filling up fully. This means that the humidity is low enough to allow for long runtimes that increase efficiency and also not high enough to fill the bucket fully. This suggests a link between the location of the dehumidifier and the efficiency.

Conclusion and Future Study Draft

Future research and studies would benefit from more data with the inlet and outlet sensors to determine runtime. On Top of that, daily efficiency calculations of the dehumidifier would be beneficial for more data. Within the scope of the current research this study fills in the gap amongst portable dehumidifiers and works towards finding current constraints of portable dehumidifiers and conditions that lower efficiency to then work on a solution for them.

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