Design and Monitoring of a Residential AC Condensate Collection System

***Bryan Danley*[1] *Philip McCreanor*[2]**

Abstract – The cooling cycle of residential air conditioning systems causes water to condense from the air. This water can be collected and repurposed elsewhere in the house to reduce the human footprint on the environment. A water collection system has been designed to quantify the amount of such condensate can be collected. A tipping bucket flow gauge was constructed and installed on a residential air conditioning unit monitored by an Arduino Mega 2560. The flow gauge tips every 8.24 ± 0.17 mL of water. While the air conditioner is running, approximately 1.87 ± 0.04 L/hr of water can be collected. However, the air conditioner does not run continuously. Therefore, taking into account the time the system was off, on average 0.668 ± 0.14 L/hr can be collected. This extrapolates to approximately 112 liters of water saved per week.

Keywords: Air conditioning, condensation, sustainability, water, retrofit

INTRODUCTION

Typical residential air conditioner evaporator coils accumulate water condensate due to the cooling of the humid air. The condensate extracted from the air drops from the coils and is drained from the house. The condensate has the potential to be collected and repurposed for use elsewhere in or around the house to help reduce the human footprint on the environment.

The goal of this research was to quantify the amount of water condensate that can be collected from such a residential air conditioning system. The designed system measures both amount of drained water and thermodynamic properties of air both before and after the air conditioning system.

THE SYSTEM

The designed system was comprised of two major parts: data collection and water collection. The water collection system begins with a tipping bucket rain gauge that empties into a plastic storage tub monitored and periodically pumped into the yard for irrigation. The data collection system monitors both the upstream and downstream air flow collecting wind speed, temperature, and humidity.

Water Collection

Water condensate from the evaporator coils drains down ¾” PVC piping dropping into a vertical PVC column as seen in the top right of Figure 1a. At the base of the column is a funnel which directs water flow into the center opening on a nominal 2” Schedule 40 PVC tee. The tipping bucket is mounted inside the PVC tee, shown in Figure 1b, similar to the set-up in [1].

The bucket was laser cut from 0.06” thick clear acrylic with dimensions in inches displayed in Figure 1c. The assembled bucket was mounted inside the tee using a ¼” diameter bolt such that the maximum tip in either direction

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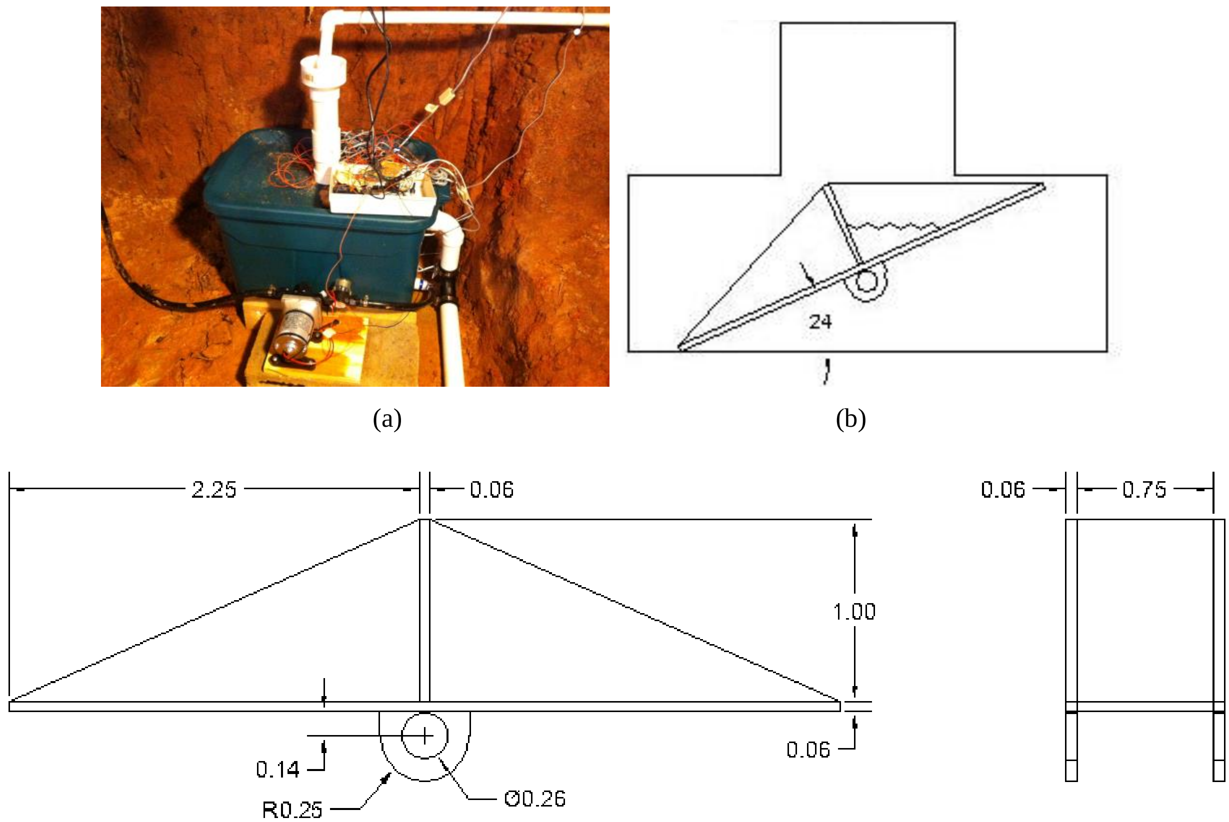
is approximately 24 degrees (see Figure 1b). This ensures that that elevated side of the bucket is parallel to the ground which maximizes the capacity of the bucket.

Water is funneled into the top of the PVC tee filling the elevated end of the bucket. The elevated end of the bucket collects water in this manner until the weight of the water causes the bucket to tip, thus, emptying the full bucket and elevating the empty bucket on the opposite end. The now elevated bucket end is situated at the base of the funnel and the process continues back and forth in this fashion.

Statics analysis on the acrylic bucket was performed before construction to estimate the volume of water required to cause a tip. At the instance before tipping, the only support is the pivot bolt and the moment caused by the weight of the acrylic in one direction is equal to the moment caused by the weight of the water in the other direction. The elevated bucket should fill to approximately 59.5% of its capacity before tipping and pouring out approximately 8.23 mL of water.



(a) (b)

(c)

Figure 1. a) Water from the coils is funneled down the PVC column into the plastic tub. b) The tipping bucket is mounted inside a PVC tee located under the lid of the tub. c) The tipping bucket measures approximately four and a half inches long, three quarters of an inch wide and an inch and a quarter tall.

Collecting water in this fashion reduces water flow measurement to a count of bucket tips. In order to test the volume per tip of the bucket, a burette, filled with 50 mL of water, was situated above the mounted bucket inside the PVC tee. The valve of the burette was fully opened and the reading on the burette was taken after the fifth bucket tip. Therefore, the difference in start and end volume of water accounts for 5 tips of the bucket. The results were consistent with the expected value, concluding that the bucket tips every 8.24 ± 0.17 mL.

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A photogate was used to count bucket tips. The photogate was comprised of an LED and a photoresistor situated on opposite sides of the PVC tee such that the bucket tipping breaks the photogate. To increase the opacity of the bucket, both sides were painted black.

The photoresistor voltage is dependent on its resistance which varies based on its exposure to light. The photoresistor resistance is low in direct view of the LED and high when the bucket obstructs the photogate. The photoresistor resistance varies between approximately 0.6 ohms in the unobstructed condition and 5.5 ohms in the obstructed condition as measured in a dark lab to simulate the environment under the house. The difference between the blocked and unblocked photoresistor voltage drop was increased by placing a 5.6 ohm resistor in series with the photoresistor.

An Arduino Mega 2560 was used to measure the voltage across the photoresistor. The Arduino reads analog signals between 0 and 5 V as an integer between 0 and 1023 using the analogRead() function. In order to determine the blocked and unblocked photoresistor voltages, water was poured through the top of the PVC tee in a dark lab while the Arduino monitored the photoresistor voltage drop. Figure 2 depicts the analogRead output for ten tips of the buckets. The unblocked, default, photoresistor voltage is read at approximately 300 and spikes up to approximately 900 as the bucket breaks the line of site. Therefore, any voltage measured above a tolerance of 500 is recorded as the tipping of the bucket. The bucket obstructs the photogate for a minimum measured time of 30 milliseconds (width of the peaks). These results indicate that a 5 ms sample rate on the Arduino will safely catch the breaking of the photogate for every tip. At the end of every minute, the tip index was stored to an SD card.

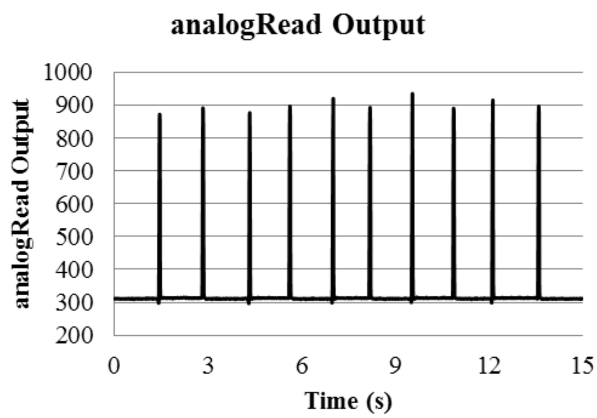

Figure 2. The photoresistor voltage remains relatively constant around 300 unobstructed and peaks around 900 during the tipping of the bucket.

Once the water has entered the plastic tub, it is stored and periodically pumped into the yard for irrigation. Two #M8750 float switches monitor the water level in the tub. When water reaches the upper float switch, the pump turns on and remains on until the lower float switch is deactivated. This is wired using a Model 275-218 double pole double throw (DPDT) plug-in relay switch in the configuration shown in Figure 3.

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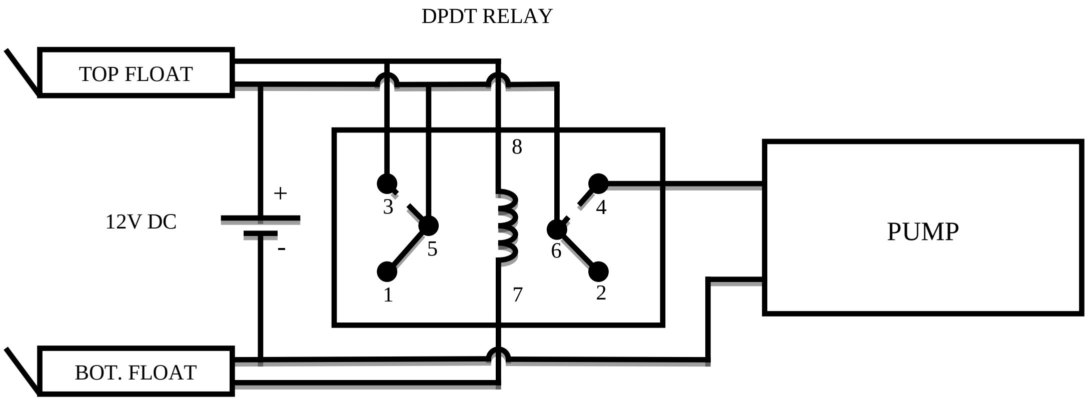

Figure 3. A double pole double throw relay switch is wired with two float switches and a pump to maintain water level in the plastic tub between an upper and lower limit.

Data Collection

In addition to the water flow measurements taken by the bucket assembly, air flow properties were monitored in order to perform a thermodynamic analysis of the system. Wind speed, temperature, and relative humidity were collected in both the upstream and downstream ducts. Two Modern Device Wind Sensors, two DHT11 temperature and humidity sensor modules, and the Arduino Mega 2560 were employed to monitor these properties.

Two small circuit boards were prepared. One wind sensor and one DHT11 module were installed on each of the boards. Each board was attached to the end of a short segment of ½" PeX tubing. The opposite end of both PeX segments contained a ½" x ½" Barb x MPT male adapter. The threaded end of the adapter is mounted to the duct segment as shown in Figure 4. The wires were run through the tubing and the opening sealed using electrician's putty. The PeX tubing is sized such that the sensors at the end are situated in the center of the round duct.

Figure 4. The sensors are fixated at the end of a segment of PEX tubing and the tubing is mounted to the duct wall.

The sensors were connected to the same Arduino as the tipping bucket and the data was stored on an SD card.

The wind sensor was installed in a wind tunnel to determine a correlation between the output voltage and wind speed. The sensor was zeroed and compared with a pitot tube in wind speeds in the range of 0 to approximately 5000 ft/min. The correlation between the sensor output and wind speed is

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$$V = e^{1.0844E - 4.158} \tag{1}$$

where V is the wind speed in ft/min and E is the voltage in volts. Both temperature and wind speed data was collected every 2 minutes.

RESULTS

The equipment described above was set-up on a house in Macon, Georgia. Data was collected and stored on the SD card. After a week, the data was taken from the SD card. After approximately 36 hours, the tipping bucket index had stopped incrementing. Investigating the issue, it appeared as though the weather proofing of the photo gate had failed and the LED and photoresistor leads had corroded. Additionally, the wind speed data seems to vary with the temperature, and as a result, no thermodynamic analysis could be performed on the system.

However, the inlet wind speed sensor did give a good indicator as to when the air conditioning unit was on or off. Figure 5 displays an overlay of the sensor output and the tipping bucket index showing that as the AC was on, the bucket would be tipping.

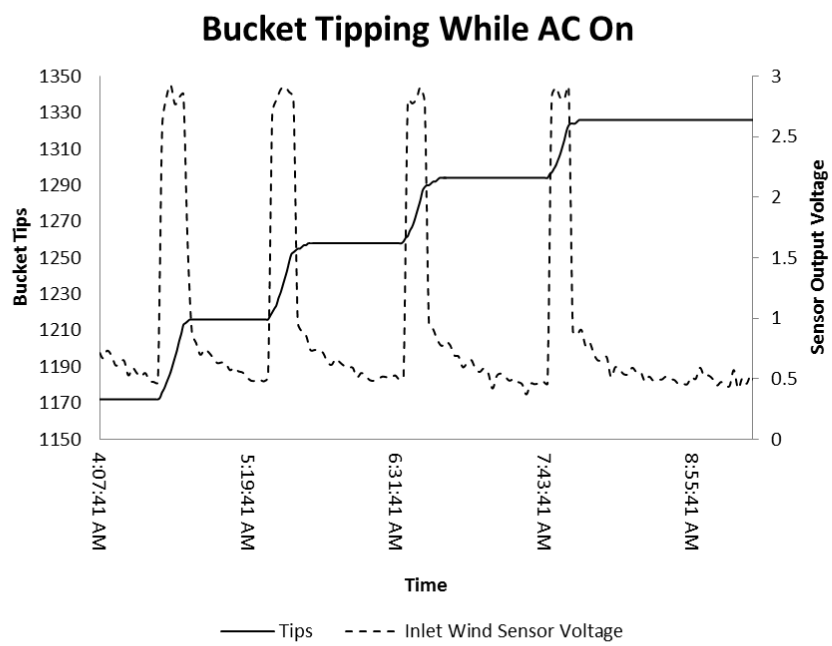

Figure 5. Overlay of the inlet wind speed sensor output and the bucket tip index over time.

For the approximately 36 hours that the system was functioning properly, the bucket tipped 2920 times, a total of 24.06 ± 0.50 L. The temperature drop across the coils was approximately 7 °C and the relative humidity increased approximately 40%. During the 36 hours of testing the outside temperature was approximately 24 °C and the humidity was 40%.

DISCUSSION

When converted, 24.06 liters in 36 hours is equivalent to a rate of 0.668 ± 0.014 L/hr. However, the air conditioner did not run continuously. At the beginning of each short run of the air conditioner, the flow rate would accelerate and for the few minutes after each run, water would still be dripping off the coils. The water that drips off the coils

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in the brief period of time after the system shuts off is still counted toward the water collected from the system. Of the approximately 36 hours that the system was operational, the air conditioner was only running for 13 hours and 22 minutes. Thus, the system produced approximately 1.87 ± 0.04 L/hr while it was running.

Extrapolating the data, it is estimated that in the conditions tested, approximately 112 liters of water can be collected and repurposed each week.

FUTURE WORK

During this research, the water collected had been pumped into the yard for irrigation. Future work on the project can potentially reuse this water elsewhere in the air conditioning system. For instance, preliminary work in [2] suggests that spraying water on the coils can reduce the energy consumption of the air conditioning process.

Additionally, a group of Mercer University students have tasked themselves with devising a more reliable method for monitoring the bucket tips. The group also seeks to send the data wireless to a remote computer that can be viewed in real time. This eliminates the need to shut the system off to collect the data. Lastly, the group seeks to install the system on multiple houses.

Also, work can be done to correlate data collected from the systems to the weather outside.

CONCLUSION

Typical residential air conditioner coils accumulate water condensate and drain this condensate from the house. Collecting and repurposing this water elsewhere in the house has the potential to reduce the human footprint on the environment. A condensate collection system has been designed to quantify the amount of condensate that can be collected from such a residential AC system. Condensate that drips from the coils will be sent through a tipping bucket rain gauge into a storage tub and periodically pumped into the yard for irrigation.

The rain gauge collects inflowing water, tipping upon filling to a certain, consistent level. Use of a tipping bucket gauge reduces collection measurements to counting the number of tips. An Arduino monitors a photogate, composed of an LED and a photoresistor, whose voltage alters when the line-of-sight between the two components is obstructed by the bucket to count the number of bucket tips.

The water leaving the gauge drains into a tub which, controlled by a pair of float switches in a double pole, double throw relay, is pumped out into the yard. Temperature, relative humidity, and velocity of the inlet and exit air are also collected to provide data to be used in theoretical analysis of condensate collection. Temperature and relative humidity are measured using a DHT11 Sensor Module and velocity of the flow is measured using a hot wire technique. An Arduino collects data from all sensors and stores them on an SD card.

Weather proofing on the photogate failed after approximately 36 hours of operation and the wind sensors were far too sensitive to air temperature to produce meaningful results. However, from the 36 hours of data collected, it is estimated that approximately 112 liters of water can be collected per week.

ACKNOWLEDGEMENTS

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Bryan is a senior mechanical engineering student at Mercer University School of Engineering. He has spent four years in the Engineering Honors Program at Mercer working on research projects dealing with maze solving robots, truss analysis software, and air conditioning systems. He has been inducted into and held officer positions in Sigma Xi and Tau Beta Pi. After graduation, Bryan seeks to further his education by enrolling in graduate school.

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