Global Science and Technology Journal
Vol. 6. No. 3. September 2018 Issue. Pp.44-56

Quantification of Condensate Water Generated from Air Conditioning System

Md. Arafat Ali[1], Sumaiya Saifur[2], and Muhammad Ashraf Ali[3]

Condensate water generated from air conditioning system is often treated as wastewater and discharged to the building drainage system. In this study, controlled experiments have been carried out to assess generation of condensate water under different weather and operational conditions. The most important parameters affecting condensate water generation are time, difference between outdoor and indoor temperature and humidity. The difference between outdoor and indoor humidity has been found to affect generation of condensate water most significantly; as the difference increases, water generation increases. Water generation also increases as the difference between indoor and outdoor temperature increases. The experimental results have been used to develop and validate an empirical relationship for estimating generation of condensate water. Apart from estimation of condensate water generation in residential and commercial buildings, the relationship could be used to properly design condensate water drainage system of air conditioners. The quantity of condensate water generated from air conditioning system appears to be quite significant. Recycling of condensate water could reduce water demand from city water supply system particularly during the hot and humid months of the year, thus reducing pressure on precious ground and surface water resources.

Keywords: Condensate water, recycling, empirical model.

Broad Field of Research: Wastewater Management

1. Introduction

With growing urban population, demand for water has also been increasing at a high rate in Dhaka city. But access to water has been a critical issue for the city dwellers. Groundwater, extracted through deep tube wells, accounts for about 78% of total water supply (DWASA, 2016). But high dependence on groundwater has caused a sharp declination of groundwater level, groundwater level is declining at an average rate of 2.5 m/year (Rahman et al., 2016). Dhaka city water supply authority (Dhaka WASA) is therefore putting more emphasis on use of surface water sources for potable water supply. However, widespread pollution of surface water bodies surrounding Dhaka is a major obstacle in utilization of these water sources (Alam et al., 2012). The situation is similar in many major cities of Bangladesh. In this situation, rainwater harvesting and reuse of grey water are gaining importance for sustainable water supply. However, use of condensate water generated from air conditioning system has not received much attention, although condensate water has been successfully recycled in commercial and public buildings in a number of countries (Khan and Al-Zubaidy, 2013; Lawrence and Perry, 2010; Bryant and

Department of Civil Engineering, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh, Email: arafatshagor@gmail.com[1], ssaifur003@gmail.com[2] and ashraf@ce.buet.ac.bd[3]

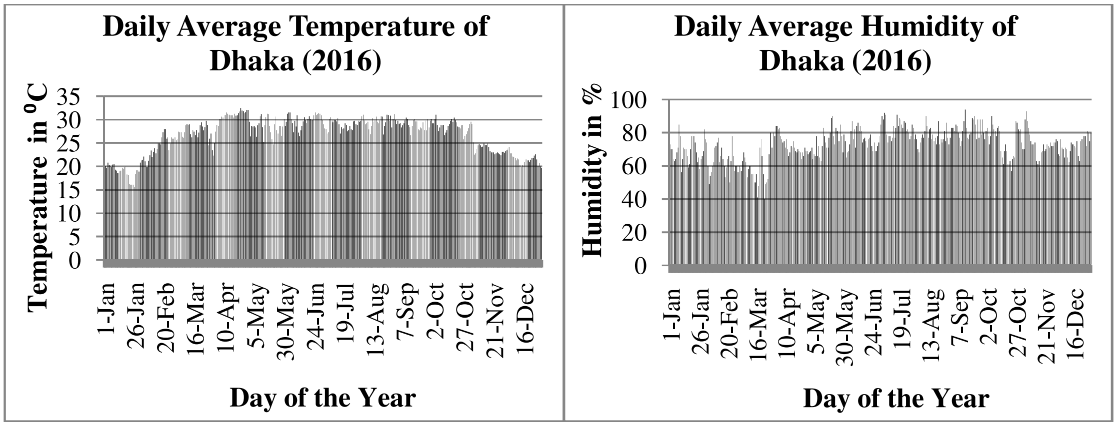
Ahmed, 2008; Guz, 2005). Due to hot and humid weather, significant quantity of condensate water is expected to be generated from air conditioning systems in Bangladesh, which can be used in different ways. This study focuses on estimation of condensate water through controlled experiments, and development of empirical relationship that would allow estimation of condensate water generation under different weather and operational conditions. This research presents an empirical relationship for prediction of condensate generation based on easily measurable parameters, which can be used to predict condensate water generation under a wide range of conditions. Section 1 of this paper describes the background and objectives of this research. Section 2 presents a literature review summarizing results of similar studies conducted earlier. Section 3 describes the methodology followed in the research. Section 4 presents the important results obtained from this research. Finally, Section 5 presents the major conclusions.

2. Literature Review

When water vapor in the air (often described as humidity) comes in contact with a colder surface, the water changes from gas to a liquid and collects onto the cold surface. The water vapor in the air that becomes liquid is referred to as condensate. The condensate that collects on refrigeration equipment is of significant volume and could be a potential alternate water source for different uses. Condensate is usually of good quality, with very low solids contents (Bryant and Ahmed, 2008). In some countries, commercial and public buildings are recycling condensate water for use in cooling towers, for irrigation, gardening and cleaning (Khan and Al-Zubaidy, 2013; Bryant and Ahmed, 2008; Lawrence and Perry, 2008; Guz, 2005).

Climate plays a vital in the generation of condensate water. As a rule of thumb, cooling condensation water generators do not work efficiently when the temperature falls below 18.3°C (65°F) or the relative humidity drops below 30%. Bangladesh has a subtropical monsoon climate characterized by wide seasonal variations in rainfall, temperatures, and humidity. Regional climatic differences in this flat country areminor. Three seasons are generally recognized: a hot, humid summer from March to June; a cool, rainy monsoon season from June to October; and a cool, dry winter from October to March. In general, maximum summer temperatures range between 32°C and 35°C. April is the warmest month in most parts of the country. January is the coldest month. Figure 1 shows the annual temperature and humidity of Dhaka city in 2016. It shows relatively high temperatures and very high humidity throughout most of the year; higher values of both these parameters are conducive to higher condensate water generation.

Figure 1: Daily Average Temperature and Humidity of Dhaka City



Data source: Bangladesh Meteorological Department

In order to evaluate possible recycling of condensate water, it is important to have good estimates of condensate water generation; quality of condensate water is also an important consideration. A number of studies have reported quantities of condensate water generated from air conditioning system (Khan and Al-Zubaidy, 2013); few studies have reported empirical relationships for estimation of condensate water generation. Bryant and Ahmed (2008) estimated condensate water generation over a 28-day period for an institutional building. The average generation was found to be 145 gallons/day, and the generation was found to be tied to the capacity of the particular air handling unit (expressed in ton) of the air conditioning system. Bryant and Ahmed (2008) proposed a generation rate of 8 gallon of condensate water generation per day per ton.

Guz (2005) reported condensate water generation from air conditioning system; a shopping mall at San Antonio, USA is reported to produce 250 gallons of condensate water each day, while a central library system in the same town produces 43,200 gallons per month. Bahrain Airport Service uses 2.3 million gallons of condensate water per year for diverse purposes such as toilet flushing, washing and landscape. Guz (2005) reported a typical rate of production for large buildings during summer months as 0.1 to 0.3 gallons of condensate per ton of air conditioning for every hour the cooling system is operated. This range is based on average production rates measured at a small number of large facilities. Based on this limited data, Guz (2005) has proposed the following formula for estimation of condensate water generation.

Condensate Water (gph) = (Tons of capacity) (Load factor) (0.2 gallons) *Eq. 1*

Khan and Al-Zubaidy (2013) reported the following Eq. 2 for estimation of condensate water generation from cooling coil.

$$m_w = V.\ \rho\ (w_{\text{outdoor air entering cooling coil}} - w_{\text{cooling coil leaving air}}) \qquad \text{Eq. 2}$$

where, m_w = *Mass of condensate water* ($l.hr^{-1}$, $l.min^{-1}$, $kg.sec^{-1}$)

V = *Volume flow of air* ($m^3.sec^{-1}$, $l.sec^{-1}$)

ρ = *Density of air (kg.m^{-3})*

w = specific humidity of air (g.kg^{-1}, kg.kg^{-1})

These estimates and relationships are, however, not very useful for estimating condensate water generation under different operational conditions, and different climatic conditions, which vary significantly in the context of Bangladesh.

3. Methodology

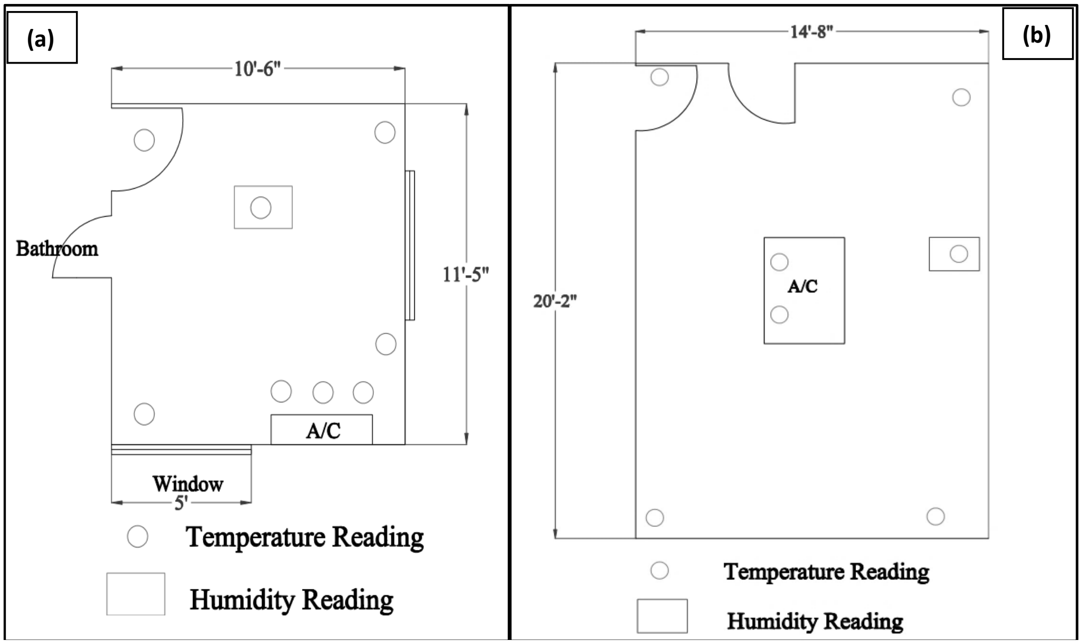
In this study, generation of condensate water has been measured in a single room of two residential building and one institutional building. The residential buildings were located in Asad Avenue, Mohammadpur, Dhaka and Bashundhara Residential Area, Dhaka. The institutional building was located at the International Training Network Centre (ITN) of Bangladesh University of Engineering and Technology, Dhaka. The capacities of the air conditioners at these locations were 1.5 ton, 1.5 ton, and 3.0 ton, respectively.

In order to estimate condensate water generation, the effect of weather condition (particularly temperature and hygrometer), room environment and time of operation have been considered to be important. The devices used to measure relevant parameters included: (1) Thermometer, (2) Dry Bulb and Wet Bulb Hygrometer, (3) Anemometer, (4) Container for collection of water, and (5) Measuring Cylinder. Figure 2 shows layout of the room and location of measuring devices at the experimental rooms at Bashundhara and ITN-BUET. At Bashundhara (Fig. 2a), four thermometers were placed at four corners of the room for recording temperature, and one thermometer was placed in the middle of the room. In addition, three thermometers were placed in front of the air conditioner. One thermometer was placed outside the room for recording ambient air temperature. For measurement of humidity, one hygrometer was placed in the middle of the room and one outside the room. Air flow velocity from the air conditioner was measured using an anemometer. Similar arrangements were made at the other two experimental locations.

3.1 Measurement of Temperature

Before starting the air conditioner, temperature readings of all thermometers placed inside and outside of the experimental rooms were taken. The temperature inside the room was calculated as the average of all the readings of thermometers placed inside of the rooms. Subsequently, all temperature readings were taken at 30 minutes interval for 4 hours.

Figure 2: Layout of Room and Measuring Devices
Thermometer and Hygrometer: (a) Bashundhara, Dhaka; (b) ITN-BUET, Dhaka



3.2 Measurement of Relative Humidity

The readings of hygrometers placed outside and inside of the rooms were taken before commencement of experiment (i.e., starting of the air conditioner). The relative humidity was calculated from the chart using the dry bulb and wet bulb temperatures. All subsequent readings were taken at 30 minutes interval for 4 hours.

3.3 Measuring Flow from Air Conditioner

After starting the air conditioner, velocity of air passing through the louvers was measured along the louver at 4” interval using an anemometer. The measured velocity was multiplied by the cross section of louver to get the air flow. Velocity readings were taken at 30 minutes interval for 4 hours.

3.4 Collection and Measurement of Condensate Water

The water generated during each 30-minute interval (over a period of 4 hours) was stored in a container. The volume of water was measured using a measuring cylinder.

4. Results and Discussion

Effects of weather conditions and operational conditions on generation of condensate water from the air conditioners were analyzed from the experimental data. In particular, the effect of following parameters on generation of condensate water was assessed: (1) Time; (2) Difference between outside and inside temperature; (3) Difference between outside and inside humidity; and (4) Air flow from the air conditioner.

4.1Generation of Condensate Water as a Function of Time

Generation of condensate water has been found to vary significantly with time of operation. Figure 3 shows generation of condensate water (expressed as ml of water generated for each half hour period, per ton of air conditioner capacity) as a function of time of operation for one set of experiment from two experimental locations. It shows significant drop in generation of condensate water with passage of time; water generation appears to stabilize after a few hours of operation. All fourteen data sets show similar trend. In most cases significant drop in water generation was observed after the first hour of operation.

Figure 3(a): One Set of Experimental Data Showing Generation of Condensate Water as a Function of Time at Asad Avenue Site

(Experiment carried out during 8:10 am-12:10 pm on 15 April 2017)

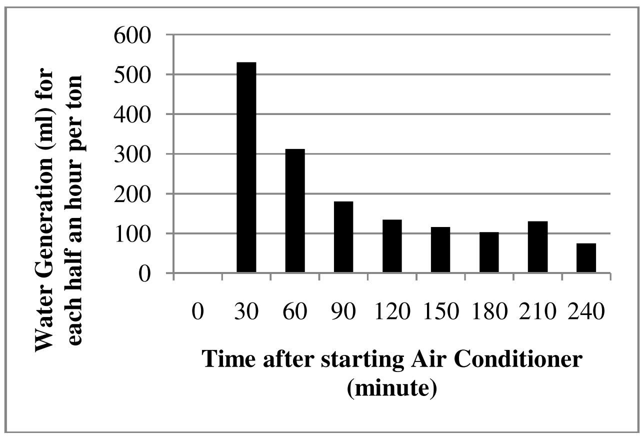
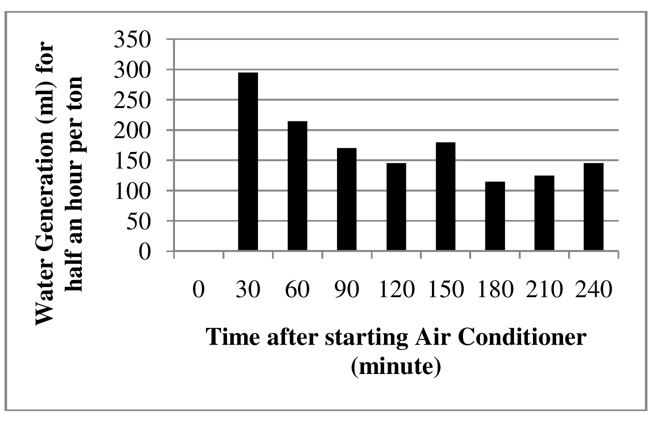


Figure 3(b): One Set of Experimental Data Showing Generation of Condensate Water as a Function of Time at BashundharaSite

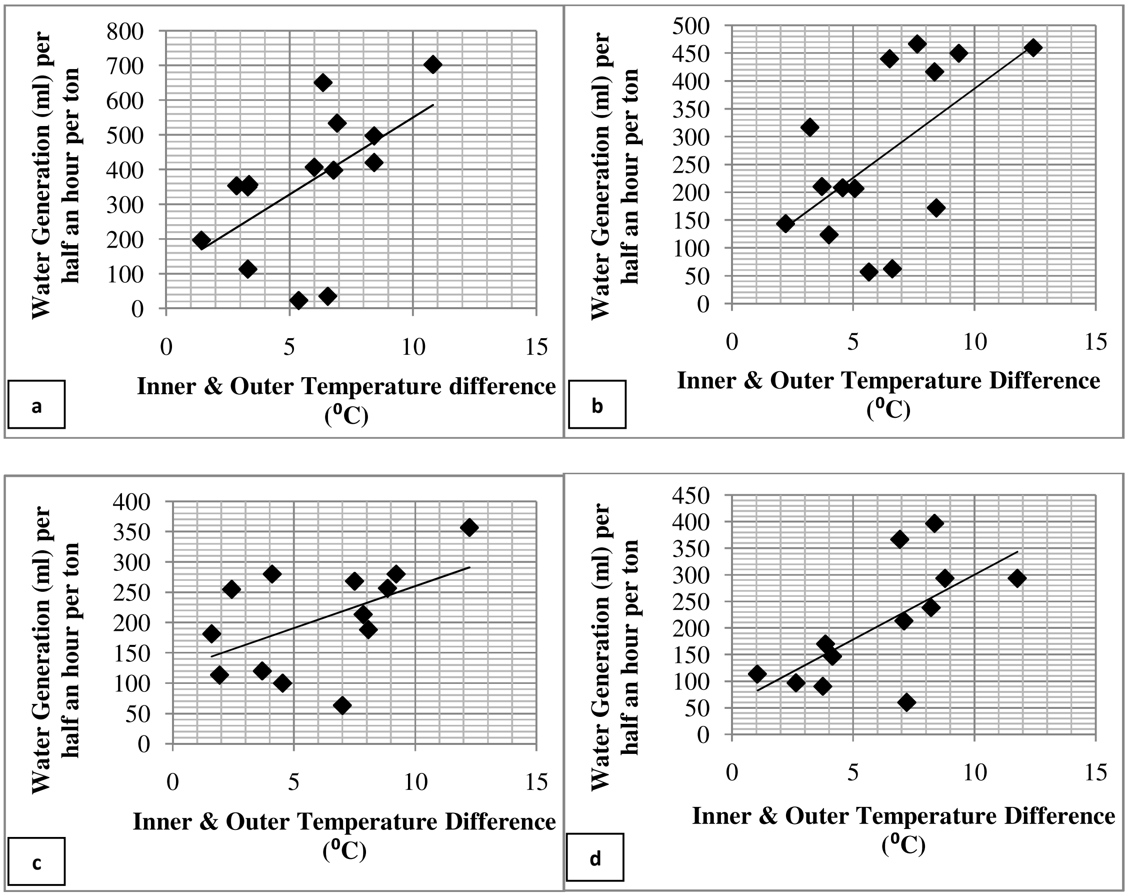
(Experiment carried out during 10:30 am-2:30 pm on 20 April 2017)



4.2Effect of Temperature on Condensate Water Generation

Figure 4 shows generation of condensate water (expressed as ml of water generated for each half hour period, per ton of air conditioner capacity) as a function temperature difference between outside and inside of the experimental rooms, for the first four half-hourly periods in all fourteen experiments carried out at the three experimental locations. In general, it shows a positive correlation between generation of condensate water and temperature difference. However, quite a few experimental data points appear to be “outliers” and fall outside this general trend.

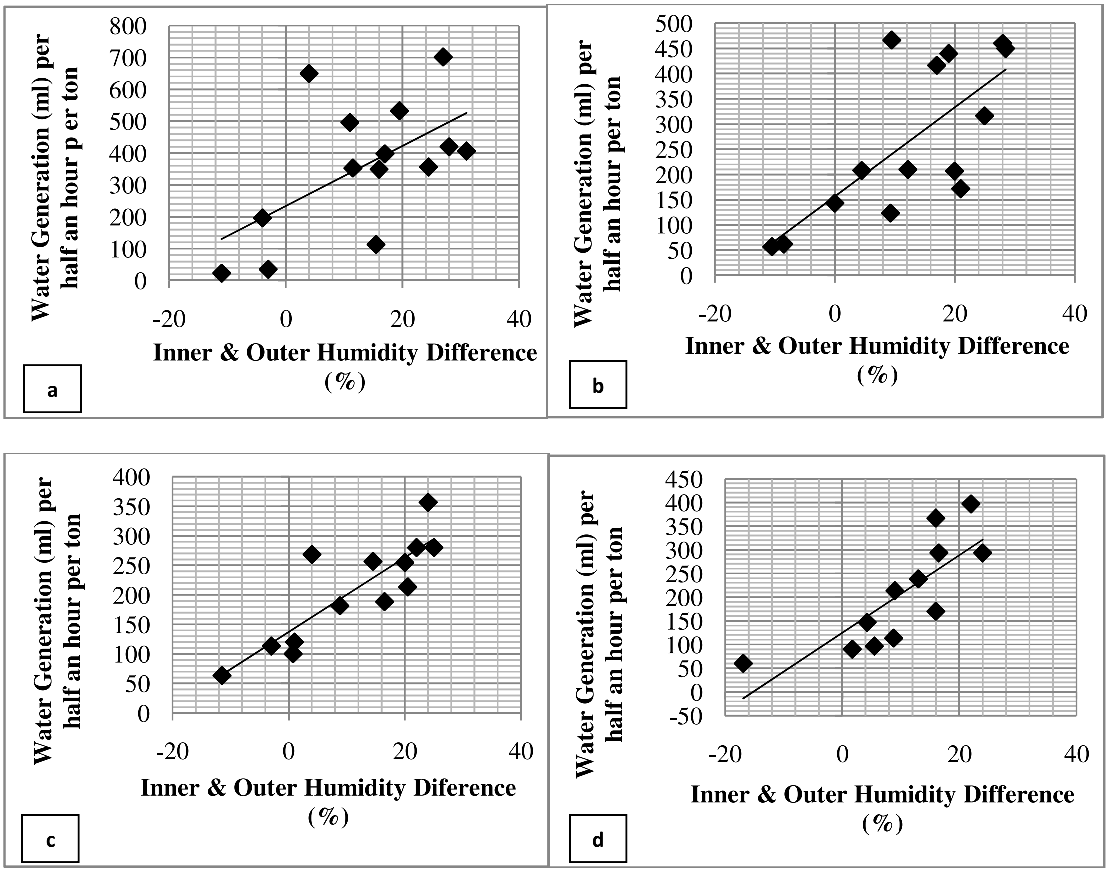
Figure 4:Generation of Condensate Water as a Function of Outside and Inside Temperature Difference for the Experimental Data Sets: (a) for First Half-Hour; (b) for Second Half-Hour; (c) for Third Half-Hour; and (d) for Fourth-Half Hour



4.3 Effect of Humidity on Condensate Water Generation

Figure 5 shows generation of condensate water (expressed as ml of water generated for each half hour period, per ton of air conditioner capacity) as a function humidity difference between outside and inside of the experimental rooms, for the first four half-hourly periods in all fourteen experiments carried out at the three experimental locations. The figures show very good correlation between generation of condensate water and humidity difference between outside and inside of the rooms.

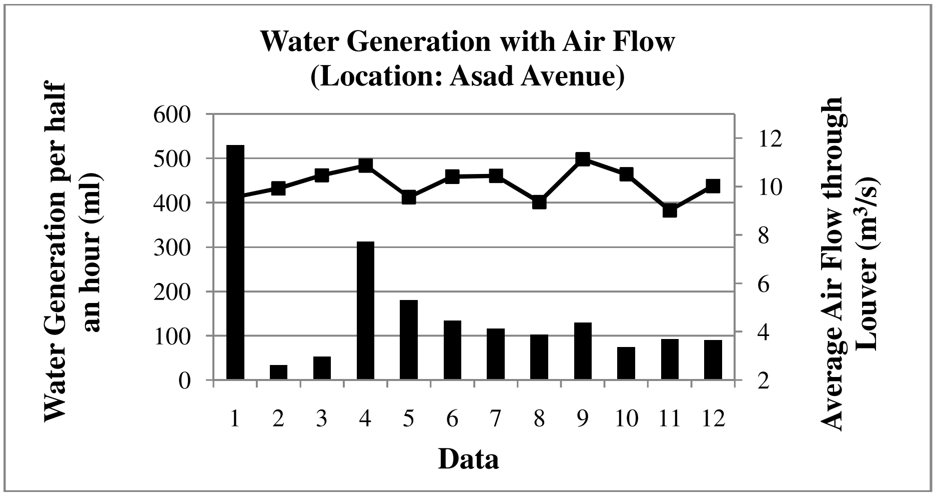
Figure 5:Generation of Condensate Water as a Function of Outside and Inside Humidity Difference for Experimental Data Sets: (a) for First Half-Hour; (b) for Second Half-Hour; (c) for Third Half-Hour; and (d) for Fourth-Half Hour



4.4 Variation of Condensate Water Generation with Air Flow

Air flow through the louver of the air conditioners was calculated from the measured air velocity and cross-sectional area of the louvers. Figure 6 shows variation of condensate water generation as a function of air flow for experiments carried out at Asad Avenue. It shows that air flow through the louver did not vary significantly during the duration of the experiment; and there is no clear correlation between air flow and water generation. Similar results were obtained from experiments carried out at the other two locations (i.e., Bashundhara and ITN-BUET)

Figure 6: Condensate Water Generation versus Air Flow through the Louvers of Air Conditioner at Asad Avenue



4.5 Analysis of Experimental Results

From analysis of experimental results, it is clear that generation of condensate water varies significantly with time, with generation dropping considerably after the first hour of operation. The other important parameters are temperature and humidity difference between outside and inside of the room. Figure 5 shows strong correlation between generation of condensate water and humidity difference. While Figure 4 shows good correlation between condensate water generation and temperature difference, some deviations are clearly visible. However, the deviations could be explained by the combined effect of temperature and humidity.

Figure 7(a) shows generation of condensate water during the first half hour of experiments as a function of “outside and inside temperature difference”. It shows that a few data points (circled in figure) are outliers; the two circled data points show generation of very low volumes of condensate water despite significant difference between outside and inside temperatures. However, when the water generation is plotted against “inside and outside humidity difference” (Fig. 7b), it becomes clear the two circled data points correspond to very low (in fact negative) “humidity difference”. This suggests that “humidity difference” has a more pronounced effect on condensate water generation, than “temperature difference”.

Figure 7:Generation of Condensate Water During the First Half Hour of Experiments: (a) as a Function of Outside and Inside Temperature Difference; the Data Points Circled Fall Outside the General Trend; (b) as a Function of Outside and Inside Humidity Difference; the Two Data Points Circled in (a) are Also Circled in This Figure.

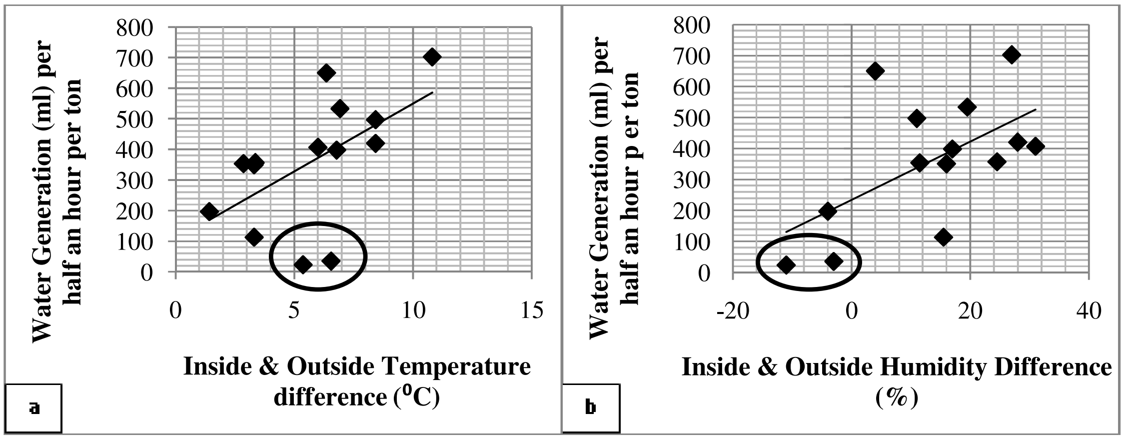
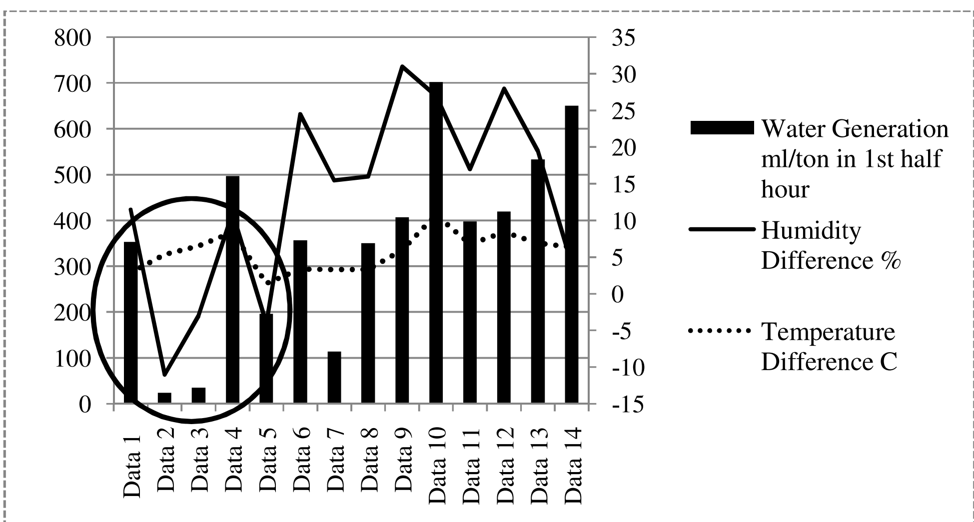


Figure 8 shows generation of condensate water and corresponding temperature and humidity differences for all fourteen data sets generated in this study. It clearly shows more pronounce effect of "humidity difference" compared to "temperature difference".

Figure 8: Generation of Condensate Water (During First Half Hour of Air Conditioner Operation) and Temperature Difference and Humidity Difference.



4.6 Estimation of Condensate Water Generation

The experimental data suggest that the volume of condensate water generated from air conditioning systems depend primarily on three parameters: (a) time; (b) difference in humidity between outside and inside of room; (c) difference in temperature between outside and inside of room. An empirical relationship was developed for estimation of condensate water generation as a function of these three parameters through regression analysis of experimental data; out of 14 data sets, 8 data sets were used for regression analysis. Eq. 3 shows the empirical relationship describing condensate water generation, while Table 1 shows the regression statistics.

$$W = 30.5*T + 5*H - 0.35*t \quad \text{Eq. 3}$$

where,

W= *Water generation for each half-hour period (ml) per ton*

T = *Temperature difference between inside and outside of room (°C)*

H = *Humidity difference between inside and outside of room (%)*

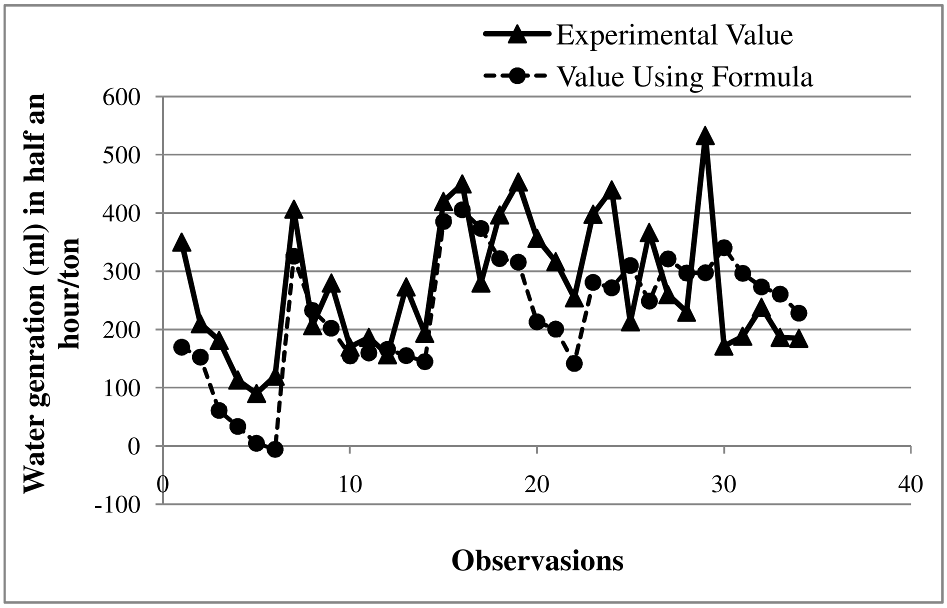
t= *time after starting the air conditioner (minute) (i.e., 30 for estimating generation during the first half hour; 60 for estimating generation during the second half hour and so on)*

Table 1: Regression Statistics

Multiple R	0.875644596
R Square	0.766753458
Adjusted R Square	0.737998692
Observations	54

The regression equation (Eq. 3) was then used to estimate condensate water generation for conditions representing the remaining 6 data sets. Figure 9 shows a comparison of these estimates and condensate water actually generated during these 6 sets of experiments. It shows reasonable agreement between the estimates and data. The empirical relationship (Eq. 3) developed in this study is based on easily measurable parameters, and could be conveniently used for prediction of condensate water generation in Bangladesh and similar other tropical countries.

Figure 9: Comparison of Experiment and Theoretical (using Empirical Formula) Value of Water Generation in Graphical form



5. Conclusions

The study focused on quantification of condensate water generation from air conditioning system. It has been found that significant quantity of water is generated from air conditioning system which could be utilized for different non-potable use, as has been done in a number of countries. Analysis of experimental data suggests that the quantity of condensate water primarily depends on three parameters: (a) time; (b) temperature difference between outside and inside environment, and (c) humidity difference between outside and inside environment. The experimental data have been used to develop and validate an empirical equation for estimation of condensate water as a function of these three parameters. Among other applications, the relationship could be used to properly design condensate water drainage system of air conditioners. Recycling of condensate water could reduce water demand from city water supply system particularly during the hot and humid months of the year, thus reducing pressure on precious ground and surface water resources.While this is probably the first comprehensive study on generation of condensate water in the context of Bangladesh, there are some limitations in this study; these include use of limited types (brand, capacity) of air conditioning system, and lack of analysis on condensate water quality. These issues should be addressed in subsequent studies.

Acknowledgement

The authors would like to express their gratitude to Dr. Md. Ashiqur Rahman, Assistant Professor, Department of Mechanical Engineering, BUET for his kind support and advice throughout the course of this study.

References

Alam, Md. A., Badruzzaman, A. B. M., & Ali, M. A. 2012, 'Water quality response to reductions in waste loading of Sitalakhya river, Bangladesh', *Journal of Water and Environment Technology*, *Vol. 10, No. 1, Pp.31-46*.

Bryant, J. A. & Ahmed, T. 2008, Condensate Water Collection for an Institutional Building in Doha, Qatar: An Opportunity for Water Sustainability, *Proceedings of the 16th Symposium on Improving Building Systems in Hot and Humid Climates*, Plano, Texas, USA, December 15-17.

Dhaka Water Supply and Sewerage Authority 2016, *Dhaka WASA Annual Report 2014-1015*

Guz K. 2005, 'Condensate Water Recovery', *ASHRAE Journal*, *Vol. 47, No. 6, Pp. 54-56.*

Khan, S. A. & Al-Zubaidy, S. N. 2013, 'Conservation of potable water using chilled water condensate from air conditioning machines in hot and humid climate', *International Journal of Engineering and Innovative Technology (IJEIT)*, *Vol. 3, No. 2, Pp.182-188.*

Lawrence, T. & Perry, J. 2010, 'Capturing condensate from High Performing Buildings'*, ASHRAE Journal*,*Vol. 52, No. 1,* Pp. 56-61.

Rahman, Md. M., Akter, M. M., Rahman, M. A., Uddin, Md. R., Khan, F., & Rahman, Md. N. 2016, 'Impacts of Excess Groundwater Abstraction and Potentials of Rainwater Harvesting to Overcome the Impacts in Dhaka City, Bangladesh', *International Journal of Emerging Technology and Advanced Engineering*, *Vol. 6, No. 7, Pp. 64-71.*