



UNIVERSITY  
OF WOLLONGONG  
AUSTRALIA

University of Wollongong  
Research Online

---

Faculty of Engineering and Information Sciences -  
Papers: Part A

Faculty of Engineering and Information Sciences

---

2014

# Integrated dehumidification and downdraft evaporative cooling system for a hot-humid climate

Sriraj Gokarakonda

*Wuppertal Institute For Climate, Environment And Energy*

Georgios Kokogiannakis

*University of Wollongong, gkg@uow.edu.au*

---

## Publication Details

Gokarakonda, S. & Kokogiannakis, G. (2014). Integrated dehumidification and downdraft evaporative cooling system for a hot-humid climate. 30th International PLEA Conference (PLEA 2014) (pp. 1-8). Ahmedabad, India: CEPT University Press.

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library:  
research-pubs@uow.edu.au

---

# Integrated dehumidification and downdraft evaporative cooling system for a hot-humid climate

## **Abstract**

Unlike in hot-dry climates, in hot-humid climates evaporative cooling techniques are not readily suitable for space cooling. In order to effectively use evaporative cooling in hot-humid climates, dehumidification of ambient air is necessary before it passes over an evaporative medium for cooling. The present study explores the combined process of dehumidification and evaporation and its effect on thermal comfort in a typical small residential building located in a hot humid climate. A novel system has been investigated with the combination of an Earth Tube Ventilation (ETV) (for pre-cooling of air), a rotary wheel desiccant dehumidifier (for dehumidification) along with a Passive Downdraught Evaporative Cooling (PDEC) tower (for evaporation) in that order. Parametric simulations using the EnergyPlus tool have been conducted in order to determine the critical dimensions and parameters of the proposed system, such as desiccant system sizing, PDEC tower height, and air and water flow rate at various points of the system. Results of indoor air temperature, humidity levels and volumetric air flow rates in the building spaces were obtained to study the influence of the proposed combined system on human thermal comfort. On a typical hot day the results from the proposed system show a relatively constant indoor air temperature of 28 °C (as opposed to peak indoor temperature of 36 °C occurred by means of natural ventilation) and indoor relative humidity in the range of 62 % - 68 %. The volumetric airflow rate from the outlet of the PDEC tower is in the range of 2.97 - 3.41 m<sup>3</sup>/s which is well within recommended levels for a dwelling unit. The proposed system displays a significant potential for providing space cooling in hot-humid climates as it paves an alternate way to the conventional energy consuming vapour compression Air Conditioning units.

## **Keywords**

system, integrated, hot, dehumidification, humid, climate, downdraft, cooling, evaporative

## **Disciplines**

Engineering | Science and Technology Studies

## **Publication Details**

Gokarakonda, S. & Kokogiannakis, G. (2014). Integrated dehumidification and downdraft evaporative cooling system for a hot-humid climate. 30th International PLEA Conference (PLEA 2014) (pp. 1-8). Ahmedabad, India: CEPT University Press.

# Integrated dehumidification and downdraught evaporative cooling system for a hot-humid climate

**Sriraj Gokarakonda**

Wuppertal Institute for Climate, Environment and Energy  
sriraj.gokarakonda@wupperinst.org

**Georgios Kokogiannakis, PhD**

SBRC, University of Wollongong

## ABSTRACT

*Unlike in hot-dry climates, in hot-humid climates evaporative cooling techniques are not readily suitable for space cooling. In order to effectively use evaporative cooling in hot-humid climates, dehumidification of ambient air is necessary before it passes over an evaporative medium for cooling. The present study explores the combined process of dehumidification and evaporation and its effect on thermal comfort in a typical small residential building located in a hot humid climate. A novel system has been investigated with the combination of an Earth Tube Ventilation (ETV) (for pre-cooling of air), a rotary wheel desiccant dehumidifier (for dehumidification) along with a Passive Downdraught Evaporative Cooling (PDEC) tower (for evaporation) in that order. Parametric simulations using the EnergyPlus tool have been conducted in order to determine the critical dimensions and parameters of the proposed system, such as desiccant system sizing, PDEC tower height, and air and water flow rate at various points of the system. Results of indoor air temperature, humidity levels and volumetric air flow rates in the building spaces were obtained to study the influence of the proposed combined system on human thermal comfort. On a typical hot day the results from the proposed system show a relatively constant indoor air temperature of 28 °C (as opposed to peak indoor temperature of 36 °C occurred by means of natural ventilation) and indoor relative humidity in the range of 62 % - 68 %. The volumetric airflow rate from the outlet of the PDEC tower is in the range of 2.97 - 3.41 m<sup>3</sup>/s which is well within recommended levels for a dwelling unit. The proposed system displays a significant potential for providing space cooling in hot-humid climates as it paves an alternate way to the conventional energy consuming vapour compression Air Conditioning units.*

## INTRODUCTION

Space cooling techniques become inevitable in extreme hot-dry and hot-humid climates where building form and construction alone cannot ensure indoor thermal comfort. Evaporation of water has been one of the available techniques used for space cooling. Special architectural features such as wind towers were used in hot-dry climates to direct the prevailing winds over a wet body like *khuskhus* pads, water filled clay pots etc. to enhance evaporation. However, high humidity in the ambient air inhibits the use of direct evaporative cooling in hot-humid climates and dehumidification of the air is necessary before it passes over an evaporative medium for cooling. This study explores an alternate to conventional vapour compression based domestic air conditioning units by using dehumidification and evaporation in a typical residential building in a hot- humid climate in India. A combination of a cooling system Sriraj Gokarakonda is a research fellow at Wuppertal Institute for Climate, Environment and Energy, Wuppertal, Germany. Georgios kokogiannakis is a senior lecturer at the Sustainable Buildings Research Centre (SBRC), University of Wollongong, Australia.

consisting of a rotary wheel desiccant dehumidifier along with a Passive Dwindraught Evaporative Cooling (PDEC) tower has been devised. An Earth Air Tunnel (EAT) for precooling of intake air has later been added to the original cooling system after analysing the preliminary results. Simulations were run with EnergyPlus to conduct a parametric analysis of the proposed system and to study its influence on thermal comfort.

## **PASSIVE DOWNDRAUGHT EVAPORATIVE COOLING SYSTEMS**

Evaporative cooling is based on the conversion of sensible heat to latent heat. When water evaporates, it uses up the heat from the surrounding air to change phase from liquid to vapour and this result in lowering the temperature of the surrounding air. A typical configuration of a passive dwindraught cooling system has a tower to draw in air into the space. The air is passed over an evaporative medium placed below the tower inlet, gets cooled and enters the space through an outlet at the bottom of the tower. A passive dwindraught was thus created through the evaporation of water within this air-stream and the necessary air circulation was achieved through either by buoyancy or by wind assisted natural ventilation.

However, modern PDEC towers include energy intensive components like fans and pumps to enhance dwindraught or to increase flow rates and are referred to as Passive and Hybrid Dwindraught Cooling (PHDC) (Ford, Phan, & Francis, 2009). To increase the evaporation of water, large droplets of water are sprayed into the air stream (e.g. by a shower tower) or a mist of water is added to the air stream (e.g. by misting nozzles in a misting tower) instead of letting the air passing over wetted pads and clay water pots. In this paper, shower tower configuration of PDEC is selected as it represents a typical system used in practice. A shower tower PDEC (PHDC) proved to be a worthy option in meeting the cooling needs of the Torrent research centre building in Ahmedabad (Leena & George, 1997). The system provided an alternative to the use of conventional Air Conditioning in such hot climates during hot-dry season. However, reliance on conventional air conditioning was recommended for the hot-humid season. This system can also be well integrated to the existing buildings. An example of such an application is in Portugal, where an existing chimney of a building has been modified to be used as a PDEC tower (Melo & Guedes, 2006). Its performance was studied by measuring the thermal parameters and humidity levels and compared against a mathematical model. The results for PDEC were encouraging, but it was concluded that a PHDC was performing better over a PDEC (Melo & Guedes, 2006).

## **DESICCANT DEHUMIDIFICATION**

Desiccant dehumidification is based on the principle of sorption with the use of desiccant chemicals. Sorption occurs due to difference in the vapour pressure exerted by the moisture in the air on the surface of desiccant which offers an area of low vapour pressure (Munters Corporation, 2002). Liquid desiccant dehumidifiers in general are large systems and are used to condition large spaces. Solid desiccant dehumidifiers are available in different sizes, configurations to suit for application in residential buildings. Two popular solid desiccant configurations that suit residential applications are packed bed and rotary desiccant wheel.

Packed bed dehumidifier consists of loosely packed silica gel beads. Ambient air is passed over this desiccant bed and the dry air is circulated into the space. It has found application in residential units in a configuration called desiccant enhanced nocturnal radiation (DESRAD) cooling and dehumidification. Chung et al., 1995, Satio (1993), Techajuntaa et al. (1999) further investigated DESRAD concept in various configurations and concluded it can be used in domestic air-conditioning in tropical humid climates.

Rotary Desiccant Wheel (DW) dehumidifier consists of finely divided desiccant silica gel beads that are impregnated into a semi-ceramic structure, which in appearance resembles corrugated cardboard that has been rolled up into the shape of a wheel. The wheel rotates slowly between two air streams called the process air and reactivation airstreams. The process air flows through the flutes formed by the

corrugations, and the desiccant in the structure absorbs the moisture from the air (Figure 1 process A-B). Re-activation (Figure 1 B-C) is the hot air (blown by a hot air blower) necessary to regenerate the saturated desiccant. Following reactivation, the hot desiccant rotates back into the process air (Figure 1 C-A), where a small portion of the process air cools the desiccant so it can collect more moisture from the balance of the process airstream. (Munters Corporation, 2002). Commercial desiccant products in the HVAC industry are mostly available in rotary desiccant wheel (DW) configuration.

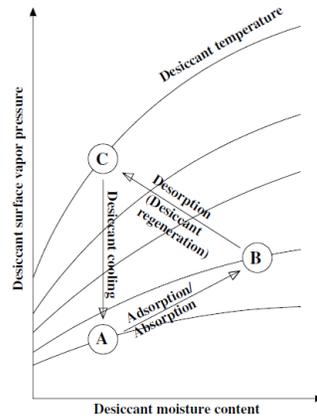


Figure 1 Desiccant dehumidification and regeneration processes (Mazzei et al. 2005)

While a rotary DW dehumidifier consumes more energy than a packed bed it has been chosen for the present study because the DW system can be easily and precisely sized with available modelling tools to fit a building case. Modelling a packed bed on the other hand involves dependence either on experimental data or rigorous analytical calculations with assumptions to be made which was beyond the time scope of the study.

## METHODOLOGY

### Location and Climate analysis

The location selected for the current study is Visakhapatnam city (Lat 17.72, Lon 83.23) in the state of Andhra Pradesh in India and where the climate is categorised as tropical hot-humid climate. In peak summer the temperature reaches as high as 38 °C and in winter it reaches a minimum of 15 °C. The diurnal variation of temperature during hot summers is usually 5-6 °C. The outdoor relative humidity levels are in general above 60% for most of the year. Relative humidity is low at noon and reaches peak during early morning before the sunrise and again drops as the day progresses .

### Description of the proposed system and sequence of operation

The proposed system consists of a rotary Desiccant Wheel dehumidifier (DW) which is integrated with a Drowdraught Evaporative Cooling shower tower (PDEC tower) through which the air is supplied into the space (Figure 2 a). An Earth Air Tunnel has later been added to the DW+PDEC system after observing the preliminary results in order to pre cool the supply air drawn into the Desiccant Wheel.

The ambient air at temperature  $T_a$  and relative humidity  $Rh_a$  is drawn into the EAT and leaves the EAT at a temperature  $T_1$  and relative humidity  $Rh_1$ . The air at  $T_1$  and  $Rh_1$  is then drawn into the inlet of DW from the outlet of the EAT. The air at the outlet of the DW is called the process air and it has been dehumidified and conditioned to a temperature  $T_2$  and relative humidity  $Rh_2$ . The process air at  $T_2$  and  $Rh_2$  is then supplied to the top of the PDEC.  $T_3$  and  $Rh_3$  are the air temperature and relative humidity at the outlet of the PDEC tower which is directly supplied for cooling the indoor space.  $T_4$ ,  $Rh_4$  is the final

temperature and relative humidity in the zone and it is expected to be less than the ambient  $T_1$  and  $Rh_1$  for the system to be able to perform well. The psychrometric representation of the proposed system can be seen in Figure 2 b.

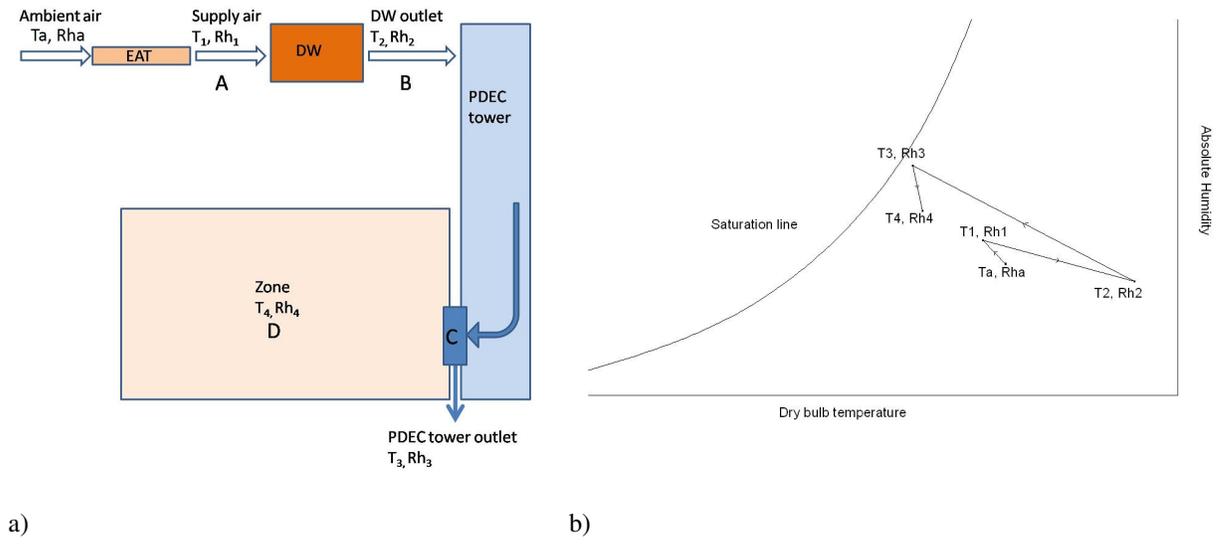


Figure 2 a) Graphical representation of the proposed system b) System representation on a Psychrometric chart

### Description of a typical dwelling unit to which the proposed system is attached

A typical dwelling unit has been modelled as three thermal zones (Figure 3). Zone 2 is connected to the proposed system of integrated dehumidifier and PDEC tower and it is referred to as zone henceforth. All rooms have a wall to window ratio of 33% which is typical in the region. The floor to ceiling height is 2.8m. The worst possible scenario is assumed for shading during the cooling period, i.e. there are no shading devices or overshadowing from the surroundings. Typical building materials used in the region are assumed for the constructions and their U-Values (in  $W/m^2K$ ) are: exterior walls - 1.946, interior walls - 1.735, roof slab - 4.6, floor slab - 0.894 and windows 5.71 (with an SHGC of 0.567).

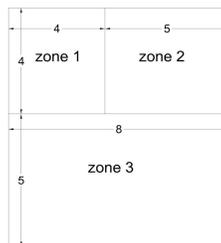


Figure 3 Typical dwelling unit (all dimensions in meters)

### MODELLING THE PROPOSED SYSTEM

The EnergyPlus whole building dynamic simulation program was used to simulate the EAT, DW and PDEC components. However, the whole proposed system of this study (i.e. ambient air → EAT →

DW → PDEC → Building zone) could not be modelled in one simulation because of the limitations of the tool to assemble such a configuration in a single sequence. For this purpose, a total of four simulations were carried out in a way that is explained below and summarised in Figure 2:

1. Ambient air→EAT (A in Figure 2): Precooling of air was simulated using an Earth Air Tunnel. The results of the simulation provide the supply air temperature at  $T_1$ ,  $Rh_1$  from the outlet of the EAT. The EAT has been modeled with a fan to provide an EAT outlet flow that matches with the supply flow rate demand of the DW dehumidifier.

2. EAT→DW (A to B in Figure 2): The DW was simulated in EnergyPlus using a modified weather file with temperature and relative humidity values obtained from the previous simulation i.e.,  $T_1$  and  $Rh_1$  as inputs. The results of this simulation provide the process air at  $T_2$ ,  $Rh_2$  from the outlet of the DW.

3. DW→PDEC (B to C in Figure 2): The PDEC tower was modelled in the third simulation. Technically, in the EnergyPlus program the PDEC tower simulation takes the inlet temperature and humidity data at the top of the tower from the original weather file. Therefore, the values of actual ambient air temperature and relative humidity in the original weather file were replaced by the output obtained from the 2<sup>nd</sup> simulation, i.e., with  $T_2$ ,  $Rh_2$ . When this 2<sup>nd</sup> simulation was run PDEC tower takes  $T_2$ ,  $Rh_2$  as the inlet values at the top of the tower and the tower outlet temperature and humidity  $T_3$ ,  $Rh_3$  are obtained. The conditions in zone 2 ( $T_4$  and  $Rh_4$ ) can in theory be calculated from the same simulation, however in this case the zone conditions cannot be obtained because the temperature and relative humidity values ( $T_2$  and  $Rh_2$ ) in the weather file for the 3<sup>rd</sup> simulation were modified from the actual ambient temperature and relative humidity (from  $T_a$  and  $Rh_a$ ) to the DW outlet temperature  $T_2$  and relative humidity  $Rh_2$  in order to be used as inlet conditions of the PDEC tower. This means that the weather file during the 3<sup>rd</sup> simulation did not include the actual weather conditions and could not therefore be used to define the boundary conditions of the building.

4. PDEC→Room (C to D in Figure 2):The fourth simulation was run to obtain the zone temperatures and relative humidity levels ( $T_4$  and  $Rh_4$ ). In this simulation boundary conditions were properly set based on the original weather file with ambient air conditions at  $T_a$  and  $Rh_a$ . The air supplied into the zone from the PDEC tower outlet (i.e.  $T_3$  and  $Rh_3$ ) has been mimicked by using a customised EnergyPlus component that supplies air into the zone at desired parameters. The results of this simulation provide the zone air conditions at  $T_4$ ,  $Rh_4$ .

Parametric studies have been done at each component level to optimise the critical parameters that impact in achieving the lowest temperature and relative humidity of the air at each of the outlets. The focus was on optimising pipe length and depth for EAT, velocity of the wheel for the Desiccant Wheel, and water flow rate and height of the tower for PDEC tower. Table 1 gives a summary of the sequence of optimization of various components, which was done based on the above listed parameters. The physical parameters of the proposed system were optimized based on the conclusions drawn from the parametric results. The highlighted area shows the selected case from each stage, which was then carried forward to the subsequent simulation stage.

**Table 1 Optimization process**

	Case 1	Case 2	Case 3	Case 4	Case 5
Earth Air Tube	Case 1	Case 2	Case 3	Case 4	Case 5
Pipe length	30	30	30	50	70
Depth	3	5	7	3	3
DW	Case 1	Case 2	Case 3	Case 4	
Velocity (m/s)	2.5	3	3.5	4	
PDEC	Case 1	Case 2	Case 3	Case 4	
Max water flow rate (m <sup>3</sup> /s)	0.00001	0.0005	0.005	0.016	
PDEC - height (m)	5.0	5.0	5.0	5.0	
PDEC	Case 5	Case 6	Case 7	Case 8	Case 9
Max water flow rate (m <sup>3</sup> /s)	0.0005	0.0005	0.0005	0.0005	0.0005
PDEC - height (m)	3.00	5.00	7.00	9.00	11.00

## RESULTS

A period of two representative weeks during which peak outdoor temperatures occur is taken for study (Figures 4 and 6). It can be observed from Figure 4 that there is a significant decrease in the zone temperature in the range of 3-8 °C after adding the proposed system (without EAT) in comparison to the zone temperature without any system and open to natural ventilation. The addition of the EAT further decreases the zone temperature and brings it close to the comfort limits (in the range of 28 – 30 °C).

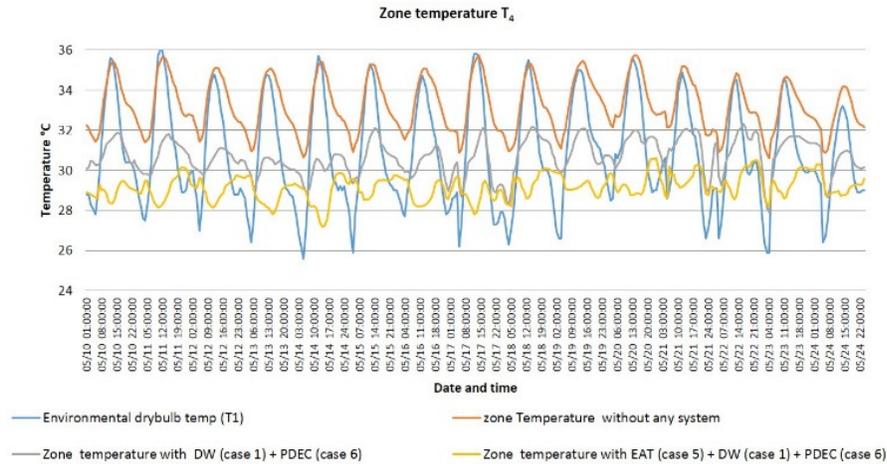


Figure 4 Zone temperature ( $T_4$ ) after adding EAT (case 5) to pre cool the supply air

A typical warm day chosen from the above two-week period to analyse the diurnal variation in zone temperature and zone relative humidity levels. From Figure 5 it can be seen that zone temperatures during the day are lower than that of the night for the system configuration with EAT (case 5) + DW (case 3) + PDEC (case 6). The zone air temperature increases in the night and at times exceeds the ambient air temperature (see Figure 5).

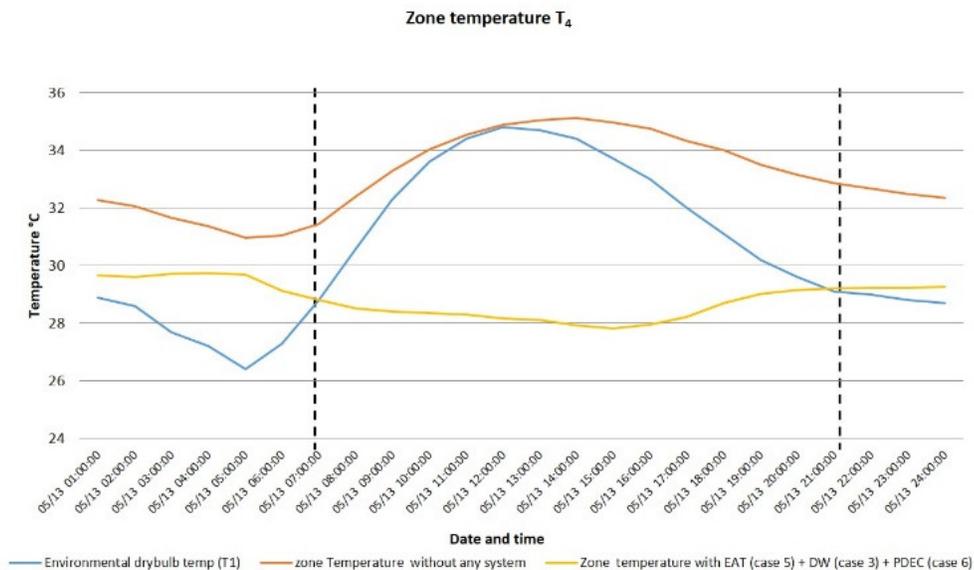


Figure 5 Diurnal variations in zone temperature ( $T_4$ )

The relative humidity in the zone with the proposed system was lower during daytime and higher during the nights than the relative humidity values of the naturally ventilated case. However, zone relative humidity levels are maintained well below the maximum permissible level of 75% (Figure 6) (CIBSE, 2006) throughout the period of the study.

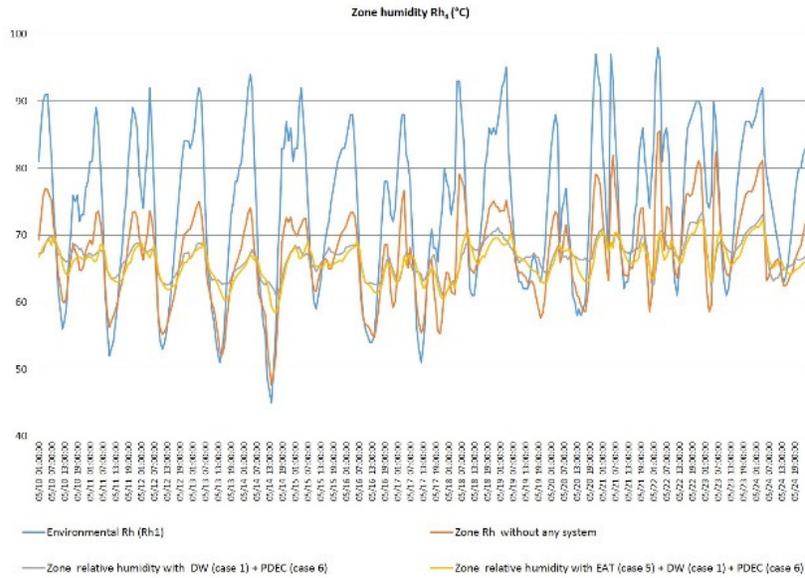


Figure 6 Zone humidity (Rh4) after adding EAT to pre cool supply air

Figure 7 shows that the proposed system results in a slightly higher relative humidity (up to 8%) compared to the naturally ventilated zone humidity levels during the day. However, during the nights the system reduces (by up to 7%) the relative humidity in the zone. An air flow rate of 2.97 - 3.41 m<sup>3</sup>/s was also observed at the outlet of the PDEC tower ensuring the recommended ventilation levels within the space as per ASHRAE (2009) for residential dwellings.

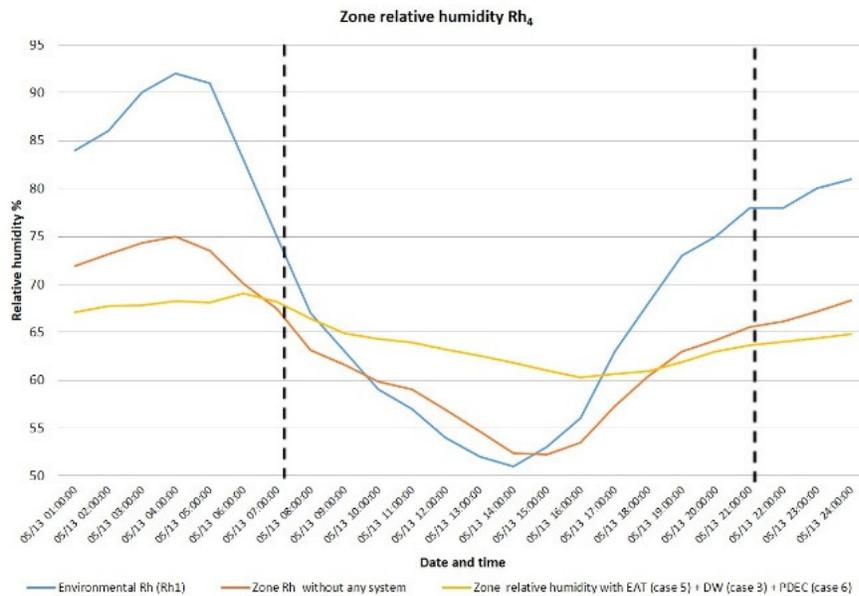


Figure 7 Diurnal variation in zone relative humidity (Rh4)

## CONCLUSION

An integrated cooling system of desiccant dehumidifier and PDEC was evaluated for a typical dwelling in a hot humid climate in India after being combined with an earthtube ventilation system. A process for enabling the simulation of the proposed system has been reported. The system's performance was investigated with a parametric analysis and it was found that by using the EAT+DW+PDEC system as opposed to using natural ventilation the peak indoor summer temperatures were reduced by about 8 °C while indoor relative humidity remained below 75%. The proposed system could provide space cooling in hot-humid climates and could be an alternative to high energy consuming conventional vapour compression AC units. This study analysed a worst-case scenario of a building without any shading and by assuming typical materials that are not of high thermal standards. With improvements however in building designs, the proposed system could ensure good levels of indoor thermal comfort.

## REFERENCES

- ASHRAE. (2009). In *ASHRAE Handbook - Fundamentals (I-P Edition)* (S. 25.1-25.16).
- Chung, W., Lu, M., Shyu, J., & Yan, J. (1995). Development and experimental validation of two novel solar desiccant-dehumidification-regeneration systems. *Energy*, 20, 751-757.
- CIBSE. (2006). Environmental criteria for design CIBSE Guide A. In M. Humphreys, & F. Nicol, *Environmental design CIBSE Guide A* (7th edition Aug., S. 1-4). London: CIBSE.
- Ford, B., Phan, R. S., & Francis, E. (2009). *Passive and Hybrid Draught Cooling in buildings* Design Source book. London, UK: Unpublished.
- Leena, T., & George, B. (1997). *Home: Architecture and Development*. Abgerufen am 3. July 2010 von Architecture and Development Web site: <http://www.archidev.org/index.php>
- Mazzei, P., Minichiello, F., & Palma, D. (2005). HVAC dehumidification systems for thermal comfort: a critical review. *Applied thermal engineering*, 25, 677-707.
- Melo, A. C., & Guedes, M. C. (2006). *Passive Draught Evaporative Cooling Applied on Existing Fabric: Using Traditional Chimney as Case Study in Portugal*. Instituto Superior Técnico, Lisboa, Portugal. Geneva: PLEA.
- Munters Corporation. (2002). *The Dehumidification Handbook*. (L. G. III, Hrsg.) Amesbury: Munters Corporation.
- Satio, Y. (1993). Regeneration characteristics of adsorbent in the integrated desiccant:collector. *ASME Journal of Solar Energy Engineering*, 69-75.
- Techajuntana, S., Chirattananon, S., & Exell, R. (1999). Experiments in a solar simulator on solid desiccant regeneration and air dehumidification for air conditioning in a tropical humid climate. *Renewable Energy*, 17, 549-568.