Design of Solar Powered Desiccant based Air Handling Unit

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Abstract. Using an air handling unit (AHU) is a suitable method to meet the ventilation requirements in a conditioned space. This paper proposes two novel design configurations of AHUs, which ensure that the excess load on the AHU cooling coil is minimized using air to air heat recovery units, a desiccant based rotary dehumidifier, and an evaporative cooler. The proposed design is also capable of harvesting surplus water in the process. The impact assessment of the proposed designs is illustrated taking the example of a typical high-humidity design case. Simplified mathematical models were used to analyze the power-saving and moisture harvesting potential of the two configurations. Calculations show that both the configurations reduce the excess load on the cooling coil by a significant amount, while also co-producing surplus water for domestic use.

1. Introduction:
Ventilation requirements are one of the major concerns while designing an HVAC system [1]. Indoor air quality and proper ventilation have become even more relevant with the advent of deadly pandemics like COVID-19. Generally, depending on the occupancy of the building, the requirement of outdoor air (fresh air) is specified. Using an air handling unit (AHU) is a suitable method to meet the air quality and flow requirements in a conditioned space. Due to the difference in temperature and humidity content between the conditioned space and ambient, excess cooling capacity has to be installed over and above the sensible and latent heat gains of the building. To meet the fresh air requirements with the minimum amount of energy, the outdoor air is to be brought closer in temperature and humidity to the conditioned space. This can be accomplished using heat recovery wheels and multiple other innovative technologies. One such technology is the use of desiccant dehumidification, utilizing solar energy. Here, the supply air is dehumidified in the desiccant wheel without cooling the air below its dew point. The process requires low-grade energy in the form of heat, which can be generated from renewable and waste heat sources. Multiple simulation-based studies are available to illustrate the potential of this technology in energy-efficient space cooling applications [2]. In this paper, two innovative designs that couple desiccant dehumidification and air to air heat recovery are studied.

2. Configurations:
The following two configurations are proposed, varying the arrangement of components and air streams. The impact of both these configurations is then compared. The excess moisture in the outlet stream of regenerative air through the desiccant dehumidifier in both the configurations is condensed to produce water, a part of which is used in the evaporative cooler. The regenerative air stream is preheated in the heat recovery unit and further heated using a solar thermal collector. Water in heating
the coil has been assumed to be around 60-70°C. Other means to heat the air can also be used subject to the local availability of the resources.

2.1. **Configuration 1:**
As illustrated in Figure 1, the outdoor air passes through a rotary desiccant dehumidifier where it loses moisture and gains heat. Thereafter, it exchanges sensible heat successively with ambient air and cold air from the evaporative cooler, before passing through the cooling coil. The desiccant dehumidifier is regenerated by the hot air stream coming from heat recovery wheel 1, which is additionally heated using the solar thermal heating coil.

2.2. **Configuration 2:**
Configuration 2, as shown in Figure 2 is similar to Configuration 1, different primarily in only two aspects. The inlet air streams for the evaporative cooler and regenerative stream for the desiccant dehumidifier have been interchanged. Also, the supply air only goes through a single heat recovery wheel (in contrary to two heat recovery wheels in Configuration 1).

3. **Design Conditions:**
To illustrate the usefulness of these configurations, a typical high-humidity design condition is assumed. All calculations and results are based on the following conditions.

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**Figure 1.** Schematic of configuration 1.

**Figure 2** Schematic of configuration 2
Indoor Temperature: 24°C  
Indoor RH: 50%

Outdoor Temperature: 35°C  
Outdoor RH: 50%

Sensible cooling load ($Q_h$): 400kW  
Latent cooling load ($Q_l$): 100kW

Number of occupants: 90  
Fresh air requirement: 30 CFM per person (From ASHRAE Ventilation Standard)  
Inlet mass flow required: 1.5 kg/s

4. Mathematical Models:  
For the sake of simplistic analysis, the following mathematical models are used to make the calculations. The assumptions are carefully taken referring to similar studies and other research articles.

4.1. Rotary Desiccant Dehumidifier:  
A lot of studies are being done on desiccant dehumidifiers with very complex mathematical models. This paper uses the following simplified equations [3] which were experimentally validated with good accuracy by the authors. The enthalpy ($h$) and relative humidity (RH) of the outlet stream (represented as $out$ in subscript) are calculated from the properties of the inlet (represented as $in$ in subscript) and regenerative (represented as $reg$ in subscript) air streams. Other parameters were calculated using a psychrometric chart.

$$h_{out} = (0.1312h_{reg} + 0.8688h_{in})$$  
$$RH_{out} = (0.9428RH_{reg} + 0.0572RH_{in})$$

4.2. Evaporative Cooler:  
Evaporative cooling was modeled as an isenthalpic humidification and cooling process. The outlet RH was taken to be 90% which is a safe assumption and has been used in multiple research articles. The process is illustrated for both the configurations in Figure 3 and Figure 4.

![Figure 3](image)

**Figure 3**. Cooling Process for configuration 1.
4.3. Heat Recovery Wheel:
The heat recovery wheel was modeled using sensible heat exchange with no moisture transfer assumption and the efficiency of the process was assumed to be 0.6.

\[ Q = \varepsilon \cdot \min (C_A m_A, C_B m_B)(T_A - T_B) \]

5. Results:
Applying the aforementioned mathematical models to the proposed configurations yields the following results. The final state of supply air before passing through the cooling coil:

- Configuration 1:
  Temperature (T) = 27.55°C; Moisture (W) = 12.8 g/kg-da; Enthalpy (h) = 60.48 kJ/kg
- Configuration 2:
  Temperature (T) = 32.72°C; Moisture (W) = 9.98 g/kg-da; Enthalpy (h) = 58.46 kJ/kg

The results show that both these configurations significantly reduce the excess load on the cooling coil and have great energy-saving potential. Moreover, the water consumed by the evaporative cooler can be harvested from the moisture in the regenerative stream, making it a completely sustainable system in all aspects as shown in Figure 5.

![Figure 4](image1.png)

**Figure 4** Cooling process for configuration 2.

![Figure 5](image2.png)

**Figure 5**. Power and water saving over conventional systems.
The power saving capacity and surplus water consumption of the two configurations are indicated by blue and red bars respectively. Power saving represents the excess power that would have been used by a conventional air conditioning system using only a cooling coil.

- Implementing the proposed AHU designs, more than 30kW power can be saved in both the configurations over a conventional refrigeration cycle–based system.

Surplus water production capacity represents the total moisture that can be harvested from the desiccant dehumidifier minus the water consumed by the evaporative cooler in a particular configuration.

- The graph indicates that both configurations are capable of generating excess water. Hence, water scarcity will not be an issue for the evaporative cooler in either configuration.

6. Conclusion and Scope for Future Work

Research studies predict that ventilation is going to be a major requirement in almost every closed space. Getting fresh outdoor air into the conditioned space comes at the expense of a great deal of energy. Heat recovery and desiccant dehumidification combined with evaporative cooling has a great potential for energy saving. Moreover, these technologies can be operated with low-grade energy like solar thermal heat and are hence sustainable. There can be multiple configurations in which these technologies can be arranged and used according to the local ambient conditions. Furthering this work, a generalized study will be done to predict the ideal configuration for a given set of ambient conditions, using more accurate mathematical models.

References

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Nomenclature

| Symbol | Description |
|--------|-------------|
| HVAC | Heating Ventilation & Air Conditioning |
| AHU | Air Handling Unit |
| RH | Relative Humidity |
| q_s | Sensible cooling load |
| q_l | Latent cooling load |
| CFM | Cubic Feet per Minute |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| h | Enthalpy kJ/kg |
| W | Moisture in g/kg-da |
| T | Temperature in ºC |