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INDIRECT EVAPORATIVE AIR COOLING AND DEHUMIDIFICATION SYSTEM

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Abstract: *In this article a mainly heat-source driven air-cooling and dehumidification system is presented which is equipped with a desiccant based air dehumidifier unit. The source of the heat can originate from renewable, e.g. solar energy, thus, a significant amount of electricity can be saved by this system compared that of vapor-compressor systems. The cooling of the treated air is provided by the evaporation of desalinated water into the external ambient air. Because of the applied method the dew point of the processed air is usually not reached, therefore the increased relative humidity can be an issue. To solve this problem a supplementary desiccant-based system with hygroscopic solution is used to decrease the humidity of the cooled air. The regeneration of the desiccant is driven by the external heat source such as solar collector.*

Keywords: *air conditioning, evaporation, solar energy, renewable energy, desiccant*

1. INTRODUCTION

The air temperature and air humidity in the interiors of both the residential and industrial buildings may reach values outside the human comfort zone during summer season [1]. The reason of this can be both geolocation and the local climate or the weather extremes. To provide appropriate air conditions for the comfortable working and residential environment, the climatization of the indoor air may be necessary. By this process both the appropriate temperature and humidity can be achieved which fit in the range of the human comfort zone [2]. For this purpose – in the most cases – compressor-driven vapor-compression refrigeration is used. These systems contain compressors driven by electric motors which electric energy demand responsible for a crucial part of the consumed energy. A minor part of the electrical energy is used for the ventilators, pumps, and control units. These type of A/C units may be qualified by their Seasonal Energy Efficiency Ratio (SEER), which is – in some cases – a misleading quantity. If we define this number as the ratio of the cooling energy during a season and the total electrical energy consumed by the system in the same measurement unit during the same season, we get a number around between 4÷6. Value 4 means that for one unit of electrical energy consumed we can move 4 units of heat energy out from the conditioned space. Even if this is the lowest value it seems to be great thus 3 units of heat is transported "free" in this way. Unfortunately, the gross cooling efficiency is much lower: the efficiency of the production and the transportation losses of the electric energy have significant negative effect on the total cooling efficiency (e.g. nuclear power plants have an average 0.33-0.37 thermal efficiency which is even greater than their electric efficiency). If we calculate the ratio of the cooling energy and the primary energy used to drive the system, we will get much worse values.

The appropriate changing of the indoor air properties (temperature and humidity) can be done by another method differs from the previous vapor compression one. As an option, the direct evaporation of water in air can be used to decrease the temperature [3]. This kind of A/C unit does not require high power compressor, instead of this, pumps and ventilators with lower power demand are the main parts of the system. Both direct and indirect evaporative systems are in use: the direct system evaporates water into the conditioned air while the indirect system evaporates water into the outer air. Both systems use the cooling effect of the vaporization of the water (the water has a high value of heat of vaporization). However, the first system not only cools but also humidifies the indoor air (increase its absolute water vapor content: g_{H2O}/kg_{dryair}) [4]. The indirect system uses a portion of the process water to evaporate, thus the remained water cools down which is then used to cool the indoor air through a heat exchanger. This method allows to keep the absolute humidity constant [5].

It is true, that the absolute humidity of the air keeps constant in case of indirect cooling, but its relative humidity increases which value therefore could be move out of the human comfort zone [6]. The reason of this can be found in the temperature parameters: usually the temperature of the cooled water is only some degrees below that of the temperature of the indoor air which temperature is above the indoor air's dew point. Therefore, condensation does not occur in the heat exchanger, consequently the cooled air has the same amount of vapor that it has initially. Nevertheless, if the absolute humidity of the air is constant while its temperature decreases it leads the increase of the relative humidity (partial pressure of vapor/partial pressure of vapor at saturated case) [7]. To get cooled air parameters which are in the comfort zone it is necessary to decrease its absolute humidity. This can be done by using an auxiliary air-dehumidifier unit which also requires energy (in case of certain types, most part of this energy is heat as in the follows). By applying desiccant based dehumidifier system, within a certain time interval it is necessary to regenerate the diluted solution which can be done by heating up the solution using a a heat source [8]. This heat source is responsible for the main energy demand of the complex system. For this purpose, solar energy (heat energy) is a possible solution.

An experimental A/C system is under construction in the laboratory of the Department of Fluid and Heat Engineering (University of Miskolc, Hungary), which consist of an indirect evaporative air-cooling subsystem equipped with air dehumidification system. The aim of this system is to present in detail the function of each part while its operation can be parameterized and measured within different pre-set air conditions. The regeneration of the diluted desiccant solution is done by using electric heater instead of solar energy mentioned previously. The reason is that the electric power can be adjusted and measured much simpler and more precisely than by using solar heaters as heat source. In the following the setup and the operation of this experimental system will be presented.

2. THE BUILDUP AND OPERATION PRINCIPLE OF THE SYSTEM

The simplified scheme and the operation of the system can be observed on Figure 1. The whole system can be divided to two subsystems: one is responsible for the cooled water which is then used to cool the indoor air. Another part is the air-drying unit. The working principle of the system is the following.

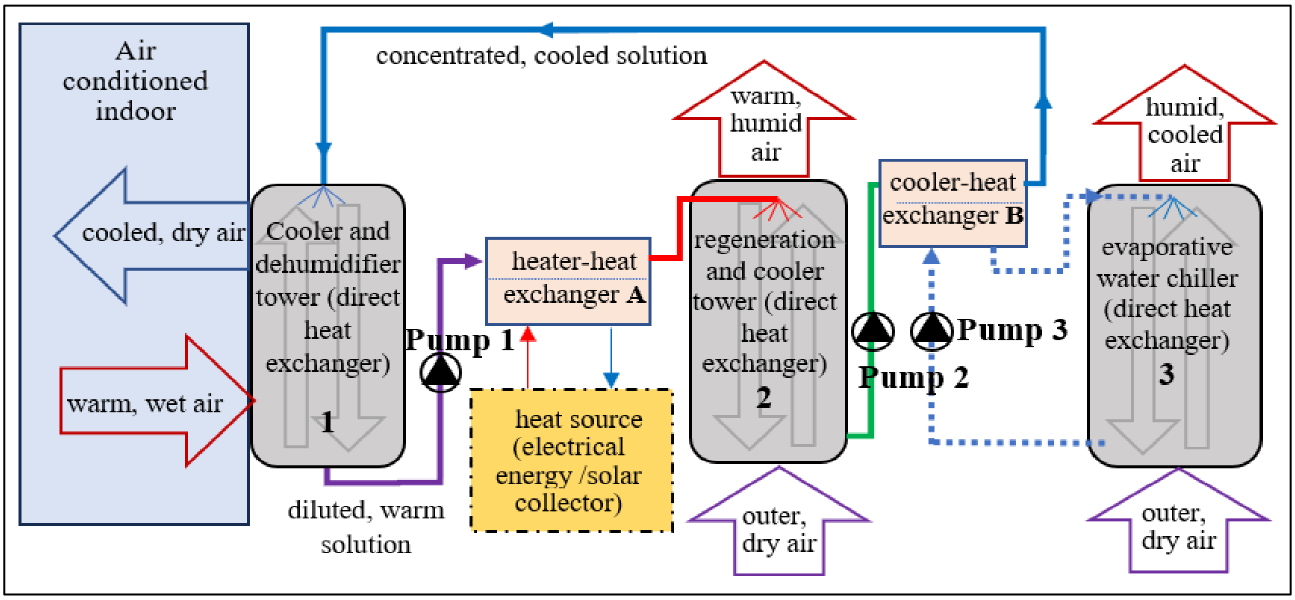

Figure 1: Scheme of the experimental system.

In the evaporative water chiller (**3**) soft water is sprayed into the external ambient air in counterflow direction. Due to the continuous adiabatic vaporization the water droplets cool down while they reach the bottom of the chiller [9,10]. This cooled water is then used to cool down the concentrated desiccant solution in heat exchanger **B** (plate heat exchanger). Following this, the cool solution sprayed into counterflow tower **1** where it directly mixes with the indoor air to be processed. Here both mass and heat transport occur at the same time: the cool droplets cool down the ambient air by heat exchange while a portion of the water vapor in the air is absorbed by the droplet due to the hygroscopic behavior of the solution. For this purpose, calcium-chloride ($CaCl_2$) or lithium-bromide (LiBr) aqueous solutions are used. The $CaCl_2$ is cheap, non-toxic and has high hygroscopic potential, but it is highly corrosive. The LiBr has higher hygroscopic potential and it is less corrosive but more expensive and has somewhat higher toxicity (slightly psychoactive). Based on these it is widely used in desiccant based air dryer units [11]. Following the heat and mass transfer, the warmer solution will be diluted as well. This solution is then needed to be regenerated which means some of the water has to be expelled from the solution. This can be done by pumping (pump **1**) and heating up the solution in plate heat exchanger **A** which increases the partial pressure of the water vapor on the free surface of the solution [12]. This process requires large amount of heat which can be originated from renewable energy, for example from solar collectors. Since this is the most significant energy consuming part of the whole system, if the source of the heat comes from solar energy, the system can be operated inexpensively while it requires mostly renewable energy. Our experimental system will contain an electric heater which is better for experimental purposes and for measurements. The hot solution then pumped into the regeneration tower **2** where it is sprayed into the outer warm air. In this direct type heat exchanger not only the cooling of the solution but also the vaporization of a portion of the absorbed water occurs. The warm and concentrated solution then pumped out from the bottom of the tower into heat exchanger **B** by using pump **2**. After it cools down the cycle starts again.

In the reality, more heat exchangers will be used to increase the efficiency of the system than it is shown on Figure 1. Since the regenerated solution is hotter than the outer air, the application of an air-liquid heat exchanger is worthy. With that the solution can almost reach the temperature of the outer air, hence cooler solution enters the heat exchanger **B** which finally leads lower temperature at the exit (or smaller heat exchanger). The efficiency can be further increased by application of another air-liquid exchanger: the temperature of the cooled solution can be decreased further by using the airflow, which exits the cooling tower **3**. Due to the vaporization of the water not only the droplets but also the air cool down during the process which leads cooler air leaving the tower.

The lowest available temperature – since the cooling is rely on the adiabatic evaporation – is strongly depended on the psychrometric properties of the outer air (i.e. temperature, humidity, pressure etc.). In ideal case the lowest temperature of the cooling water would be the same as the wet bulb temperature of the outer air. Due to the non-ideal heat and mass transport in tower **3** the achievable temperature is slightly higher. The wet-bulb temperature of the air can be calculated by using the Stull equation [13] or the equ. given by Chen & Chen [14] which gives less error in the range of 20°C÷45°C. Table 1. gives some values at given air-conditions.

Table 1. Wet-bulb temperature of the air at different temperatures and humidities

Dry bulb temp., °C	30	30	30	35	35	35	38	38	38
Relative humidity, %	40	50	70	40	50	70	40	50	70
Wet bulb temp., °C	20.5	22.3	25.6	24.5	26.6	30.3	27.0	29.2	33.1
Cooling, ΔT, °C	9.5	7.7	4.4	10.5	8.6	4.7	11	8.8	4.9

Observing Table 1 it is clear, that this type of cooling works well only in dry climate: if the air has high humidity the evaporation of the water decreases which gives wet bulb temperatures close to the temperature of the air. However, at dry climate this process (theoretically) can produce around 10°C decrease, which is appropriate for cooling purposes.

3. CONCLUSIONS

An experimental indirect evaporative system is briefly presented in this paper which is going to be built in the departmental laboratory. The aim of this system is mainly educational: the engineering students will have the opportunity to discover the background of the sub-processes and they can meet the operation of the theories in practice. For investigations the system will be placed in the laboratory climate chamber (3m×5m×3m), where its operation and performance will be investigated during constant, pre-set air conditions.

BIBLIOGRAPHY

[1] Shaharon, M. N., Jalaludin, J., Thermal comfort assessment-A study toward workers' satisfaction in a low energy office building, American Journal of Applied Sciences, 9(7): 1037., 2012

[2] ANSI/ASHRAE standard 55–2010, Thermal Environmental Conditions for Human Occupancy. American Society for Heating, Refrigerating and Air Conditioning Engineers Inc, Tullie Circle, NE, Atlanta, 1971

[3] Guan, L., Bennett, M., & Bell, J., Evaluating the potential use of direct evaporative cooling in Australia, Energy Build. 108: 185–194., 2015

[4] J.M. Wu, X. Huang, H. Zhang, Theoretical analysis on heat and mass transfer in a direct evaporative cooler, Applied Thermal Engineering 29(5–6): 980-984, ISSN 1359-4311, https://doi.org/10.1016/j.applthermaleng.2008.05.016., 2009

[5] Duan, Z., Zhan, C., Zhang, X., Mustafa, M., Zhao, X., Alimohammadisagvand, B., & Hasan, A., Indirect evaporative cooling: Past, present and future potentials, Renewable and sustainable energy reviews, 16(9): 6823–6850., 2012

[6] Moran, J. M., Shapiro, H. N., Boettner, D. D., Bailey, M. B., Fundamentals of Engineering Thermodynamics, John Wiley & Sons Inc. Issue 8, 2014

[7] Bishoyi, D., Sudhakar, K., Experimental performance of a direct evaporative cooler in composite climate of India, Energy and Buildings, 153: 190–200, 2017

[8] Rafique, M. M., Gandhidasan, P. Rehman, S. L., Al-Hadhrami, M. A., Review on desiccant based evaporative cooling systems. Renew. Sustain. Energy Rev. 45: 145–159, 2015

[9] Camargo, J.R., Ebinuma, C.D., Cardoso, S., A mathematical model for direct evaporative cooling air conditioning system, Engenharia Térmica, 4: 30–34., 2003

[10] Kovacevic, I., Sourbron, M., The numerical model for direct evaporative cooler. Appl. Therm. Eng. 113: 8–19., 2017

[11] Fu, Huang-Xi, Xiao-Hua Liu., Review of the impact of liquid desiccant dehumidification on indoor air quality, Building and Environment 116: 158-172., 2017

[12] Wang H., Chen H., Chen W., Sun H., Xu X., Vapor-Liquid Equilibrium Study of LiBr + H2O and LiBr + CaCl2 + H2O Systems, Front Chem. Jan 23, 7:890. doi: 10.3389/fchem.2019.00890, 2020

[13] Stull, R., Wet-bulb temperature from relative humidity and air temperature, J. Appl. Meteorol. Climatol. 50: 2267–2269., 2011

[14] Chen H.-Y., Chen C.-C., An Empirical Equation for Wet-Bulb Temperature Using Air Temperature and Relative Humidity, Atmosphere, 13(11): 1765. https://doi.org/10.3390/atmos13111765, 2022