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Muhammad N. Ashraf
Department of Agricultural Engineering, Bahauddin Zakariya University

Riaz, Mahmood
Department of Agricultural Engineering, Bahauddin Zakariya University

Muhammad H. Mahmood
Department of Agricultural Engineering, Bahauddin Zakariya University

Miyazaki, Takahiko
Faculty of Engineering Sciences, Kyushu University

他

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Study on Solid Desiccant-Based Air-Conditioning for Wet-Markets

Muhammad N. Ashraf [1], Mahmood Riaz[1,2], Muhammad H. Mahmood [1,*], Takahiko Miyazaki[3], Muhammad Sultan[1], Muhammad Khalid[1], Zahid M. Khan[1]
[1]Department of Agricultural Engineering, Bahauddin Zakariya University, Multan 60800, Pakistan
[2]Agricultural Mechanization Research Institute (AMRI), Multan-Punjab, Pakistan
[3]Faculty of Engineering Sciences, Kyushu University, Kasuga-koen 6-1, Kasuga-shi, Fukuoka 816-8580, Japan.
*Corresponding author email: hamidmahmood@bzu.edu.pk

ABSTRACT: *The higher relative humidity inside wet-markets results in the growth of pathogenic micro-organisms that affect qualitative and nutritive attributes of the products prompting epidemic health problems to the occupants as well as consumers. In this study, M-cycle evaporative cooler (MEC) coupled solid desiccant air conditioning system (DAC) was investigated for wet market applications in Punjab, Pakistan. The model of Beccali was used for performance investigation of the desiccant wheel while MEC and heat exchanger were evaluated by governing equations from literature. The study area (i.e. Punjab) was divided into four zones i.e. Northern Punjab (Z_1), Upper Punjab (Z_2), Central Punjab (Z_3), and Lower Punjab (Z_4) based on variations in environmental conditions. The results revealed that the proposed DAC system can effectively achieve optimum temperature and relative humidity conditions in the summer season in Z_2, Z_3, and Z_4. However, the proposed system was not applicable in Z_1 because of the lower temperature and humidity conditions in this zone.*

Keywords: Wet market, Human thermal comfort, Desiccant, Dehumidification, Air-conditioning

1. INTRODUCTION

Human thermal comfort is a crucial subject in commercial places. It becomes more critical in wet places where the higher relative humidity of air creates allergic conditions [1,2]. Wet markets are the places used worldwide to sell fruits, vegetables, meat, seafood, and poultry. It consumes a higher quantity of water to sustain the freshness of vegetables, meat, and to keep poultry and seafood alive. This water evaporates into air increasing the latent heat load inside the market [3,4]. The higher moisture level encourages the growth of viruses and other pathogenic organisms [5]. The growth of these micro-organisms directly affects human health as well as the quality and nutritive contents of fruits and vegetables in the market. Moreover, the recent incidence of airborne viruses in many countries increases the importance of environmental health as an element of the air conditioning systems [6]. It shows that in the case of wet markets, it's not only temperature control that provides a healthy environment but it is also important to remove moisture and contaminants to sustain food quality. However, efficient energy use in agricultural productions also an important factor while considering food security [7–10].

Vapor Compression Air-Conditioning (VAC) system is traditionally used in air conditioning applications. It removes humidity by the condensation of water vapors without precise control over water removal. The ambient air passes through a cooling coil whose surface temperature is lower than the dew point temperature of the inlet air and hence, condensation occurs [11–13]. This over-cooled air is then sensibly heated to get the desired temperature as shown in Fig. 1. The figure shows the working principle of a conventional VAC system as well as a psychrometric representation of the properties of air while passing through different components of the system. The ambient air enters the system at point 1 where it passes through a cooling coil and condensed to a temperature lower than its dew point temperature at point 2. The condensed air is then reheated by passing through a heating coil to achieve the desired temperature at point 3.VAC system has certain drawbacks including its no distinct control over humidity,

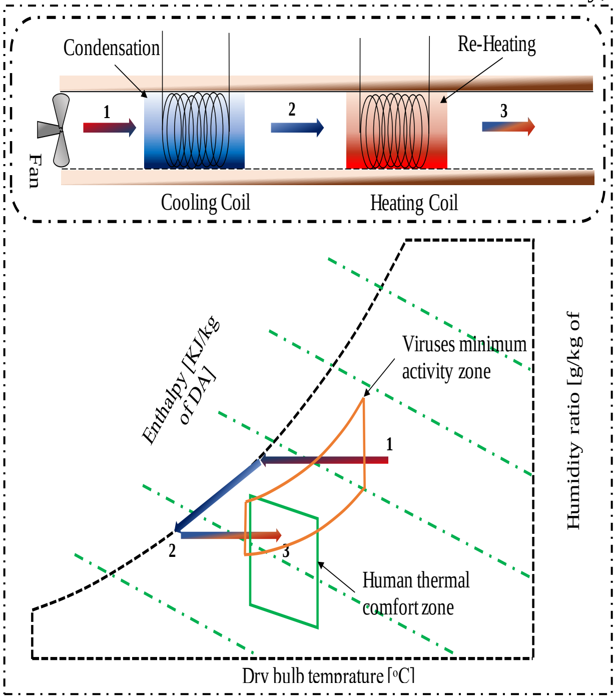

Fig. 1. System configuration and psychrometric representation of properties of air in conventional VAC system [14,15]

Chlorofluorocarbons (CFCs) emissions, higher energy consumption, and operating costs [6]. On the other hand, Desiccant Air-Conditioning (DAC) system has precise control over the humidity level. It uses desiccant material to remove water droplets from the air. Desiccant is a hygroscopic material that attracts moisture due to a difference in vapor pressure [15]. DAC combines the properties of desiccant material for latent heat load and evaporative cooling for sensible heat load. It has certain advantages over VAC i.e. use of low-grade thermal energy, low operating costs, CFC's free green technology, and energy savings [15–17]. The humidity control ability of DAC makes it an attractive alternative to the traditional system in wet market applications. Furthermore, the DAC system has a wide range of applications including heating and ventilation in commercial buildings, agricultural products storage, and grain drying [18–23].

In this study, the acceptability of the DAC system was investigated for wet market applications in Punjab, Pakistan. The main aim of the study was to test the potential of a DAC system to provide human thermal comfort and environmental conditions that resist the incubation of viruses inside wet markets. Experimental models were used to evaluate the temperature and humidity handling ability of a MEC coupled DAC system. The performance was inspected based on system ability to provide thermal comfort to occupants and optimum thermal conditions to control viruses' growth inside the market.

2. METHODOLOGY

A MEC coupled DAC system was investigated in this study for its potential application in wet markets in Punjab, Pakistan. The components and configuration of the proposed air conditioning system are shown in Fig. 2. The figure depicts the DAC system consisted of four components i.e. desiccant wheel, heat exchanger, M-cycle evaporative cooler (MEC), and a low-grade heat source. The ambient air enters the desiccant wheel, where its humidity level is decreased by removing moisture as represented by the point (a-b). This is an isenthalpic process in which the temperature of air increased without changing enthalpy as represented on the psychrometric chart (a-b). Silica-gel was used as the desiccant material in desiccant wheel. After dehumidification, the dry and hot air passes through a flat plate heat exchanger which lowers its temperature by sensibly cooling it (b-c). Finally, the air stream passes through a MEC system which further lowers its temperature to get the desired temperature. This air is supplied to the air conditioning space. On the other side, the heated air is required to regenerate the desiccant material. The ambient air is used for this purpose, which passes through a heat exchanger that increases its temperature by the heat provided by the supply air. This temperature is not enough to regenerate the material, so a heat source is added to further increase air temperature. Finally, desiccant material is regenerated by this hot air stream.

The mean monthly temperature and relative humidity data was taken from Meteonorm 7.3. Monthly averages of ten years meteorological data are shown in Fig. 3. The figure depicts the monthly variations in temperature and relative humidity in all the four studied zones. Human thermal comfort [24] and viruses minimum activity zones [5,25–27] were developed by cited literature shown in Fig. 4. Punjab was divided into four zones based on variations in climatic conditions. These zones were named as Northern Punjab (Z_1 that includes Murree), Upper Punjab (Z_2 that includes Islamabad, Rawalpindi, Jhelum, Gujrat, and Sialkot), Central Punjab (Z_3), and Lower Punjab (Z_4). Ambient air temperature and relative humidity were also represented on psychrometric chart (Fig. 4) to check the suitability of the DAC system in the studied zones.

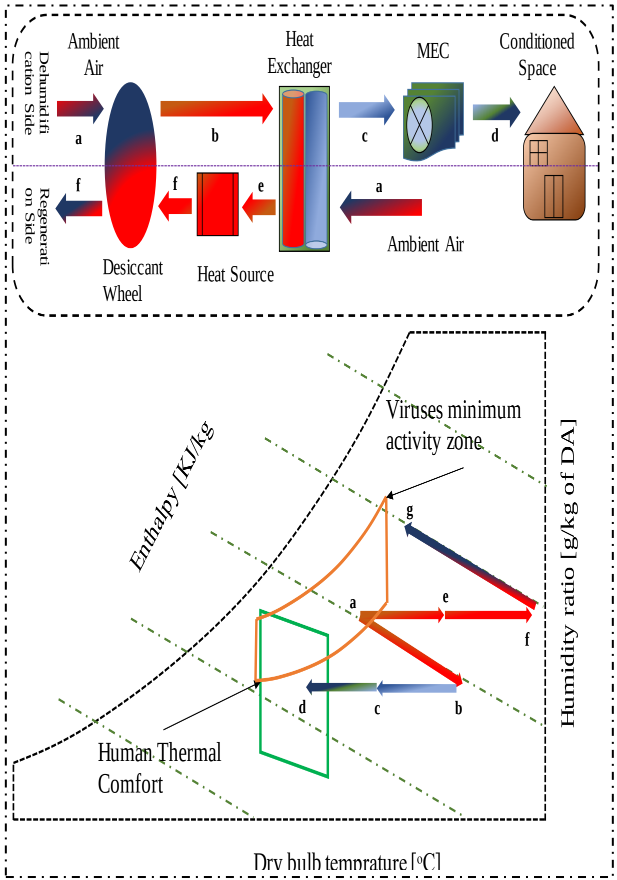

Fig. 2. System configuration and psychrometric representation of properties of air in the proposed DAC system [11,28,29]

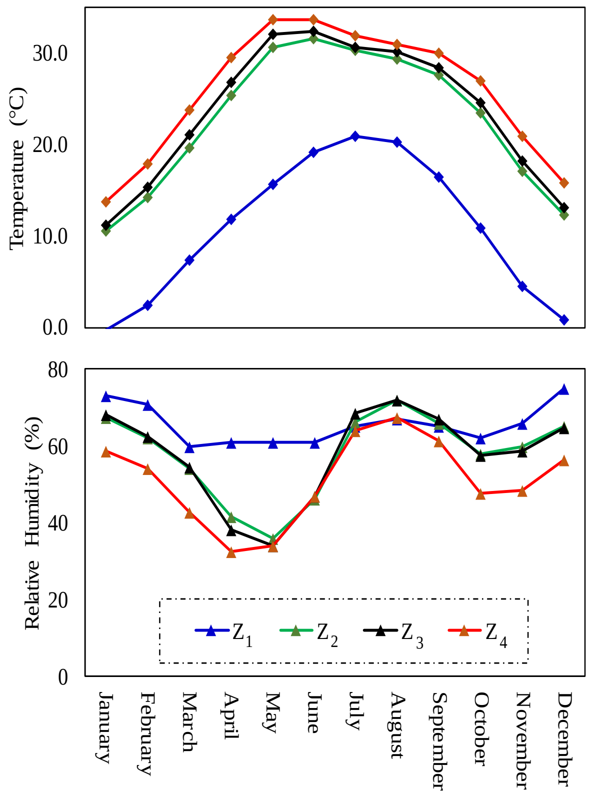

Fig. 3. Monthly temperature and relative humidity variation in the four studied zones of Punjab, Pakistan.

The regeneration temperature was kept low at 60ºC and heat exchanger effectiveness was taken as 0.9 in accordance with previous literature [18,30]. Beccali model [32] (eq. 1-3) was used to evaluate the performance of desiccant wheel while MEC performance was investigated based on simplified correlation (eq. 4) developed by M. Sultan et al [33]. Performance of heat

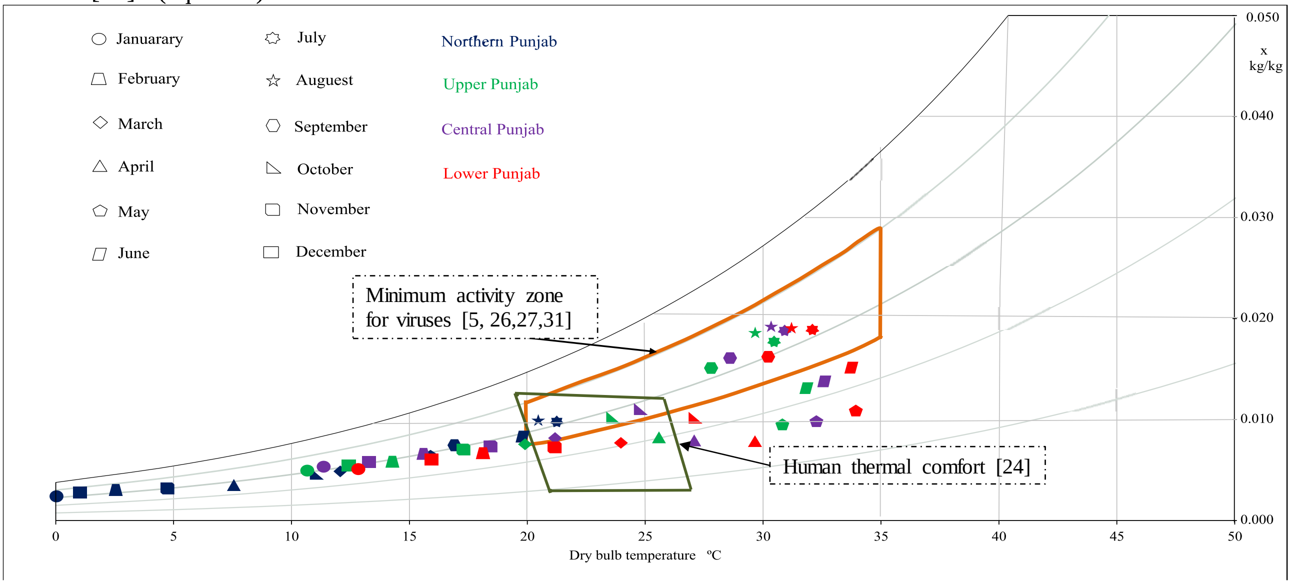

Fig. 4. Human thermal comfort [24] and viruses' minimum acticity zones [5,24,26,27,31] developed by literature. Coloured symbols depicts the temperature and relative humidity conditions in developed four zones.

exchanger was examined by governing equation (eq. 5) given below [18].

$$h_b = 0.1312h_f + 0.8688h_a \quad (1)$$

$$RH_b = 0.9428RH_f + 0.0572RH_a \quad (2)$$

$$\frac{RH_b e^{0.053T_b}}{18671} = \frac{h_b - 1.006T_b}{2501 - 1.805T_b} \quad (3)$$

$$T_d = 6.7 + 0.2630(T_c) + 0.5298(X_c) \quad (4)$$

$$T_c = T_b - \varepsilon_x(T_b - T_a) \quad (5)$$

Where, h_b, h_f and h_a are enthalpies of air (kJ/kg) at stages b, f and a respectively. RH_b, RH_f and RH_a are relative humidity (%) at stages b, f and a respectively. T_b, T_d, T_c and T_a are temperatures (°C) at stages b, d, c and a respectively. X_c is absolute humidity (g/kg of dry air) at stage c while ε_x is effectiveness of heat exchanger.

3. RESULT AND DISCUSSIONS

The ambient temperatue and relative humidity condition of the studied zones have great variations. Due to these variations, all climatic zones have different response towards DAC potential. The results show that the proposed DAC has no potential in Northern Punjab due to heating requirement in this zone. Other three zones have almost same response towards DAC potential. There were four months of summer (i.e. June, July, August, and September) in which cooling, and dehumidification were required. Lower Punjab has other two months (i.e. April and May) having cooling potential, but it can be achieved by MEC alone to provide human thermal comfort. The proposed DAC system can effectively achieve human thermal comfort in summer environmental conditions as shown in Fig. 5. Moreover, the viruses' thermal minimum activity zone was also achieved during this season. The distinct control over humidity made DAC capable of achieving desired humidity conditions with low regeneration temperature (60 ºC) for desiccant material i.e Silica gel. The maximum dehumidification was done in the month of August in which higher ambient relative humidity has to be tackled. This may lead to higher regeneration temperature to achieve desired dehumidification rate. Thus, the amount of water to be dehumidified depends on the ambient air conditions. Higher the ambient temperature lower will be the dehumidification. For example, Z_2 has a constant relative humidity of 66% with temperatures of 30.3°C and 27.6°C in the months of July and September, respectively. However, decrease in the relative humidity was higher (50%) in September than the decrease (48%) in July. In this regard, higher relative humidity of ambient air also supports greater dehumidification. Moreover, cooling capacity of the MEC also depends upon the relative humidity. Greater the humidity of ambient air lower will be the decrease in temperature and vice versa.

Ambient conditions during these months of summer don't lie in viruses' thermal survival zone. However, wet markets with higher relative humidity in this scenario may lead to growth of these viruses. The proposed system can handle these wet conditions by ensuring human thermal comfort as well as providing viruses free zone as shown in Fig. 5. The figure reflects the performance ability of DAC as well as MEC system. Both the systems perform well under hot and humid ambient conditions to provide optimum conditions. Although, MEC is restricted to only some month where there is only the need of sensible cooling. While DAC can perform better with the conditions with higher relative humidity and temperatures. However, it is not suitable in some scenarios (e.g. May and April in lower Punjab) where there is no need of dehumidification as represented in Fig. 5. A comparison between ambient climatic conditions and controlled by the proposed DAC system is shown in Fig. 6. The figure depicts highest ambient temperature in Z_4 durring the months of summer while lowest was found in Z_2. On the other hand, highest relative humidity was found in Z_3 and lowest was found in Z_2. It is clear from these results that temperature control is important in Z_4 while humidity control is important in Z_3. Moreover, there is higher risk of viruses incubation Z3 than any other zone. Thus, dehumidification is more crucial in Z_4 than any other studied climatic zone. It is important to note that dehumidification quantity depentds on both of the temperature and relative humidity. Lower degrees of temperature and higher percentages of relative humidity enhances the dehumidification while higher temperature and lower relative humidity decreases the dehumidification rate. Finally, the proposed DAC is the best alternative to conventional air conditioning system for wet markets applications in the studied region.

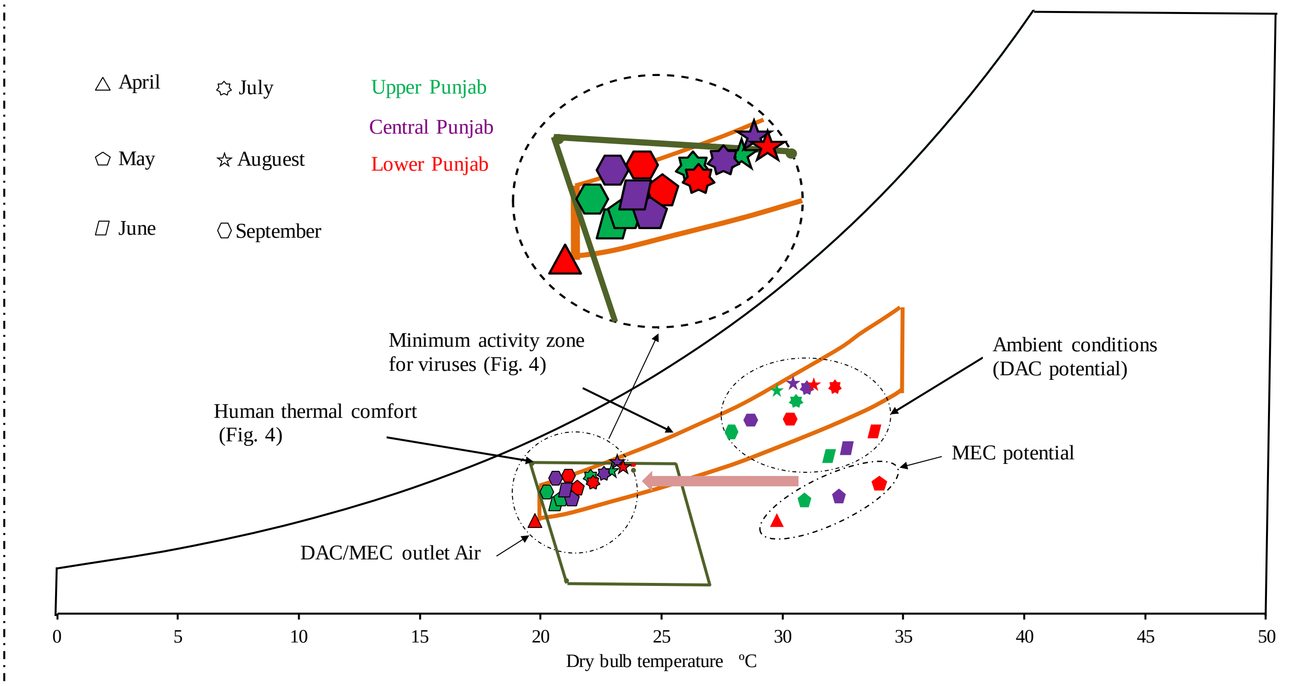

Fig. 5. Results of experimental models for temperature and humidity control by the proposed DAC and MEC systems.

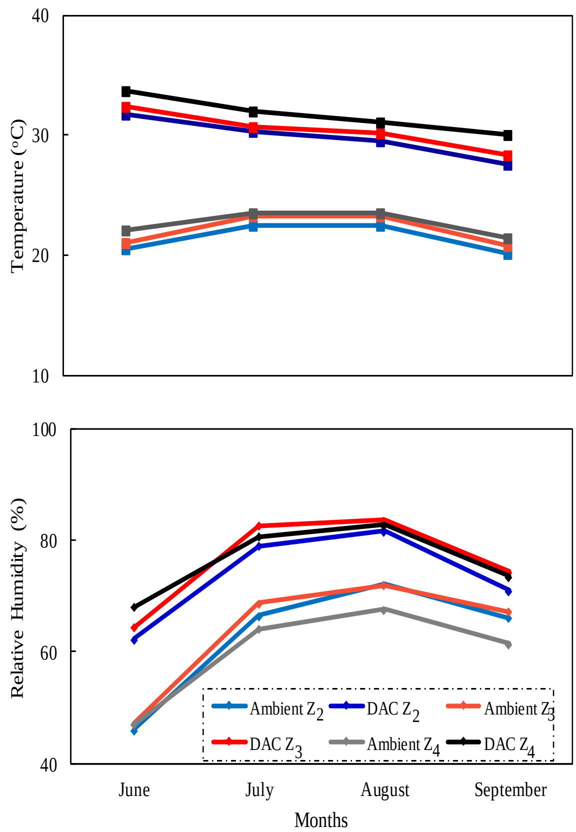

Fig. 6. Comparison between ambient air temperature and humidity conditions and the prosed DAC saystem in the four studied zones.

CONCLUSIONS

In this study, a desiccant based dehumidification air conditioning (DAC) system was investigated for wet market applicability. The proposed system can effectively achieve optimum human thermal comfort as per ASHRAE standards with lower regeneration temperature of 60 ˚C with low grade waste heat which can be generated using biogas, solar concentrator, solar collectors, etc. Applicability of the proposed DAC system was checked for the general thermal and humidity conditions of wet markets. DAC was able to solve the stated problem (viruses incubation environment in wet markets) by effectively controlling the moisture level in thermal minimum activity zones of viruses. Based on the key findings of the present study, DAC was found to be more economical, green, and alternative approach for proper ventilation and humidity control of wet markets to provide good environmental health.

4. REFERENCES

[[1] Duan J, Xie J, Deng T, Xie X, Liu H, Li B, et al. Exposure to both formaldehyde and high relative humidity exacerbates allergic asthma by activating the TRPV4-p38 MAPK pathway in Balb / c mice. Environ Pollut 2020;256. https://doi.org/10.1016/j.envpol.2019.113375.

[2] Kormuth KA, Lin K, Ii JP, Vejerano EP, Tiwari AJ, Cox SS, et al. Influenza Virus Infectivity Is Retained in Aerosols and Droplets Independent of Relative Humidity 2018;218:739–47.

https://doi.org/10.1093/infdis/jiy221.
[3] Lee SH, Lee WL. Site verification and modeling of desiccant-based system as an alternative to conventional air-conditioning systems for wet markets. Energy 2013;55:1076–83. https://doi.org/10.1016/j.energy.2013.04.029.
[4] Yang W, C. Marr L. Mechanisms by Which Ambient Humidity May Affect Viruses in Aerosols AND VIABILITY 2012;78:6781–8. https://doi.org/10.1128/AEM.01658-12.
[5] Arundel A V, Sterling EM, Biggin JH, Sterling TD. Indirect health effects of relative humidity in indoor environments 1986;65:351–61.
[6] Liu W, Lian Z, Radermacher R, Yao Y. Energy consumption analysis on a dedicated outdoor air system with rotary desiccant wheel 2007;32:1749–60. https://doi.org/10.1016/j.energy.2006.11.012.
[7] Ashraf MN, Mahmood MH, Sultan M, Banaeian N, Usman M, Ibrahim SM, et al. Investigation of Input and Output Energy for Wheat Production: A Comprehensive Study for Tehsil Mailsi (Pakistan). Sustainability 2020;12:6884. https://doi.org/10.3390/su12176884.
[8] Banaeian N, Omid M, Ahmadi H. Energy and economic analysis of greenhouse strawberry production in Tehran province of Iran. Energy Convers Manag 2011;52:1020–5. https://doi.org/10.1016/j.enconman.2010.08.030.
[9] Banaeian N, Zangeneh M. Study on energy efficiency in corn production of Iran. Energy 2011;36:5394–402. https://doi.org/10.1016/j.energy.2011.06.052.
[10] Safa M, Samarasinghe S, Mohssen M. Determination of fuel consumption and indirect factors affecting it in wheat production in Canterbury, New Zealand. Energy 2010;35:5400–5. https://doi.org/10.1016/j.energy.2010.07.015.
[11] Mazzei P, Minichiello F, Palma D. HVAC dehumidification systems for thermal comfort : a critical review 2005;25:677–707. https://doi.org/10.1016/j.applthermaleng.2004.07.014.
[12] Byun J, Patel HA, Thirion D, Yavuz CT. Reversible water capture by a charged metal-free porous polymer. Polymer (Guildf) 2017;126:308–13. https://doi.org/10.1016/j.polymer.2017.05.071.
[13] Gadalla M, Saghafifar M. Performance assessment and transient optimization of air precooling in multi-stage solid desiccant air conditioning systems. Energy Convers Manag 2016;119:187–202. https://doi.org/10.1016/j.enconman.2016.04.018.
[14] Hamdy M, Askalany AA, Harby K, Kora N. An overview on adsorption cooling systems powered by waste heat from internal combustion engine. Renew Sustain Energy Rev 2015;51:1223–34. https://doi.org/10.1016/j.rser.2015.07.056.
[15] Sultan M, El-Sharkawy II, Miyazaki T, Saha BB, Koyama S. An overview of solid desiccant dehumidification and air conditioning systems. Renew Sustain Energy Rev 2015;46:16–29. https://doi.org/10.1016/j.rser.2015.02.038.
[16] Abdullah MO, Tan IAW, Lim LS. Automobile adsorption air-conditioning system using oil palm biomass-based activated carbon: A review. Renew Sustain Energy Rev 2011;15:2061–72. https://doi.org/10.1016/j.rser.2011.01.012.
[17] Hindoliya HPDA. Solid Desiccant Cooling System Employed with Ventilation Cycle : A Sensitivity Analysis 2012;93:351–6. https://doi.org/10.1007/s40032-012-0038-9.
[18] Mahmood MH, Sultan M, Miyazaki T, Koyama S. Desiccant Air-Conditioning System for Storage of Fruits and Vegetables : Pakistan Preview. Evergreen 2016;3:12–7. https://doi.org/10.5109/1657381.
[19] Mahmood MH, Sultan M, Miyazaki T. Solid desiccant dehumidification-based air-conditioning system for agricultural storage application: Theory and experiments. Proc Inst Mech Eng Part A J Power Energy 2019:095765091986950. https://doi.org/10.1177/0957650919869503.
[20] Mahmood MH, Sultan M. Significance of Temperature and Humidity Control for Agricultural Products Storage : 2019. https://doi.org/10.1515/ijfe-2019-0063.
[21] Muhammad H. Mahmood, Muhammad Sultan, Takahiko Miyazaki SK. Study on desiccant air-conditioning system for agricultural product storage in Pakistan. Intellect. Exch. Innov. Conf. Eng. Sci., vol. 1, 2015, p. 13–4. https://doi.org/10.1145/3132847.3132886.
[22] Shazia Hanif, Muhammad Sultan, Takahiko Miyazaki SK. Effect of drying air parameters on energy consumption in desiccant grain drying. 3rd Int Exch Innov Conf Eng Sci 2017;3:131–4.
[23] Sultan M, Miyazaki T, Saha BB, Koyama S. Steady-state investigation of water vapor adsorption for thermally driven adsorption based greenhouse air-conditioning system. Renew Energy 2016;86:785–95. https://doi.org/10.1016/j.renene.2015.09.015.
[24] ASHRAE. Thermal Environmental Conditions for Human Occupancy. ASHRAE 2010.
[25] Abad FX, Pinto RM, Bosch A. Survival of Enteric Viruses Environmental Fomites 1994;60:3704–10.
[26] Peterson LR, Gerding DN. Survival of Influenza Viruses on Environmental Surfaces 1982;146:47–51.
[27] Guan J, Chan M, Vanderzaag A. Inactivation of Avian Influenza Viruses on Porous and Non-porous Surfaces is Enhanced by Elevating Absolute Humidity 2016:1–8. https://doi.org/10.1111/tbed.12499.
[28] Rafique MM, Rehman S, Lashin A, Arifi N Al. Analysis of a Solar Cooling System for Climatic Conditions of Five Different Cities of Saudi Arabia n.d. https://doi.org/10.3390/en9020075.
[29] Rafique MM, Gandhidasan P, Al-hadhrami LM, Rehman S. Energy , Exergy and Anergy Analysis of a Solar Desiccant Cooling System 2016;4:78–83.

https://doi.org/10.7763/JOCET.2016.V4.257.
[30] Sultan M, El-Sharkawy II, Miyazaki T, Saha BB, Koyama S, Maruyama T, et al. Insights of water vapor sorption onto polymer based sorbents. Adsorption 2015;21:205–15. https://doi.org/10.1007/s10450-015-9663-y.
[31] Asim N, Amin MH, Alghoul MA, Badiei M, Mohammad M, Gasaymeh SS, et al. Key factors of desiccant-based cooling systems: Materials. Appl Therm Eng 2019;159:113946. https://doi.org/10.1016/j.applthermaleng.2019.113946.
[32] Beccali M, Butera F, Guanella R, Adhikari RS. Simplified models for the performance evaluation of desiccant wheel dehumidification. Int J Energy Res 2003;27:17–29. https://doi.org/10.1002/er.856.
[33] Sultan M, Miyazaki T, Niaz H, Shabir F, Ashraf S, Khan ZM, et al. Thermodynamic assessment of solar chimney based air-conditioning system for agricultural and livestock applications. InProceedings 4th Int Conf Energy Environ Sustain Dev (EESD, 2016) 2016;2016:1–9.