JSESD004: Evaporative Cooling in Tertiary Hospitals' Operating Theatre Rooms – A Review

Winnie Mutenhabundo[1], Tawanda Mushiri[2] and Patson Zvandasara[3]

[1]*Harare Institute of Technology (HIT), Zimbabwe*
[2]*Scientific and Industrial Research and Development Centre (SIRDC), Zimbabwe*
[3]*Department of Gynaecology and Obstetrics, University Zimbabwe*

Abstract

Among government healthcare institutions, tertiary hospitals are mandated to provide a quaternary level of healthcare service as they are better resourced. Fifty percent of this service is executed in operating theatre rooms. The air quality necessary in hospitals' operating theatre rooms requires the use of effectual heating, ventilation and air conditioning (HVAC) systems as it affects the well-being of surgical personnel and the healing process of the patients. However, these HVAC systems consume a lot of energy, making their energy efficiency a major concern. With such a scenario, effort has to be channelled towards the adoption of energy-efficient HVAC technologies, and evaporative cooling is one such technology which is green not only in energy efficiency, but also through its use of a non-polluting refrigerant. This research presents a review of evaporative cooling systems and their application in hospitals' operating theatre rooms. The cooling effect in evaporative cooling is produced when air is driven through a dampened cloth, and the air's sensible heat vaporises some of the liquid on the cloth, dropping the air's dry bulb temperature with an increase in the air's humidity. Presented in detail is the evaporative cooling system's principle of operation, system types, selection criteria and the applicability of evaporative cooling in operating theatre rooms. It was found that evaporative cooling technologies are not only cost effective, but they can reduce energy consumption of hospitals operating theatre rooms' air conditioners by 75%. This technology is useable in hot and humid climates and also in tropical savanna climates with hot wet summers and dry cold winters, like Zimbabwe's.

Keywords: air conditioning, evaporative cooling, microclimate, operating theatre room, tertiary hospitals

Introduction

For any society to be able to respond to life threatening emergencies, health facilities, particularly hospitals, become very critical resources (WHO, 2015). Among healthcare institutions, tertiary hospitals play a bigger role in providing quaternary level of care as they are generally equipped with specialists and other fundamental resources (Maria et al., 2015). As sick people seek medical attention in these hospitals, research has revealed that 50% of their medical requirements are taken care of in the operating theatre rooms (Harsoor & Bhaskar, 2007). Thus, the engine room of a hospital is the operating theatre room (Scott & Shafi, 2018).

Results of the treatment offered in the hospital are highly dependent on the surrounding climate, – based on the temperature, humidity and air velocity (Oxana, 2012; Teke & Timur, 2014). Problems encountered in theatre rooms include hypothermia, anaesthetical gas pollution and thermal discomfort (Alberani et al., 2005), as a result of insufficient air exchange, poor regulation on thermal parameters, and ventilation system operation (Nastase et al., 2016). Operating theatre room occupants are also a source of contamination as airborne contaminants generated from them can be conveyed to the surgical site by the airflow contact at the locality of the surgical staff (Dong et al., 2017). Therefore, the distribution of airflow in the theatre has an effect on the provision of a clean operating microenvironment, capable of inhibiting surgical site infections (SSIs) (Cao et al., 2018).

A comfortable environment can be achieved by controlling microclimatic parameters and air movement. Thus, a conducive environment can be achieved through the provision of HVAC systems (Alberani et al., 2005), either as decentralised or centralised air conditioning systems (Oxana, 2012; Kang, 2017), thereby lessening the possibilities of infections. With an effective HVAC system in the theatre, proper healing of the patients and a comfortable and healthy environment for the surgical team are a possibility (Liu et al., 2015).

Nevertheless, it has been revealed that the use of HVAC systems has increased energy consumption of buildings, and this energy demand will rise with population growth (Cuce & Riffat, 2016), with a consequent increase in energy costs and greenhouse gas emissions (Chiesa et al., 2017). Therefore, there is need to treat issues of energy, environment and technology simultaneously as they are interrelated and well-connected as presented in Fig. 1 (Rafique et al., 2016)

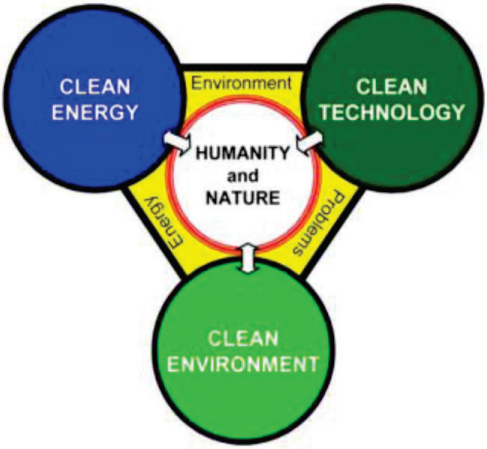


Figure 1: Energy, environment and technology (Rafique et al., 2016)

It is paramount to mitigate the energy consumption and global warming effect of HVAC systems by adopting alternative technologies which are energy-efficient (Mariotti & Moro, 2016). Research has highlighted that a special consideration to the building and HVAC system design should be taken to lessen the dependence on conventional energy sources consumption through the adoption of other systems (Papakostas & Slini, 2017).

Evaporative cooling is a passive, energy-efficient and non-polluting system that uses water (R718) as a refrigerant, contributing to the attainment of Paris Climate Agreement goals set at the 21st Conference of the Parties (COP 21) (Chiesa et al., 2017; Goldsworthy & White, 2010). The current research presents a review of evaporative cooling systems and their application in hospitals' operating theatre rooms.

The Review

Evaporative Cooling

Different types of air conditioning systems are used to cool domestic and commercial buildings, however, the global need to reduce the energy demand of buildings through the use of green technologies remains key to having sustainable development (Pomianowski et al., 2015; Chiesaa et al., 2017).

Therefore, the amount of energy consumed by the system and its potential for greenhouse gas emission has a great effect on the choice of the system to be employed for the various applications.

Evaporative cooling is a technology that supplies cool air to a room's occupants in a way which reduces GHG emissions and energy consumption, making it a green technology (Pomianowski et al., 2015). It is a concept that is defined as cooling air by increasing its water vapour content (Peng et al., 2015). The cooling effect is achieved through water's enthalpy of vaporisation manipulation, whereby air is driven through a dampened cloth and air's sensible heat vaporises some of the liquid on the cloth, dropping the air's dry bulb temperature with an increase in the air's humidity (Bishoyi & Sudhakar, 2017; Chen et al., 2017).

The essential phenomena which occur are that at normal temperature and pressure, more heat is needed to vaporise a given quantity of water than to raise its temperature by 10°C and the other is that unsaturated air can absorb extra water vapour. In other words, the air becomes cooler while its humidity level increases (Cuce & Riffat, 2016). Therefore, an evaporative cooling system works well in hot and arid climatic conditions due to the prominent humidity increment potential of air with a subsequent temperature drop (Rong et al., 2017; Cuce & Riffat, 2016; Attage & Jayasinghe, 2014).

Evaporative cooling is achieved through two main processes: direct and indirect cooling. For efficiency improvement, other technologies such as the desiccant system (Guan et al., 2015), are incorporated. In areas which are characterised by humid climates, direct evaporative cooling does not yield results since the air will already be saturated by moisture (Peng et al., 2015). In such instances, indirect cooling or hybrid systems have to be employed (Rafique et al., 2015; Xie & Jiang, 2015).

Direct evaporative cooling

Direct systems are the simplest of them all as outdoor air is drawn into an enclosed space, making contact with water which will either be entrapped in a porous pad or in the form of a spray (Malli et al., 2011; Porumb et al., 2016a). As the air gets wet, its temperature decreases owing to the liquid water to water vapour transition, because the entrapped water will cool and moisten the air during evaporation. This process is also called adiabatic cooling since the only heat gain and heat loss occur between the air and the water with which it is in contact (Maurya et al., 2014). However, the use of a direct evaporative cooler is limited to hot and dry climates in which the dry air entering is capable of absorbing the moisture from the wet pad.

This is impossible in humid climates in which the air is already saturated with moisture (Peng et al., 2015; Rafique et al., 2015; Rong et al., 2017; Mohammad et al., 2013).

Indirect evaporative cooling

Indirect systems have two air streams in which heat and mass transfer occur as water evaporates (Xuan et al., 2012). A heat exchanger with two sides separates the air streams with the dry side for air cooling and the wet side for water and air cooling. Thus, to cool the room, the air used passes through a heat exchanger enclosed in an evaporatively cooled space (Porumb, et al., 2016a; Porumb, et al., 2016b). Even though the temperature of the air drops, the increase in air humidity will be slight since there will be no change in the quantity of water vapour in the air as compared to direct evaporative cooling, thus making it more attractive (Rafique et al., 2015; Porumb et al., 2016a). There is a lower temperature drop in an indirect system than a direct system since for an indirect system to be effective, the wet bulb has to be within the 55% to 75% range. The air-water transfer process at the wet side of the indirect evaporative cooler is limited by entering the air's wet bulb temperature. Consequently, there is low cooling capacity as cooling the entering air below its wet bulb temperature is impossible (Duan et al., 2016; Porumb et al., 2016(a)).

Liquid and Solid Desiccants

Desiccants are solid and liquid materials that attract water vapour from the air. This absorption is made possible because of the difference in vapour pressure between the desiccant's surface and the air (Mohammad et al., 2013). For the dehumidification process to be said to have happened, air to be dehumidified gets into contact with the desiccant material until the vapour pressure reaches equilibrium since the desiccant has a lower pressure. The desiccant dehumidification system is made up of the dehumidifier and the regenerator. After water transfer between the desiccant and the air, the desiccant solution gets weakened and is thus sent to the regeneration unit for moisture release, with the aid of heat from external sources. The processes which occur in a desiccant dehumidification system are presented in Fig. 2.

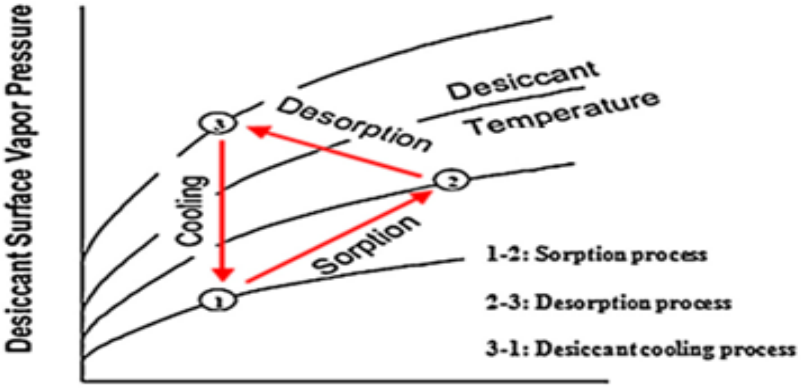


Figure 2: Desiccant dehumidification process

The choice of making use of either solid or liquid desiccant materials depends on process requirements. The types of solid desiccants include polymers, alumina, silica, zeolites, hydratable salts and mixtures, whilst liquid desiccants include lithium chloride, lithium bromide, calcium chloride, tri-ethylene glycol and mixtures (Shehadi, 2018). Structures with solid desiccant normally work with a wheel infused with the material to adsorb water vapour from air passing through it, whilst liquid systems make use of packed beds, towers and spray chambers and are more efficient than solid ones (Oliveira et al., 2000).

The use of liquid desiccants has been done in several dehumidification systems and has been found to produce decent coefficient of performance. Also, the desiccant can be reactivated using solar or other low grade waste heat sources at a lower temperature of the range 51-60^{o}C (Sultan et al., 2015). Unlike solid systems, desiccants also tend to have a lower pressure drop of the process air stream and can filter bacteria, microbial contamination and viruses (Islam et al., 2018; Oliveira et al., 2000).

Hybridisation

To offer sensible cooling to the dehumidified air, several cooling processes are used such as vapour compression, vapour absorption, vapour adsorption, direct evaporative cooling or indirect evaporative cooler units (Guan et al.,

2015). Combining the desiccant dehumidification concept with a cooling system presents an efficient hybrid air conditioning system which can work in hot and humid climates (Rafique et al., 2016). Shehadi (2018) has done a comparison on vapour compression-based air conditioning systems and desiccant dehumidification-based air coolers, as presented in Table 1.

Table 1: Comparisons between traditional vapour compression systems and desiccant-based cooling systems (Shehadi, 2018)

Parameter	**Traditional vapour compression system**	**Desiccant dehumidification system**
Cost of operation	High	Saves 40%
Driving energy source	Electricity, natural gas, vapour	Low grade energy e.g. solar, waste heat
Humidity control	Average	Accurate
Quality of indoor air	Average	Good
System instalment	Average	Slightly complicated
Capacity for energy storage	Average	Good

In the hybrid system, the ambient air which is saturated is dehumidified first to remove latent heat load using desiccants, after which it is sent to the cooling system for sensible heat load removal (Fakhrabadi & Kowsary, 2016). Such a system is capable of accomplishing independent temperature and humidity regulation. The hybrid desiccant cooling system classification is based on the types of cooling technology employed in reducing the temperature of the dehumidified air Fig. 3.

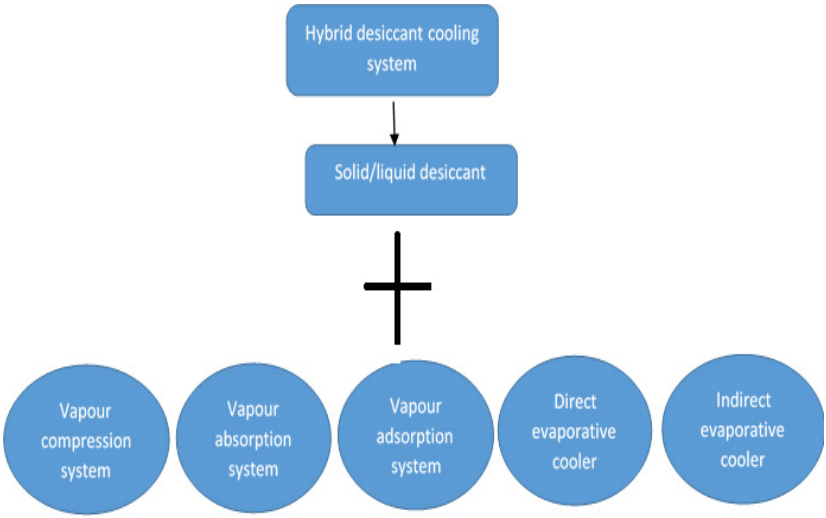
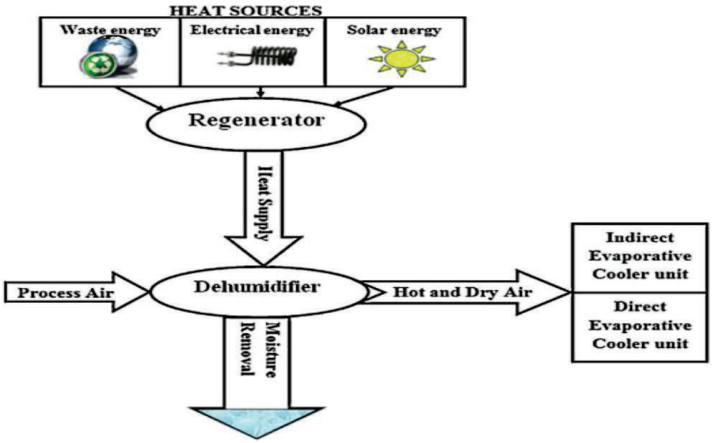


Figure 3: Hybrid desiccant cooling system

Mechanical vapour compression is usually used for air conditioning, but evaporative cooling is one alternative which consumes only a quarter of the electrical energy required by vapour compression systems. An ordinary evaporative cooling system works well in hot and dry climates. For hot and humid climates, sensible heat loads can be handled very well. However, to contain indoor relative humidity, latent heat load needs to be removed, and that is when desiccant dehumidifiers are used. There is no re-heating required in the desiccant dehumidification-based air cooler, since temperatures will not be lowered below dew-point to remove moisture as is the case in normal vapour compression air-conditioning systems. According to Sultan et al. (2015), by using desiccants in the cooling systems, the energy consumption of vapour compression-based air conditioner can be reduced by up to 5% for heating and 30% for cooling. The hybrid desiccant evaporative cooling process is presented in Fig. 4.



.

Figure 4: Hybrid desiccant evaporative cooling system

The hybrid desiccant evaporative cooler is made up of the dehumidifier in which ambient air enters and the moisture it contains is removed through absorption by the solid or liquid desiccants (Jouhara & Yang, 2018). For cooling, the dehumidified air is channelled towards either the indirect evaporative or the direct evaporative cooler, depending on product air requirements. In another cycle, the used or saturated desiccant with moisture is directed towards the regenerator for moisture removal so that after the reactivation it can be channelled back to the dehumidifier for air moisture removal (Shehadi, 2018). The regeneration process is done in the presence of heat which can be supplied by electrical sources or other renewable sources of thermal energy such as solar and biogas (Brumana & Franchini, 2016; Calise et al., 2014; Rafique et al., 2015).

The effectiveness in terms of the temperature of a direct evaporative cooler is from 70% to 95%, whilst that of an indirect cooler is between 40% and 60%. With regards to moisture addition, the direct system increases moisture content of the cooled air, whilst the indirect system tends to deliver sensible cooling only to the air without moisture addition.

2.4 Evaporative Cooling in Hospitals

Holcatova (2003) has alluded to the fact that surgical suites without air conditioning expose personnel to two major risks, that is, heat stress and toxic risk of anaesthetic gases (Holcátová et al., 2003; Cao et al., 2018). It has

also been found that the use of air conditioning systems helps in regulating temperature and humidity in hospital rooms (Czarniecki et al., 1991).

Evaporative cooling can be used to air-condition hospital theatre rooms as it has the potential to reduce energy consumed by traditional air conditioning systems and the greenhouse gas effect (Jouhara & Yang, 2018). When hybridised with a desiccant dehumidifier, more positive results are even yielded as liquid desiccants dehumidification systems can filter bacteria, microbial contamination and viruses, (Islam et al., 2018). This capacity is even more desirable since surgical site infections will be minimised because of the filtration.

To increase the cleanliness of the air, ultraclean ventilation systems and laminar airflow systems are adopted for air distribution in the theatre rooms (Cao et al., 2018; Dascalaki et al., 2008). The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 170-2013-Addendum (m) has allowed the use of "adiabatic high pressure water atomising" humidifiers whilst using Reverse Osmosis water, an ultraviolet C sterilisation light and a submicron filter (refer to American Society for Testing and Materials D-1193-06 2011, Standard for Reagent Water) (Wilson & Kozlik, 2017).

Several researches have been conducted on theatre room air quality requirements and the use of HVAC systems, including traditional vapour compression-based systems. Work was also done on assessing the possible use of evaporative cooling and enhancing its performance such as through incorporating electrospray technique (Salazar et al., 2018). Some of these researches and their findings are presented in Table 2.

Table 2: Pioneer research work on hospital microclimate and evaporative cooling

Year	Author	Research title	Findings
1991	Czarniecki et al.	Investigations of the microclimate in hospital wards	A too-high or too-low temperature causes discomfort in patients.
2017	Dong et al.	Investigation of the thermal plume around a simulated standing operator in an operating room	The working intensity of the medical staff has an impact on the development of the thermal plume.

2015	Liu et al.	Analysis of thermal environment in a hospital operating room	The thermal Comfort Model is a more comprehensive model for thermal comfort analysis.
2003	Holcátová et al.	Comparison of the environment in operating theatres in two hospitals	The positive effect of ventilation systems such as air conditioners was confirmed.
2018	Cao et al.	Do surgeons and surgical facilities disturb the clean air distribution close to a surgical patient in an orthopaedic operating room with laminar airflow?	The provision of higher clean airflow rate in the operating microenvironment may be an effective way to prevent the development of Surgical Site Infections.
No date	Alberani et al.	Climatisation in operating theatres	HVAC systems for achieving thermal comfort and for obtaining a healthy environment.
2008	Dascalaki et al.	Air quality in hospital operating rooms	Even though mechanical ventilation and active scavenging systems were employed in the audited ORs, medical personnel are still exposed to poor indoor air quality.
2016	Nastase et al.	Indoor environmental quality in operating rooms: An European standards review with regard to Romanian guidelines	Re-evaluation needed on indoor air quality domain standards for improved, high quality medical units' environment for both, patients and medical staff.

2016	Cuce & Riffat.	A state of the art review of evaporative cooling systems for building applications	Evaporative cooling has a great potential to save energy and is a very cost effective way compared to other methods.
2016	Cuce	Thermal performance assessment of a novel liquid desiccant-based evaporative cooling system: An experimental investigation	The system provided attractive findings for temperate and humid climatic conditions.
2004	López-Herrera et al.	An experimental study of the electrospraying of water in air at atmospheric pressure	The electrospray technique produces fine droplets.
2017	Parhizkar et al.	Performance of novel high throughput multi-electrospray systems for forming of polymeric micro/ nanoparticles	The throughput of particles was increased, particles with narrow size distribution was produced from all four uniform electrospray jets.
2018	Salazar et al.	Electrospray technique to produce fine sprays of desiccant liquids: Application to moisture removal from air (hospital setup)	A combination of desiccant liquid and electro-hydrodynamic techniques is considered a challenging topic to produce a very fine spray that leads to an increase in surface contact.

Discussion

The operating theatre room is regarded as the engine room of a hospital. The results of the treatment process depend on the surrounding climate in terms of humidity, temperature and air velocity. Insufficient air exchange, poor regulation on thermal parameters and ventilation system operation result in hypothermia, anaesthetical gas pollution and thermal discomfort. The provision of either decentralised or centralised HVAC systems helps control microclimatic parameters and air movement, providing a conducive environment for patients' healing and surgical team comfort.

Conventional vapour compression-based HVAC systems which have been traditionally used in theatre rooms have been known to increase the energy consumption of buildings, and are also responsible for greenhouse gas emissions. Adopting alternative technologies which are energy-efficient and non-polluting, is key. Passive cooling systems like evaporative cooling are energy-efficient and use water, a non-polluting refrigerant. Evaporative cooling consumes about a quarter of the electrical energy required by conventional vapour compression systems. To achieve cooling using the evaporation phenomenon, direct, indirect and hybrid evaporative cooling systems have been developed. The direct system increases the moisture content of the cooled air, whilst the indirect system tends to deliver sensible cooling only to the air, without moisture addition. In terms of temperature control, the effectiveness of a direct evaporative cooler is from 70% to 95%, whilst that of an indirect cooler is between 40% and 60%.

Hybrid systems are employed in humid climates whose air is moisture saturated, as direct evaporative cooling does not yield desired results. During hybridisation, ambient air is dehumidified first to remove latent heat load using desiccants, after which it is directed towards the cooling system for sensible heat load removal.

Therefore, when used to air-condition hospital theatre rooms, evaporative cooling has the potential to save energy and reduce greenhouse gas effects in air conditioning. Hybridisation with a desiccant dehumidifier, yields more positive results as liquid desiccant dehumidification systems have the ability to filter bacteria, microbial contamination and viruses. This capacity of the hybrid system is desirable to minimise surgical site infections. Other techniques such as electrospraying enhance system performance since the desiccant-air contact surface area will be increased.

Conclusion And Recommendations

The air quality necessary in hospitals' operating theatre rooms affects the well-being of the surgical personnel and the healing process of the patients.

With conventional HVAC systems being energy consumptive, the adoption of energy-efficient HVAC technologies is highly recommended. Evaporative cooling helps reduce energy consumption and greenhouse gas effects, resulting in green air conditioning. Hybrid evaporative cooling systems make evaporative cooling adoptable in various climatic regions. The use of liquid desiccants results in the reduction of SSI because of the filtration capacity of the desiccants.

References

Alberani, L., Cannistraro, G., Lupo, G., Mazzacane, S., Piccolo, A., Plutino, D., & Ponterio, L. (2005). Climatization in operating theatres: A review of the state of the art. In *Proceedings of Conference CLIMAMED – 2nd Mediterranean Congress of Climatization* (pp. 65-77). Conference ClIMAMED, Madrid.

Arandara1, K.P., Attage, R.A., & Jayasinghe, M.T.R. (2014). Thermal comfort with evaporative cooling tropical climates. In *Proceedings of International Conference on Sustainable Built Environment (ICSBE)* (pp. 334-390). Kandy, Sri Lanka.

Bishoyi, D., & Sudhakar, K. (2017). Experimental performance of a direct evaporative cooler in composite climate of India. *Energy and Buildings, 153,*190-200. Elsevier, Amsterdam. doi: 10.1016/j.enbuild.2017.08.014.

Brumana, G., & Franchini, G. (2016). Solar-powered air conditioning for buildings in hot climates: Desiccant evaporative cooling vs. absorption chiller-based systems. *Energy Proceedia, 101.* 288-296. Elsevier, London. doi: 10.1016/j. egypro.2016.11.037.

Calise F., Dentice d'Accadia M., Roselli C., Sasso, M., & Tariello, F. (2014). Desiccant-based AHU interacting with a CPVT collector: Simulation of energy and environmental performance. Solar Energy, 103. 574-594. Elsevier, London. doi: 10.1016/j.solener.2013.11.001.

Chen, Y., Luo, Y., & Yang, H. (2017). Energy saving potential of hybrid liquid desiccant and evaporative cooling air-conditioning system in Hong Kong. In *Proceedings of the 8th International Conference on Applied Energy, ICAE 2016* (pp. 2125-2130). Elsevier, Hong Kong.

Chiesaa, G., Grossoa, M., Bognia, A., & Garavaglia, G. (2017). Passive downdraught evaporative cooling system integration in existing residential building typologies: A Case Study. *Energy Procedia, 111*, 599-608. Elsevier, Turin. Doi: 10.1016/j. egypro.2017.03.222.

Chiesaa, G., Hubermanb, N., Pearlmutterb, D., & Grossoa, M. (2017). Summer discomfort reduction by direct evaporative cooling in Southern

Mediterranean areas. *WIREs Energy and Environment, 11*(3). Wiley, New Jersey. DOI: 10.1002/wene.423

Cuce, P.M. (2016). Thermal performance assessment of a novel liquid desiccant-based evaporative cooling system: An experimental investigation. *Energy and Buildings, 138,* 88-95. Elsevier, Berlin. doi: 10.1016/j. enbuild.2016.12.029.

Cuce, P.M., & Riffat, S. (2016). A state of the art review of evaporative cooling systems for building applications. *Renewable and Sustainable Energy Reviews, 54,* 1240-1249. Elsevier, Amsterdam. doi: 10.1016/j. rser.2015.10.066.

Czarniecki, W., Kopacz, M., Okolowicz, W., Gajewski, J., & Grzedziiqski, E. (1991). Investigations of the microclimate in hospital wards. *Energy and Buildings, 16*(1-2), 727-733. Elsevier, Amsterdam. doi: 10.1016/0378-7788(91)90044-4.

Dascalaki, E.G., Lagoudi A., Balarasa, C.A., & Gaglia, A.G. (2008). Air quality in hospital operating rooms. *Building and Environment, 43*(11), 1945-1952. Elsevier, Berlin. Doi: 10.1016/j.buildenv.2007.11.015.

Dike, V.E. (2015). "Why nations fail" to develop. The case of Nigeria. *SAGE Open, 5*(4) https://doi.org/10.1177/2158244015611714

Dong, Z., Zhou, B., Li, F., Wang, Y., Lin, X., & Wu, X. (2017). Investigation of thermal plume around a simulated standing operator in an operating room. *Procedia Engineering, 205,* 1940-1945. Elsevier, London. Doi: 10.1016/j.proeng.2017.10.053.

Duan, Z., Zhan, C., Zhao, X., & Dong, X. (2016). Experimental study of a counter-flow regenerative evaporative cooler. *Building and Environment, 104,* 47-58. Elsevier Ltd, New Dehli. doi: 10.1016/j. buildenv.2016.04.029.

Fakhrabadi, F., & Kowsary, F. (2016). Optimal design of a hybrid liquid desiccant-regenerative evaporative air conditioner. *Energy and Buildings, 133,* 141-154. Elsevier, Netherlands doi: 10.1016/j.enbuild.2016.09.048.

Goldsworthy, M., & White, S. (2010). Optimisation of a desiccant cooling system design with indirect evaporative cooler. *International Journal of Refrigeration, 34*(1), 148-158. doi: 10.1016/j.ijrefrig.2010.07.005.

Guan, L., Bennett, M., & Bell, J. (2015). Evaluating the potential use of direct evaporative cooling in Australia. *Energy and Buildings, 108,* 185-194. Elsevier, Amsterdam doi: 10.1016/j.enbuild.2015.09.020.

Guangyu, C., Madeleine, C.A.S., Amar, A., Liv-Inger, S., & Jan, G.S. (2018). Do surgeons and surgical facilities disturb the clean air distribution close to a surgical patient in an orthopaedic operating room with laminar

airflow?'. *American Journal of Infection Control. Elsevier Inc., 46*(10), 1115-1122. Elsevier, Philadephia doi: 10.1016/j.ajic.2018.03.019.

Harsoor, S.S., & Bhaskar, S.B. (2007). Designing an ideal operating room complex. *Indian Journal of Anaesthesia, 51*(3), 193-199 Wolters Klurer Medknow Publications, Mumbai.

Holcátová, I., Benešová, V., & Hartlová, D. (2003). Comparison of the environment in operating theatres in two hospitals. *Indoor and Built Environment, 12*(1-2), 121- 124. Sage, UK. doi: 10.1177/1420326X03012001019.

Islam, M.R., Alan, S.W.L., & Chua, K.J. (2018). Studying the heat and mass transfer process of liquid desiccant for dehumidification and cooling. *Applied Energy, 221,* 334-347. Elsevier, London. Doi: 10.1016/j.apenergy.2018.03.167.

Jouhara, H., & Yang, J. (2018). Energy efficient HVAC systems. *Energy and Buildings, 173,* 83-85. Elsevier, London. Doi: 10.1016/j.enbuild.2018.09.001.

Kang, Z., Zhang, Y., Dong, J., Cheng, X., & Feng, G. (2016). The status of research on clean air conditioning system in hospital operation room. *Procedia Engineering, 205,* 4129- 4134. Elsevier, Amsterdam. https://doi.org/10.1016/j.proeng.2017.10.152

Liu, C., Zhou, G., & Li, H. (2015). Analysis of thermal environment in a hospital operating room. *Procedia Engineering, 121,* 735-742 Elsevier, Amsterdam. doi: 10.1016/j.proeng.2015.09.021.

López-Herrera, J.M., Barrero, A., Boucard, A., Loscertales, I.G., & Márquez, M. (2004). An experimental study of the electrospraying of water in air at atmospheric pressure. *Journal of the American Society for Mass Spectrometry, 15*(2), 253-259. Elsevier, Amsterdam. Doi: 10.1016/j.jasms.2003.10.018.

Magalhães, A., Riboldi, C., Guzinski, C., Silva, R., & Moura, G. (2015). Level of dependence among patients in a surgical unit. *Revista Brasileira de Enfermagem, 68*(5), 542-547. SciELO, Brazil. https://scielo.isciii.es/pdf/eg/v17n52/en_1695-6141-eg-17-52-550.pdf

Malli, A., Reza, H., Lay6eghi, M., Sharifian, S., & Behravesh, H. (2011). Investigating the performance of cellulosic evaporative cooling pads. *Energy Conversion and Management, 52*(7), 2598-2603. Scientific Research, Carlifonia. Doi: 10.1016/j.enconman.2010.12.015.

Mariotti, M., & Moro, L. (2016). Indirect evaporative cooling combined with dehumidification in a MVHR system for radiant cooling. *Energy Procedia, 101,* 448-455. Elsevier, Amsterdam. Doi: 10.1016/j.egypro.2016.11.057.

Maurya, R., Shrivastava, N., & Shrivastava, V. (2014). Performance evaluation of alternative evaporative cooling media. *International Journal of Scientific and Engineering Research, 5*(10), 676-684. Ravi Mittal, Gurgaon.

Mohammad, A., Mat, B.S., Sulaiman, M.Y., Sopian, K., & Al-abidi, A.A. (2013). Historical review of liquid desiccant evaporation cooling technology. *Energy and Buildings, 67,* 22-33. Elsevier, Berlin. Doi: 10.1016/j. enbuild.2013.08.018.

Nastase, I., Croitoru, C., Vartires, A., Tataranu, L., Scott, D., & Shafi, M. (2016). Indoor environmental quality in operating rooms: A European Standards Review with regard to Romanian Guidelines. *Obstetrics, Gynaecology and Reproductive Medicine, 85,* 8-10. Elsevier, London. Doi: 10.1016/j.ogrm.2018.08.002.

Oliveira, A.C., Afonso, C.F., Riffat, S.B., & Doherty, P.S. (2000). Thermal performance of a novel air conditioning system using a liquid desiccant. *Applied Thermal Engineering, 20*(13), 1213-1223. Elsevier, London. Doi: 10.1016/S1359- 4311(99)00087-3.

Oxana, P. (2012). *Indoor climate in hospitals. What are the risk factors for patients?* (Bachelor's thesis). Mikkeli University of Applied Sciences, Finland.

Papakostas, K.T., & Slini, T. (2017). Effects of climate change on the energy required for the treatment of ventilation fresh air in HVAC Systems. The case of Athens and Thessaloniki. *Procedia Environmental Sciences, 38,* 852-859. Elsevier, Amsterdam. Doi: 10.1016/j.proenv.2017.03.171.

Parhizkar, M., Reardon, P.J.T., Knowles, J.C., Browning, R.J., Stride, E., & Pedley, R.B. (2017). Performance of novel high throughput multi electrospray systems for forming of polymeric micro/nanoparticles. *Materials and Design. 126,* 73-84. Elsevier, London. Doi: 10.1016/j. matdes.2017.04.029.

Peng, J., Li, L., Liu, F., & Chen, S. (2015). Application on evaporative cool technique in garment workshop in hot-humid area. *Procedia Engineering, 121,* 2029-2036. Elsevier, Berlin. Doi: 10.1016/j.proeng.2015.09.203.

Pomianowski, M., Andersen, C.H., & Heiselberg, P. (2015). Technical potential of evaporative cooling in Danish and European condition. *Energy Procedia, 78,* 2421-2426. Elsevier, Amsterdam. Doi: 10.1016/j. egypro.2015.11.211.

Porumb, B., Mugur, B., & Porumb, R. (2016b). Potential of indirect evaporative cooling to reduce the energy consumption in fresh air conditioning applications. *Energy Procedia Volume, 85,* 433-441. Elsevier, Berlin. Doi: 10.1016/j.egypro.2015.12.224.

Porumb, B., Ungureşan, P., Tutunaru, L.F., Şerban, A., & BAlan, M. (2016a) A review of indirect evaporative cooling technology. *Energy Procedia, 85,* 461-471. Elsevier, Amsterdam. Doi: 10.1016/j.egypro.2015.12.228.

Rafique, M.M., Gandhidasan, P., Rehman, S., & Al-hadhrami, L.M. (2015). A review on desiccant based evaporative cooling systems. *Renewable and Sustainable Energy Reviews, 45,* 145-159. 'Elsevier, London. https://doi.org/10.1016/j. rser.2015.01.051

Rafique, M. M., Gandhidasan, P., & Bahaidarah, H.M.S. (2016). Liquid desiccant materials and dehumidifiers – A review. *Renewable and Sustainable Energy Reviews, 56,* 179-195. Elsevier, London. https://doi.org/10.1016/j.rser.2015.11.061

Rong, L., Pedersen, P., Jensen, T.L., Morsing, S., & Zhang, G. (2017). Dynamic performance of an evaporative cooling pad investigated in a wind tunnel for application in hot and arid climate. *Biosystems Engineering, 156,* 173-182. Elsevier, UK. https://doi.org/10.1016/j.biosystemseng.2017.02.003

Salazar, M.G., Jiménez, R.Z., Loscertales, I.G., & Reyes, A.H. (2018). Electrospray technique to produce fine sprays of desiccant liquids. Application to moisture removal from air. *Energy and Buildings, 162,* 187-197. Elsevier, Amsterdam. Doi: 10.1016/j.enbuild.2017.11.071

Scott, D., & Shafi, M. (2018) The WHO surgical checklist: Improving safety in our operating theatres. *Obstetrics, Gynaecology and Reproductive Medicine, 35*(9), 241-274. Oxford, London. Doi: 10.1016/j.ogrm.2018.08.002.

Shehadi, M. (2018). Review of humidity control technologies in buildings. *Journal of Building Engineering, 19,* 539-551. Elsevier, London. doi: 10.1016/j.jobe.2018.06.009.

Sultan, M., El-sharkawy, I.I., Miyazaki, T., Saha, B.B., & Koyama, S. (2015). An overview of solid desiccant dehumidification and air conditioning systems. *Renewable and Sustainable Energy Reviews, 46,* 16-29, Elsevier, London. Doi: 10.1016/j.rser.2015.02.038.

Teke, A., & Timur, O. (2014). Assessing the energy efficiency improvement potentials of HVAC systems considering economic and environmental aspects at the hospitals. *Renewable and Sustainable Energy Reviews, 33,* 224-235. Elsevier, London. https://doi.org/10.1016/j.rser.2014.02.002

WHO (2015). Comprehensive Safe Hospitals Framework. *Safe Hospitals Initiative.*

Wilson, L.V., & Kozlik, G. (2017). How you can "own" ASHRAE Standard 170, ventilation of health care facilities. *In Proceedings of the PDC Summit 1, 2017.* Phoenix.

Xie, X., & Jiang, Y. (2015). Comparison of two kinds of indirect evaporative cooling system: To produce cold water and to produce cooling air. *Procedia Engineering, 121,* 881-890. Elsevier, London. Doi: 10.1016/j.proeng.2015.09.044.

Xuan, Y.M., Xiao, F., Niu, X.F., Huang, X., & Wang, S.W. (2012). Research and application of evaporative cooling in China: A review (I) – Research. *Renewable and Sustainable Energy Reviews, 16*(5), 3535-3546. Elsevier, UK. Doi: 10.1016/j.rser.2012.01.052.