Coupled Evaporative and Desiccant Cooling Systems for Tropical Climate

ZEYNAB EMDADI[a,b]*, ALI MALEKI[a] , MASITA MOHAMMAD[b], NILOFAR ASIM[b] , MOJTABA AZIZI[a]
[a] Catalysts and Organic Synthesis Research Laboratory, Department of Chemistry, [b] Solar Energy Research Institute
[a] Iran University of Science and Technology, [b] Universiti Kebangsaan Malaysia
[a]1684613114, Tehran, [b]43600 Bangi, Selangor,
[a]IRAN, [b]MALAYSIA
emdadi58@gmail.com *, maleki@iust.ac.ir, masita@ukm.edu.my, nilofarasim@ukm.edu.my, azizi.m_58@yahoo.com

Abstract: - The major consumer of energy in buildings is the Heating, Ventilation, and Air-Conditioning (HVAC) system, which is tightly linked to local climatic conditions. The utilization of HVAC requires improvements to its passive cooling strategies due to its high energy consumption. This article tries to attract the researchers' attention on utilizing the coupled evaporative and desiccant cooling systems in a tropical climate and their required sustainable improvements. Meanwhile, the emphasis on utilizing certain materials for evaporative cooling applications has been made. This review indicated that the multiple green materials such as agricultural and industrial waste and geopolymers are effective as a dehumidifier replacing chemical desiccant in desiccant based evaporative cooling systems.

Key-Words: - Evaporative cooling, Desiccant cooling, Porous material, HVAC, Geopolymer

1 Introduction

Despite the reported huge energy consumption by air conditioning systems, demands for them in ever increasing alongside environmental changes and improved living standards. It is therefore important that sustainable development effectively improve the energy utilization ratio of air conditioning systems [1]. Meanwhile, increasing shortage of energy resources, global warming, and blackouts resulting from weather conditions have further encouraged the search for increasingly efficient methods to conserve energy, decrease greenhouse gas emissions, and guaranteeing power supplies. These facts call into question traditional methods of energy production [2-4].

In a tropical climate, HVAC's energy consumption is related to factors such as space cooling and dehumidification. Researchers have attempted to develop proper passive cooling systems, which include the evaporation cooling system coupled to a dehumidifier in order to realize the desired thermal comfort in humid climates. Meanwhile, rapid industrialization created an unending production of agricultural and industrial wastes, and the utilization of these solid wastes as resource materials will help reduce pollution and improve the economy. In addition, to develop green desiccant-based evaporative cooling system using industrial and agricultural waste and byproducts to prepare green desiccant and geopolymer materials that are suitable for humid climate.

This article focuses on utilizing the coupled evaporative and desiccant cooling systems in a tropical climate and their required sustainable improvements and also to achieve the aspired thermal comfort in this context.

2 The Objectives Consideration

Ecological security will be a highest point worldwide concern that obliges that diminishment about Vitality utilization. An approach on assistance attain this objective will be the usage for passive and low-energy techniques to actuate thermal comfort. Using climatic designs will also interpret on diminished energy costs. A suitableness design is a starting venture should minimize the distribution of climatic stress, and more fabricating design ought to reflect their encompassing climate will help decrease the reliance ahead mechanical heating/cooling [5].

A selection suitableness cooling design may be an intricate procedure. Cooling necessities have on a chance to be determined and their advantage and disadvantage require should a chance to be precisely investigate in the recent past setting on choice.

An important parameter in selecting of an appropriate design of an evaporating cooling technique is the environmental humidity. The evaporative cooling technique will be suitableness to hot and dry temperature climate, while the indirect evaporative cooling system is prober for the climate of humidity.

2.1 Evaporative and Desiccant Cooling Systems

The global heating, ventilation, and air-conditioning (HVAC) systems load which are the main energy consumer in buildings, is expected to increase by 6.2% annually, as per Fig.1 [6].

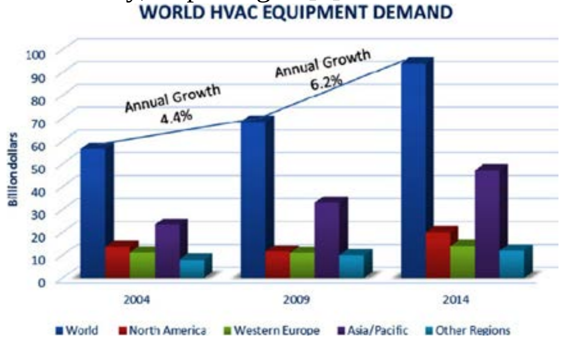

Fig. 1, HVAC equipment demand and annual growth.

The tropics are regions where the climate is regarded as uncomfortable due to the high amounts of received solar radiation, resulting in high temperatures, the high relative humidity, and many sunny days throughout the year. The recent rapid urbanization throughout the region, especially in countries such as Singapore, Malaysia, and Indonesia (Fig. 2) results in increased energy consumption due to the environmental changes and enhanced living standards, which represents a major concern in the region [7] and makes it vital that we elucidate the improvement of the energy utilization ratio of air conditioning system *vis-à-vis* sustainable development [1]

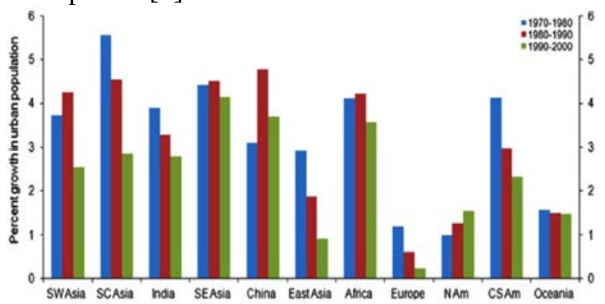

Fig. 2, Annual rates of the change in urban population measures by region and by decade.

In the construction of tropical houses, cooling becomes one of the major concerns. This becomes quite a major problem due to the heat gain by the roof, which makes up 70% of the total heat gain by a house.

Passive cooling strategy represents one of the most viable approach towards natural cooling of buildings [8]. It involves using a controller that corral the total effect of heat gain to result in an interior that reports a temperature lower than that of its natural surroundings [9]. Passive cooling strategies mostly involve preventive approaches against overheating in building interiors [10]. Kamal [8] listed the most frequently reported techniques for passive cooling, which included solar shading, insulation, induced ventilation techniques, radiative cooling, evaporative cooling, earth coupling, and desiccant cooling.

Evaporative cooling (EC) utilizes the natural cooling effect to lower the internal temperature of buildings. For the purpose of controlling the increase in the temperature of urban surfaces and creating a stabilized thermal environment, the evaporation of cool urban surfaces, such as walls and fences of buildings, are seen as a viable and passive cooling strategy that might actually work [11]. Generally, evaporative cooling systems are applied when the wet-bulb temperature remains under 25 °C [12]. The level of success of evaporative cooling is influenced by factors such as passing air through damp pads [13], falling water [14], or airstream spraying [15].

2.2 Materials for Evaporative Cooling Application

Cooling via the usage of porous materials is not a new concept, having already been in development since antiquity. The utilization of porous jars to cool or maintain the coolness of water is still being practiced in certain hot and dry parts of the world.

The Evaporative Cooling (EC) project integrates viable porous cooling ceramic into buildings in order to enhance the potential evaporative cooling nature of the building. EC by porous ceramic elements has an added inconvenience, mostly pertaining to the material itself. That is to say, in direct evaporative cooling systems, the effectiveness relies on the quantity of moisture that the air is capable of containing, while in ceramic evaporative cooling, it also relies on the characteristics of the ceramics (porosity, exposed surface, etc.) [16]. Some of different candidate materials that retains water included slag, bentonite, and diatomite. If integrated into a passive evaporative cooling system, they should increase the rate of water-absorption and water absorption capacity, while decreasing the release rate of the adsorbed water [17]. Porous materials exhibit inherent capillary action, especially with water levels exceeding 1 m, which means that the water that is required for the purpose of evaporation can be drawn from a rainwater tank without the aid of a pump. Despite the fact that porous ceramics (lotus ceramics) were previously fabricated by quite a number of researchers, [18, 19] and demonstrated higher levels of water retention and excellent cooling properties, owing to their excellent capillary lift of water, there is plenty room for their improvement. The advantages would be more profound if these materials were synthesized using a more environmentally friendly process, which avoids firing at high temperatures.

Geopolymers [20], or inorganic polymers, are excellent candidates for evaporative cooling system over porous ceramics, due to the fact that they can be synthesized via processes that is environmentally-friendly, *sans* firing at high temperatures [21]. Geopolymer materials adhere to the requirements of sustainable development; it is a lower temperature process that could also use significant amounts of industrial and agricultural waste materials as a secondary raw material to be converted to a new product. This new material would result in decreased energy consumption, waste production, and global CO_2 emissions, and exploitation of natural resources [22]. Conventional geopolymers are possible, as per its constituents/processing methods. Some of these customizable properties include compressive strength, shrinkage, setting, acid resistance, fire resistance, and thermal conductivity. However, these aforementioned properties are not inherent in all geopolymetric formulations. Inorganic polymers can be used to determine the correct mix and processing design that will optimize properties and/or reduce costs for a given application [21].

Similar to any technological development, the respective formulations and recipes are customized to realize the objectives at minimal costs. This is feasible with adequate know-how in the context of the reactivity of raw materials and chemistry, which allows us to optimize both techniques and costs to obtain optimal performances [23].

2.3 The conjunction of desiccant in evaporative cooling system

The evaporative cooling units are operable, exhibiting a high coefficient of performance (COP) in dry climatic conditions [24]. However, the saturated air prevalent in humid climate reduces the effectiveness of the cooling units, which necessitates that it works alongside a desiccant (dehumidifier), functioning as a moisture remover from processed air, rendering them more functionally effective. The desiccant (dehumidifier) is made up of desiccant materials (silica gel, lithium chloride, lithium bromide, etc.) that are capable of removing moisture from the air. A desiccant material absorbs/adsorb and retain water vapor from air via absorption/adsorption [25, 26]. The evaporative desiccant cooling system is made up of a desiccant dehumidifier, a regenerator, and a cooling unit [27]. In a desiccant-based evaporative cooling technique, the latent and sensible loads are removed separately using the desiccant dehumidification system and cooling unit, respectively. The type of cooling units utilized to decrease the temperature of dehumidified air defines the type of hybrid desiccant cooling system. The desiccant evaporative cooling systems leads to a significant decrease in the electrical energy consumption as opposed to conventional units, while also reducing the number of discomfort hours within conditioned space [28].

Some advantages of using desiccant cooling technology alongside an evaporative cooler include:

- It can be utilized for hot/humid climates due to the fact that evaporative cooling alone is not suitable for such climatic conditions.
- Energy usage is significantly decreased compared to the vapor compression cycle as preheating is not required. It is also an environmentally friendly system as it lacks refrigerants, which are detrimental to the ozone.
- Separate and better control of sensible/latent loads. The desiccant wheel controls the latent part, while the evaporative cooler controls the sensible part.
- The system can be maintained at low cost as it operates at close to atmospheric conditions.
- Low grade energies such as solar and biomass can effectively be used to run the system.

The desiccants are made up of natural or synthetic substances that are able to absorb or adsorb water vapor due to the difference of water vapor pressure between the surrounding air and the desiccant's surface in both liquid/solid states. Each liquid/solid desiccant system reports its own respective advantages/shortcomings. Adsorption faces problems when the physical or chemical nature of the desiccant, generally solid, remains unchanged in the dehumidification process; absorption faces problems when a change occurs, generally with liquids [29, 30]. Silica gel is a common adsorption solid. It behaves in a manner similar to a sponge, and in fact, its structure is significantly porous. Its pores' diameter measures a few nanometers across, while its volume accounts for approximately half of its total volume. Attractive forces between the vapors and the solid are reliant upon specific solid–vapor pair and on the physical structure of the solid. The adsorption desiccants are usually chemical compounds, such as synthetic polymers, silica gels, titanium silicates, natural or synthetic zeolites, activated alumina, and ''silica +'' [31-33].

3 Conclusion

The development of suitable passive cooling systems that include evaporation cooling system coupled to a dehumidifier to achieve the desired thermal comfort in the context of humid climates has been presented. This review work showed, despite the fact that the coupled evaporative and desiccant cooling systems are an effective in multiple climates including hot and arid regions but also for tropical climate. Meanwhile, using agricultural and industrial waste materials and geopolymers as green methods are an environmental friendly for evaporative cooling system applications. As the requirements of sustainable development, in depth investigation on different parameters which influence the performance of coupled evaporative and desiccant cooling system is need further attention.

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