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Research Article

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Approach for Integrating Indirect Evaporative Cooling System into Contemporary Architecture

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Abstract

Nowadays, the knowledge of building ecology focuses on energy efficiency and how to integrate environmental and climatic parameters into HVAC and thus enhances space qualities such as comfort ability. The aim of this paper is to demonstrate the rule of Indirect Evaporative Cooling systems in sustainability of contemporary architecture in hot-arid and hot-humid climate. An approach for integrating a novel Sub-Wet Bulb Temperature Evaporative cooler into contemporary architecture is presented. The system uses porous clay materials, as wet media, embedded with heat pipes heat exchangers, the supply air and working air flows were staged in separate ducts and in counter flow direction. Modelling and experimental results show that supply air would be cooled to below wet bulb temperature achieving a considerable cooling capacity and effectiveness. This performance would make the system a potential alternative to conventional mechanical air conditioning systems in buildings.

Keywords: Contemporary architecture; Building design; Indirect evaporative cooling; Sub-wet bulb temperature; ceramic; Wall mounting; Roof mounting

Introduction

The emerging practice of integrated design in contemporary architecture provides the strategies to achieve high performance, low energy, and cost-effectiveness. This is concluded through careful ground-up consideration of how energy efficiency can be integrated into the architecture design. This paper focuses on the integration of indirect evaporative cooling system into building design to reduce the amount of energy required. It is a cost-effective strategy for building economies without necessarily increasing energy consumption.

The Climate of Qatar is a subtropical humid, hot desert climate with low annual rainfall, very high temperatures in summer, especially in the inland areas. Current research efforts are directed towards design of providing cooling, especially in residential buildings, which improves energy efficiency and reduces power consumption.

One of the ancient, environmentally benign and natural methods used for cooling is known as Evaporative Cooling systems that use only water and a blower to circulate air. The warm, dry air is pulled through a water-soaked pad. As the water evaporates, a cooling effect on the surrounding air occurs. Evaporative Coolers use only a fraction of the energy used by traditional air conditioning systems [1].

This paper presents two stages Sub-Wet Bulb Temperature Evaporative Cooler (SWB EC) using porous ceramic and heat pipes as heat exchangers media. A review of the literature on Indirect Sub-Wet Bulb Temperature Evaporative cooling systems based on the combination of heat pipes and ceramic containers reveals no previous study of the integration of Indirect Evaporative Cooling into contemporary architecture.

The paper is divided into two sections. The first section outlines technical description of the proposed system, sizing of its main component and their possible disposition. The second investigates the integration of the system into contemporary architecture includes: installation, orientation, location, maintenance and possible designs.

Materials and Methods

The materials used in the experiment consisted of a laboratory test rig that was built to test the porous ceramic sub-wet bulb temperature evaporative cooler. A technical explanation of the Indirect Evaporative Cooling System shows the concluded results. The cooler consists of a porous ceramic container filled with water. Water permeates through the multitude of pores in the container. Exposure to air movement causes water to siphon to the surface of the ceramic container where it evaporates and so creates a cooling effect. The proposed evaporative cooler combines porous ceramic materials with passive heat pipes, which transfer the coolth to the interior of a building while discharging process air that causes evaporation and thus high humidity outside the building. This therefore provides a simple and low energy cooling effect without creating a moisture problem. Sub-Wet Bulb Temperature Evaporative Cooler Sizing calculated taking into account the outdoors and indoors design conditions. An experimental set was built to measure the performances of the Ceramic-Pipes Evaporative Cooler using both heat pipes and ceramic heat exchangers. A technical consideration is concluded to validate the proposed cooling system to be integrated into building design.

Technical Presentation of the Proposed Cooler

The SWBT Evaporative Cooling system combines ceramic panels and heat pipes as Heat exchangers media. This combination will

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allow the development of a compact system which will have a major advantage over other passive cooling systems in that it can be retro-fitted into existing building.

As shown in Figures 1 and 2, the porous ceramic panels were placed between the dry and wet air sections to form small and narrow ducts with air flowing at low velocity. The dry section side of the porous ceramic panel is sealed with a thin non-permeable membrane while the wet section allows water to seep through the micro-pores of ceramic panels forming a thin water film. In the wet section side, the ceramic panels are cooled through water film evaporation and then cooling the liquid inside the condenser sections of the heat pipes. The liquid pressure is then lower than the equilibrium vapor pressure. This pressure difference drives a rapid mass transfer to the evaporator end (hot point) of the heat pipe at the dry section, where the water absorbs the latent heat and evaporates, cooling the outlet supply air. This results in a drop of the temperature of the air in the dry section without changing its moisture content while the air in the wet section is rejected at saturation state. This system is appropriate to any type of climate, since the humidity of the supply air, comparing to the inlet air, remain unchanged [2,3].

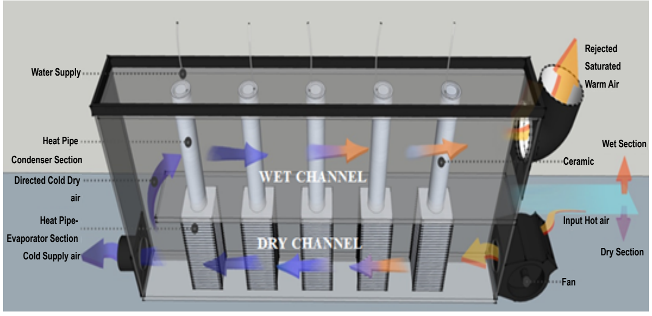

Figure 1: Components of the proposed evaporative cooler illustrated in a small test rig.

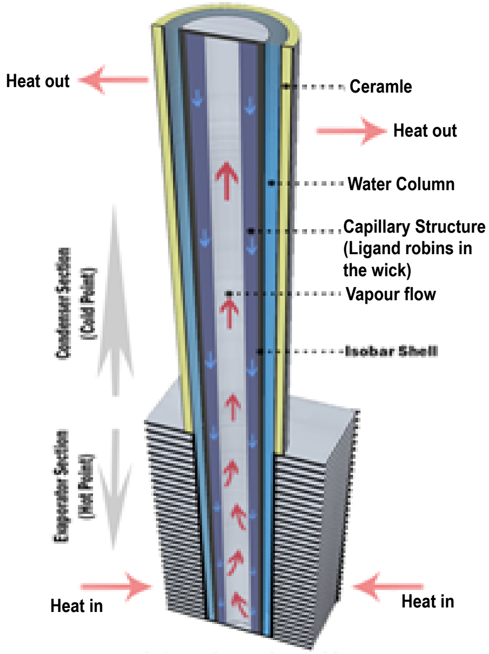

Figure 2: Heat pipe operating principle.

The proposed Sub-WetBulb Temperature Evaporative Cooler is an innovation in the Evaporative Cooling systems and is still not commercialized. A detailed study on the system design should be done in order to make it ready for domestic use. This paper focuses on the study of the Evaporative Cooling sizing and how it will be integrated into buildings.

Sub-Wet Bulb Temperature Evaporative Cooler Sizing

Usually, an Indirect Evaporative Cooling (IEC) system uses 100 percent outdoor air and a variable speed blower to circulate cool air. According to the American Society of Heating, Refrigerating and Air conditioning Engineers (ASHRAE), the energy consumption of the Evaporative Cooling systems can be reduced by 60 to 75 percent over conventional air conditioning systems. This relative improvement depends on sizing, location and application.

It is particularly critical to identify the correct size of residential cooling equipment since it is the key to achieve comfortable interior conditions and saving on initial and operating costs. A correctly designed Evaporative air Cooling system will hold the room set point temperature. Oversized systems greatly aggravate the summer utility peak demand on hot days and may enhance the initial costs, reduce the efficiency, increase the energy costs and comfort may be compromised.

As the first step, it is important to select the correct outdoor and indoor design conditions such as the required indoor design temperature and maximum air change rate, then, based on the cooling capacity of the system, the design of the proposed cooler can be identified.

Outdoors and indoors design conditions

The successful application of Evaporative Cooling system will depend on the geographic location of the building, the local climate, and the owner's performance expectations for the cooling system i.e. comfort cooling or relief cooling. Generally Evaporative Cooling is effective for comfort cooling at wet bulb temperatures up to 23°C and effective for relief cooling at wet bulb temperatures up to 25°C [4]. Moreover, when considering target indoor design temperatures, the following specifications should be noted:

- Australian Institute of Refrigeration, Air-conditioning and Heating- AIRAH specifies 24°C as a design indoor temperature for refrigerated air conditioning systems.
- Australian Standard™ 2913- AS 2913 Evaporative air conditioning equipment specifies 27.4°C as the target indoor temperature for nominal evaporative air cooler capacity rating.

The supply air temperature can be calculated knowing the outdoor design condition and unit evaporation efficiency [5]:

$$to = ti - \left(e100 \left(ti - twb,i \right) \right) \qquad (1)$$

Where:

to=System outlet or supply air dry bulb temperature [°C]

ti=Air inlet (ambient) dry bulb temperature [°C]

twb,i=Air inlet (ambient) wet bulb temperature [°C]

e=Evaporation efficiency of the unit determined in accordance with AS 2913 [%]

Once the system supply air temperature has been determined, the required airflow capacity to meet the room sensible load can be determined using the following equation [7]:

$$S = 1.213 \times qv \times (tr - to) \tag{2}$$

Where:

S=Estimated sensible cooling load [kW].

1.213 = Specific heat of moist air (1.025 kj/kg K)/Specific volume of moist air (0.845 m^3/kg) at standard (sea level) temperature and pressure.

qv =The air flow rate required of the unit to handle the room cooling load [L/s].

to =System outlet or supply air dry bulb temperature [°C].

tr =Room dry bulb temperature [°C].

The Air Change per Hour (ACH) rate is then [6]:

$$\mathrm{ACH} = 3.6 \times \frac{Q_v}{V} \tag{3}$$

The air change rate through the space to be served should typically be at least 20 Air Changes per Hour (ACH) with a maximum of about 40 ACH [7]. If the air change rate is too high, then the design room temperature will need to be increased and a new air quantity should be recalculated. This process is repeated until an acceptable air change rate is achieved. If the air temperature room is selected, the unit airflow rate (Q_v) required to meet that temperature can be calculated. If the unit airflow rate is selected, the resulting room air temperature (t_r) that can be achieved for those particular conditions can be calculated [7].

Finally, where the target room air temperature and unit air flow rate are both known, the sensible cooling load that can be provided by the system can be calculated [7].

Sizing of the proposed system: The size and cooling capacity of Evaporative Coolers is measured in Cubic Feet per Minute (CFM). The formula for sizing the cooler is very simple; just multiply the length by the width by the height of the area to be cooled and divide by the air change factor. Generally, a good rule of thumb is to have 1-2 air change per hour.

For example, if typical Middle East home is 40' wide, 60' long 9' high, has a total of 21600 Cubic Feet of area to be cooled. Considering an Air Change every two minute (ACH=30), then:

$$\text{Required CFM} = \frac{21600}{2} = 10800 \text{ CFM} \tag{4}$$

Generally, each Cubic Feet meter area requires 0.5 CFM to be cooled for 2 minutes Air Change:

$$1\mathrm{ft}^3 \to 0.5 \text{ CFM} \tag{5}$$

In order to evaluate the performance of the proposed system, experimental set was built, as presented in Figure 3 [1-3].

The supply air flow rate was fixed at 0.03 L/s (0.018 kg/s). If we consider this rate to handle the room cooling load, for a dry bulb temperature of 35 °C, and a supply air temperature of 22.3 °C the estimated cooling load is then:

$$S = 1.213 \times 0.3 \times (35 - 22.3) = 4.62 \text{ Kw} \tag{6}$$

Since 1 Btu (IT)/hour [Btu/h]=2.93071070172222E-04 [kW] (7)

$$\text{Thus } S_{EC} = 15730 \text{BTU/h} \tag{8}$$

These results are obtained using evaporative cooler that integrate x m^3 of ceramic panels:

$$\mathrm{X\ m^3_{ceramic\ panel}} \to 15730 \text{ BTU/h} \tag{9}$$

Generally,

$$1\ \mathrm{m^3_{ceramic\ panel}} \to \frac{15730}{X} \text{BTU/h} \tag{10}$$

Using Equation 10, the required area of ceramic panels can be estimated based on the expected cooling load value.

The performances of the Ceramic-Pipes Evaporative Cooler should be then recalculated using both heat pipes and ceramic heat exchangers.

Small scale experimental set-up and procedure of a heat pipe based indirect porous ceramic evaporative cooler: The primary aim of this experiment is to evaluate the thermal performance of the heat pipe based IEC system. To achieve that, a prototype unit, presented in Figure 1, was built and tested under various climates and ambient air conditions [3]. The basic specifications used for the fabricated heat and mass exchangers are summarized in Table 1.

The Heat pipe based IEC experimental rig was equipped with a variable speed fan to draw the air at controlled temperature and humidity from an environmental chamber and blow throughout the test-rig, while water is drawn from an overhead tank. Ten thermocouples were installed at several points of the device to measure temperature. Data logger was used to record readings during the experiment and save the data on a computer. The experimental measurements show the air temperature at the outlet of the dry channel is about 26.4°C and that of the wet channel is 25.7°C. It is to be noted that the air temperature in the wet channel did not reach saturation conditions, as it would require a larger wet surface area. This explains the continuous temperature reduction in the wet channel. Figure 4 shows the operating properties of the airflows in the dry and wet channels. It is shown that the outlet air temperature of the dry channel is cooled by about 5°C where the temperature drops from 30 to 25°C. Again, it can be seen that the airflow outlet in the wet channel did not reach the saturation line.

Proposed Cooler Disposition

The proposed cooling system can be integrated into the building structure, such as roofs or walls, or designed as a unit, which can be portable or fixed. This part will present the disposition of each component and the different connections to be considered.

The SWBT EC system will be especially composed of ceramic panels and heat pipes, both forming dry and wet channels. The dry channel will contain the cool dry air resulting from the passage of ambient air by the evaporator section of the heat pipe. However the wet channel will contain the humid hot air, to be rejected, resulting from the condenser section of the heat pipe and the ceramic panel. When the cooling system will be integrated on the wall/ roof, it is important to place the heat pipe evaporator section towards the openings of the cooler and to insulate the ceramic and the condenser section of the heat pipe form this space as it is presented in Figure 5. Same principle should be applied in the case of portable unit.

Table 1: Basic specifications of the dimension of the IEC system.

Parameters	Specification/value
Wall thickness	4 mm
Channel length	520 mm
Channel width	60 mm
Channel height	150 mm
Number of heat pipes	3

Integrating indirect evaporative cooling system into contemporary architecture

To successfully install an Evaporative Cooling system it's important to consider several keys. This part introduces the major parameters to be identified such as air path, ducts, etc., and then the adequate position of the cooler will be discussed depending on different factors.

Importance of relief and air ducts: A very important aspect of proper operation of ECs is the releasing or relieving of the "used" evaporatively cooled air from the building. The relief air path is the path the warm indoor air will take out of the building. It is crucial to the correct and effective operation of the ECs. If the hot air is not routed out of the building the system will be unable to correctly cool the supply air. The relief path can be natural or ducted.

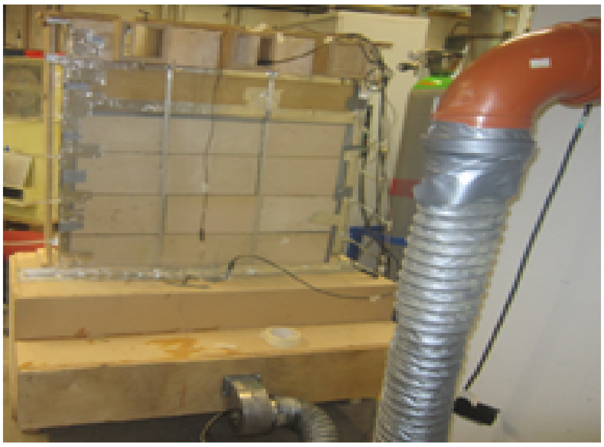

Figure 3: Experimental set of ceramic evaporative cooler.

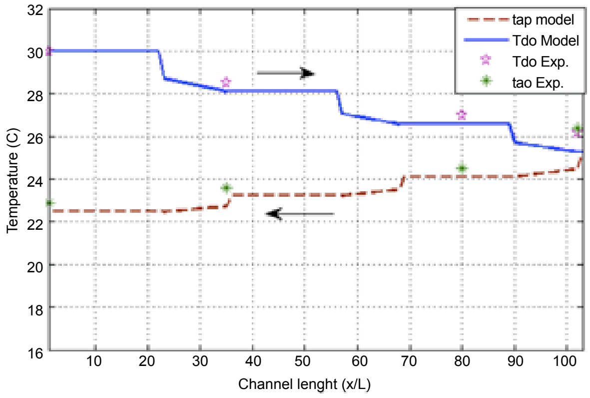

Figure 4: Air temperature variations in the dry and wet channel.

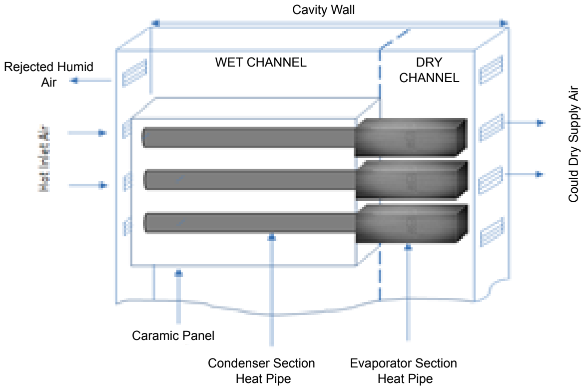

Figure 5: The components of the proposed cooler disposition.

Naturel relief is naturally provided using exterior operable windows and doors. Opening a window is the easiest way to route ECs air through a room. The supply fan air is pressurizing the interior of the building. This air will take the path of least resistance to leave the building. When an open window is located across the room from a supply air diffuser, the cool air must cross the room to be relieved [8]. This simple "open window area" to "air flow management" relationship is not always obvious since opening and closing windows and doors can affect the cooling capabilities of the system. Also, this technique may disturb the occupant security and comfort, due to noise issues and prevailing winds.

To address these issues, dedicated duct system in the ceiling space can be used. This method insures proper air relief regardless of the wind conditions. When these methods are used, additional supply fan static pressure is required to push the air to, through the dampers, and out of the building.

It is important to have a properly sealed duct system. In many residential cooling systems, the duct system passes through unconditioned zones, which may have thermally disadvantageous consequences. The insulation level of ducted systems tends to be between R-4 and R-6 (The R-value is a measure of thermal resistance used in the building and construction industry, the higher the R-value the better the thermal performance) with very high temperature differences across the insulation in many cases [9]. For instance, in the Middle East region, where slab-on-grade construction dominates, the ducts are often in the unconditioned attic. This space can reach 60°C or more under peak summer conditions, while the air in the ducts may be 12°C to 15°C.

Simulation studies show that cooling systems can easily lose 30% of their peak sensible capacity from this heat gain alone. If a radiant barrier or colored tile roof is present, peak attic temperatures might drop to 45°C. Furthermore, a white tile or white metal roof might drop the peak temperature to 37°C [8].

Very different conditions may also affect duct systems located in crawlspaces or basements. Thus, duct leakage can produce even larger impacts. Supply leaks can lose highly cooled air and depressurize the cooled space, adding more infiltration. Return leaks can draw air from unintended locations [10].

In order to reduce space conditioning energy use and to improve comfort, it is important to install duct system inside the insulated building envelope and to make sure that the ducts are sealed and tested correctly for different pressures and air flow speeds.

Figure 6 shows a ducted SWBT Evaporative Cooling system with central unit, which is placed on the insulated envelope of the roof slab. The ducts are sealed and connected to the central unit to transport the cool dry air to the different spaces of the building.

Evaporative cooler mounting: Actual study is focused on the use of ECs in residential buildings, with typical structures. Residential applications of Evaporative Cooling are common throughout the hot and dry areas in the Middle East. Residential ECs are typically smaller

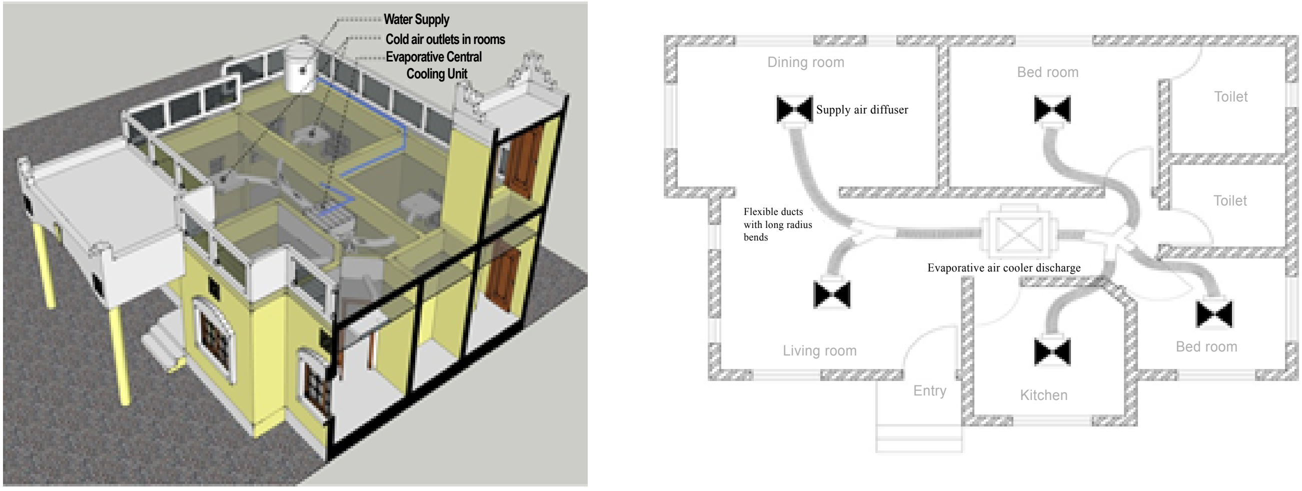

Figure 6: Illustration of the Evaporative cooling ducted air path system.

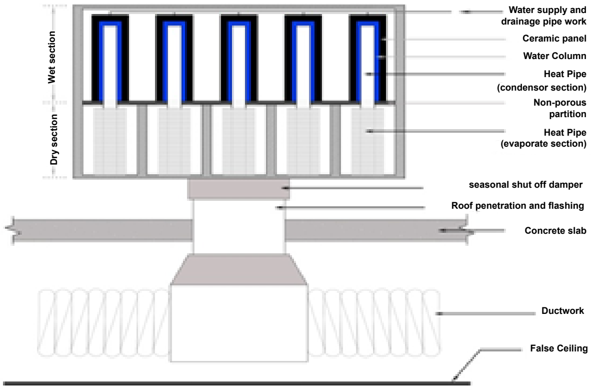

Figure 7: Roof mounted position of the proposed cooler.

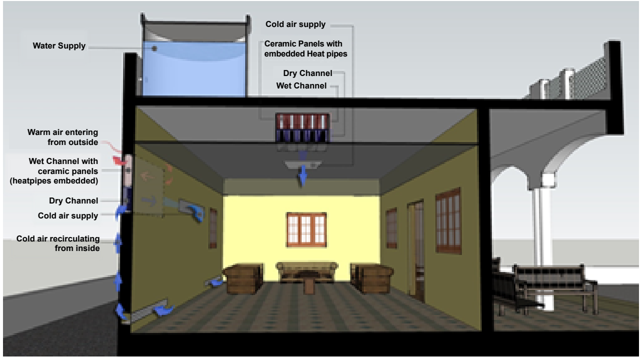

Figure 8: Ceramic panels cooling: Roof and wall cooling systems.

than commercial units but the basic components of a supply fan, water sump, sump pump, water distribution header and both pad and rigid wetted media are very similar. Many residences use Direct Evaporative Coolers (DEC), but the using of Indirect Evaporative Coolers (IEC) are becoming more accepted by users who want lower discharge temperatures and more available cooling hours [11].

The cooler should be selected depending on the type of the building and the space. Spacious villas with hallways and multiple rooms should be cooled with ducted systems. The cooler connects ductworks, which distributes the air to different rooms. However, central-location installations are used for compact small houses, which are open from room to room. Otherwise, small, portable horizontal-flow Evaporative Coolers on wheels is available as well and installed to cool a room or section of a home. The units have the advantage of portability; however, its relative small size will affect its cooling ability, which is also limited by the humidity within the targeting space. Generally, these units will provide only a slight cooling effect, especially in very hot climate.

Location and orientation of the evaporative cooler

Location: The location is a very important factor for the efficiency as well as the conception and design of the cooler. When the cooler is correctly positioned, comfort will be improved, energy bills will be decreased and occupants will get the good cooling performance of the space. The evaporative cooling system can be located as roof mounting or/ and wall mounting.

Roof mounting: Most Evaporative Coolers are mounted on the roof, as shown in Figure 7, and have a blower that discharges out of the cooler bottom (called a down-discharge cooler).

Rooftop installations represent a reasonable compromisation between first-cost and maintenance considerations. However, problems can occurs with this position such us roof deterioration, caused by routine maintenance trips and its effectiveness will be about 1°F less than a shaded cooler [12]. However in term of efficiency and supply air distribution, this solution remains effective. If ECs with ceramic and heat pipe exchangers is considered, the whole system can be fixed on the roof as a compact unit, as shown below, then, the supply air will be ducted, using ductworks supports, to the room ceiling. The roof space should be ventilated to allow built up heat to dissipate. Even in cooler climates a minimal amount of ventilation is desirable to allow built up moisture to escape. Sufficient ventilation is often achieved through the air gaps along the ridgeline or between tiles. Gable or eaves vents may also be used. However, in high humid climate, ventilation metal roofing can result in excessive condensation at night. Condensation dripping off the underside of metal roofing onto the ceiling can be avoided by installing reflective foil insulation [13].

Wall mounting: Wall cooling systems are similar to the roof

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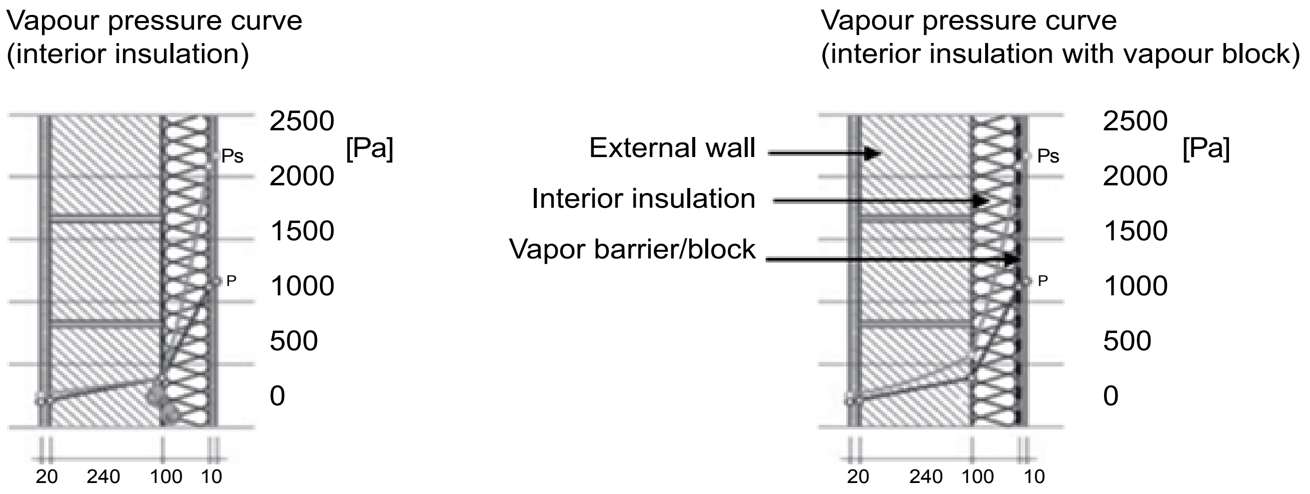

Figure 9: Vapor pressure curve of two systems: without vapor block and using vapor block

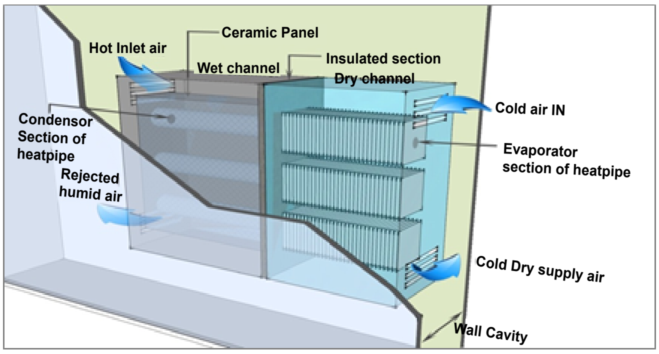

Figure 10: Proposed design of the integrated Wall/ Ceiling SWBT Evaporative Cooler [20].

Figure 11: The integration of the SWBT Evaporative Cooling systems: wall and roof mounting.

cooling, since they require the same type of installation and join the same operation restrictions. Otherwise, they can be combined, as shown in Figure 8, the wall-mounted system is placed on the invisible cavity, the dry channel is connected to the supply grill, and the warm humid air will be pulled outside the home using return grill. Considering residential buildings, with large rooms, it makes sense to fit the wall cooling system to two opposite walls. This is because the radiating effect of the body decreases with the square of the distance. It is also important to consider how the room is divided and set out when arranging energy distribution surfaces. When planning wall-cooling surface, any wall-mounted fitting such as shelves or wall cupboards, should be considered. The wall cooling system should not extend to these areas, as any furniture can prevent the energy-distributing surface from delivering cold. Otherwise, any possible attachment or drilling points would have to be included in the plans.

During cooling, it is important to ensure that the cooling system operates within an average temperature range above the dew point temperature. The Temperature of the water circulating inside ceramic panels should lie between 16°C and 19°C. Otherwise, a risk of condensation can occur if the temperature is lower than 16°C , which can cause a big damage for the wall structure. To overcome this risk, interior insulation should be considered.

Floor mounting: The integration of the proposed cooler in the Floor space still not encouraging for several factors such as acceptable floor temperature, vertical air temperature difference, radiant asymmetry and dew-point temperature which may reduce the cooling capacity of a floor system in addition of the installation of the system that could be anticipated before building construction [14].

Interior insulation: Insulation works by creating a barrier to heat transfer through ceiling or walls. It improves building envelope performance by minimizing heat loss and heat gain through walls, roof and floors.

Duct heat loss can be a concern if uninsulated ductwork is used and seasonal dampers are not tight. Adding exterior duct insulation to exposed rooftop ducts is a good idea since ducts become heated by the summer sun and can increase the supply air temperature 1 to 5 degrees, or more, depending on outside conditions and the exposed duct configuration [14]. Long interior duct runs will also benefit from duct insulation applied to the duct exterior. Considering the proposed SWBT EC, in addition of the used ductworks, vapor barrier system is needed to avoid penetration of moisture.

Modern, commercial painting, where single-layer walls consisting of brickwork or natural stone are involved, may be used on facades to avoid moisture penetration from outside [15]. The air in the wet channel is rejected at a saturation state, however, below the dew point temperature, the water vapor starts to condense and moisture starts to appear on the internal wall surface [1]. To avoid wall damage, vapor block/barrier should be attached on the top of the interior insulation, as shown in Figure 9, keeps the vapor on the 'warm side'. The vapor barrier's connection points should be watertight [16].

Orientation: Good orientation increases the energy efficiency of a cooling system making the space more comfortable to live in and cheaper to run. A good orientation leads to the decreasing of the need of auxiliary cooling. In Middle East Countries, with high humid climates and where no winter heating is required, orientation should aim to exclude sun year round and maximize exposure to cooling convective breezes.

Maintenance: (a) By draining and cleaning the Evaporative Cooler regularly, the homeowner will save a lot of works and money. Coolers need major cleaning; sediment and minerals should be removed steadily, especially during the cooling season. Otherwise, predictive maintenance should be applied at specified periods including partial or complete overhauls [17]. (b) Depending on the installation of the cooler system, the maintenance operation will be more or less simple and effective [18]. For example if the floor-mounted cooler is considered, the mechanical system is totally implemented on the basement space, so the accessibility is highly limited. Otherwise roof-mounted system is more accessible. (c) In the Middle East countries, in which hot climate is a dominant; cooler operates much of the time, it's important to look at the pads, filters reservoirs and pump at least once a month. Some rigid pads, such as ceramic, can be cleaned with soap and water or a wick of acid according to the manufacturer's instructions [19]. (d) Ordinarily, the cooler pads should be replaced every year. However, the proposed cooler integrates ceramic porous material as a rigid pad, which is extremely durable and doesn't need to be removed.

Design: The SWBT Evaporative Cooling system can be designed to suit any environment, ranging from a simple comfort cooling system within an office to complex clean room environments. The design will depend essentially on the type of the evaporative cooling and also of the space to be cooled and the position of the cooler.

As mentioned before, the cooler placed in the cavity wall will be composed of the wet channel, which should be insulated using vapor block to avoid the wall deterioration. The dry channel will be directly connected or using ductworks, to the living space as shown in Figures 10 and 11. If the system is wall mounted, it can perform the cooling for two adjacent spaces such as sacred buildings, municipal buildings, condominiums, multi-family, detached or semi-detached houses.

If the Cooler will be designed as a portable unit, the channels will be same as the integrated cooler however the vents will be bigger. Portable unit present the big advantage of accessibility of different components of the cooler for eventual maintenance operation, however the efficiency of the portable unit is less than the centralized integrated ones. This type of cooler is valid for attached, semi-attached and separated villas, which are the common building pattern in the GCC countries.

Results and Discussion

In architecture, a passive cooling refers to a building that uses no energy-consuming technology or devices in order to help maintain a comfortable inside temperature. The way energy is produced, distributed and consumed around the world is currently undergoing fundamental change of almost unprecedented proportion. Many countries struggle to upgrade their energy systems to fully support current and future requirements of energy security and access, sustainability and economic growth. In the Middle East in general and GCC in particular, a huge revolution in building construction sector is taking place. The building authority established a topic of sustainability to be involved in building design process. A new approach, built on environmentally sustainable building construction principles by adapting efficient energy use is developed in many sustainability assessment tools in the region.

The integration of Indirect Evaporative Cooling system will result in enhanced living conditions and lower running costs of buildings, and protection of the environment for the public. It has the advantage of supplying cool air at constant moisture content. With indirect evaporative cooling, a secondary air stream is cooled by water [20]. The cooled secondary air stream goes through a heat exchanger, where it cools the primary air stream. A blower circulates the cooled primary air stream.

A Sub-wet bulb temperature indirect evaporative cooling can be implemented within the construction wall or roof to have the best cooling performance. The system is suitable for the different building types that can be built in a large variety of configurations such as: single-family houses and various types of attached or multi-user dwellings.

Conclusion

The annual average electricity consumed per capita in Middle East is very high. If sustainability is to be attained, it has to address energy consumption and saving in both new building and the existing stock.

This paper presents two stages Sub-Wet Bulb Temperature Evaporative Cooler (SWB EC) using porous ceramic and heat pipes as heat exchangers media. Sizing of the main component of the proposed cooler and its possible disposition is presented and the way of integration into contemporary architecture is discussed. The paper shows that depending on the cooling load, the size of the cooler unit can be concluded. This is including the sizing of the ceramic panels and the heat pipes integration. An integrated small-scale heat pipe-ceramic evaporative cooler has been experimented. The result mainly depicts that the ceramic wet area available was not sufficient for the airflow in the wet channel to reach saturation conditions. However, the idea of using heat pipes presents a number of advantages in that effective heat transfer between the two air flows has been achieved. A dry bulb temperature of the air flow in the dry channel dropped by 5°C though the effectiveness was moderate.

According to the position of the Sub Wet Bulb Temperature Evaporative Cooler, severe factors should be considered such as ducts position and type, insulation, etc. The maintenance interventions (the accessibility of the cooler and its different components) are also the most important acts that should be taken into account.

The originality of the proposed cooling system remains in its simplicity of operation and its energy efficiency in hot humid climate, which make it suitable for integration into contemporary architecture of the Middle East in general and GCC in particular.

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