Review

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Review

Review on Evaporative Cooling Systems for Application in Buildings in Hot and Dry Climates

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Abstract: Numerous studies on evaporative cooling systems have been conducted globally, but there is a scarcity of investigations in eastern Africa. The few studies undertaken in this region have primarily focused on their application in food storage and preservation, rather than for building purpose. The goal of this study is to review the most recent advancements in evaporative cooling technology, which would be relevant in eastern Ethiopia and could provide adequate cooling, give adequate thermal comfort, use less energy, and minimize environmental effect in hot and dry areas. There aren't many studies on evaporative cooling systems for building applications in Eastern Africa as a whole, thus this review has taken into account studies conducted in regions with climates similar to eastern Ethiopia. This study covers the classification, operation, and performance of evaporative cooling systems in hot and dry climate. Evaporative cooling systems work well in hot and dry climates, as revealed by this review study.

Keywords: building; evaporative cooling system; hybrid; effectiveness; hot-dry climate

1. Introduction

The world's energy crisis has been getting worse every day, affecting households, companies, and entire economies everywhere. The high cost of fuel, of which natural gas accounts for more than half, is responsible for 90% of the increase in the average cost of producing electricity globally [1]. Price and economic pressure are major barriers to people accessing modern electricity [1].

The world is currently very concerned about the rapid depletion of energy supplies and the significant emissions of greenhouse gases that caused climate change. In some regions, extreme heat waves and droughts are becoming more common [7]. Because of the increase in global warming, building cooling load has also increased dramatically. As a result, using an air conditioning system is essential for maintaining the building's internal thermal comfort. However, the majority of heating, ventilation and air conditioning (HVAC) systems consume a lot of electricity.

In Sub-Saharan Africa, 43% of the people do not yet have access to electricity [2]. Despite having about 18% of the world's population, Africa uses less than 6% of the energy produced worldwide [2]. In Ethiopia, a country in Sub-Saharan Africa, only 45% of people have access to electricity [3]. As of 2019, the country's urban and rural areas are respectively 75% and 14% electrified [4]. Furthermore, almost 96% of Ethiopians do not have access to clean cooking technology or fuels [5]. Ethiopia nevertheless has a large potential for renewable energy because of its 45 GW of hydropower, 10 GW of wind, 5 GW of geothermal, and 4.5 - 7.5 kWh/m^2/day of sun irradiation ranges [6].

It is difficult for underdeveloped nations like Ethiopia to use conventional air conditioning (HVAC) systems due to limited access to electricity and the high upfront and operational costs associated with these systems. To tackle this problem in developing countries, energy-efficient technology and solutions for both new and old buildings must be given top priority. An evaporative

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cooling system is one energy-efficient technique that works well in a variety of climates [8]. Furthermore, a solar powered evaporative cooling system could also be a useful way to address the lack of electricity in underdeveloped nations like Ethiopia, which have abundant solar energy. Evaporative cooling systems work better than air conditioning, typically in hot-dry climates [9]. Evaporative cooling is widely used in both residential and commercial buildings, particularly in hot-dry areas like, the Middle East, the South western United States, Australia, the Indian subcontinent, Northern Mexico, Northwest China, and Eastern Africa [10].

Evaporative cooling systems can be broadly classified into two categories: direct and indirect. Direct Evaporative Cooling (DEC), which is frequently applied to home systems, lowers the air's moisture content by evaporating water [11]. For an Indirect Evaporative Cooling (IEC), the supply air was passively cooled by passing over a medium before entering the space. Therefore, unlike DEC systems, moisture is not supplied to the supply air stream. For the best performance, IEC systems were always combined with direct evaporative cooling systems or other cooling mechanisms; this configuration is known as a hybrid evaporative cooling system [12]. The comparison of the performance (COP) of an evaporative cooling system is about 15 – 20, which is higher than other refrigeration cooling techniques [19]. Table 1 displays the COP values for thermoelectric, evaporative, vapor compression, and vapor absorption cooling systems.

The objective of this review is to assess the most current advancements in evaporative cooling technologies, which have the potential to be environmentally friendly, energy-efficient, and capable of providing adequate thermal comfort in hot and dry climates. Therefore, numerous research approaches suitable for building applications and applicable in developing countries like Ethiopia were considered. Research articles indexed in Scopus, Web of Science, PubMed, Google Scholar, etc. have been considered in this review study.

Table 1. COP value for some air conditioning systems [9].

System type	Vapor Compression Cooling	Vapor Absorption Cooling	Thermoelectric Cooling	Evaporative Cooling
COP	2.0 – 4.0	0.60 - 1.20	0.20- 1.20	15.0 – 20.0

2. Climate and Comfort Condition

Climate zones are categorized using the Koppen climate classification method, which divides climates into five main groups based on seasonal patterns of temperature and precipitation. Tropical is represented by A, dry by B, temperate by C, continental by D, and polar by E [13]. The Koppen climatic classification mostly assigns the eastern part of Ethiopia to Warm Semi-Arid climatic (BSh) and Warm Desert Climate (BWh). Eastern part of Ethiopia is more widely referred to as a hot and dry climate. Ethiopia's Koppen climatic categorization is shown in Figure 1.

Human thermal comfort is characterized as a mood that expresses contentment with the surroundings. High temperatures along with elevated humidity can cause pain and in certain cases, heat stress. Furthermore, heat stress and pain cause workers to be less productive and can even cause more serious health issues, particularly in older workers [14].

The human body feels comfortable when a proper combination of air temperature, relative humidity, and motion of air is present in the occupied space. Between 22 to 27 degrees Celsius and between forty to sixty percent relative humidity, humans often feel comfortable [15]. The environment becomes hostile when the relative humidity falls below or rises over the specified range. Therefore, it is important to use cooling mechanisms to keep humans comfortable in hot and dry climate conditions.

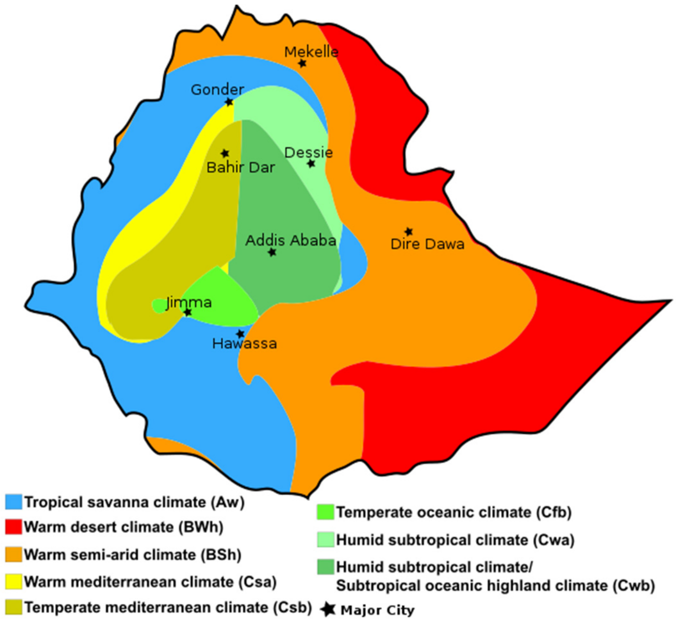

Figure 1. The Koppen-Geiger climate classification in Ethiopia [13].

3. Evaporative Cooling Technology

An evaporative cooling system is broadly categorized as direct, indirect, and combined/hybrid evaporative cooling. When using an IEC system, there is no moisture addition to the area as there is with a direct system. Direct and indirect evaporative cooling systems, as well as any other cooling mechanism like the hybrid systems are used to provide heat rejection and lower water and energy usage.

4. Thermodynamics of Evaporative Cooling

The working principle behind evaporative cooling is the thermodynamics of water evaporation or the transformation of water from a liquid phase into a vapor. The evaporation process is endothermic since it involves a phase shift that demands energy. This energy, which comes from the internal energy of water, is known as latent heat of vaporization. Therefore, throughout the process, the air and the water both cool.

Since there is typically very little heat exchange between the airstream and its surroundings, evaporative cooling is best described as an adiabatic process. On the psychometric chart, the evaporative cooling process thus follows a line of constant wet-bulb temperature. Since the lines for constant enthalpy and wet bulb temperature in the psychometric figure nearly overlap, it is also possible to assume that the enthalpy of the airstream will remain constant (H ≅ constant) [16]. Air cooling calculations frequently employ this approximation since it is reasonably precise.

$$T_{wb} \cong \text{Constant} \tag{1}$$

$$H \cong \text{Constant} \tag{2}$$

The humidity in the air can be determined using the dew point temperature [17]. The dew point can be found by decreasing the surface temperature to a point where water starts to condense. Dew point can then be determined by taking a surface temperature measurement [17].

The temperature decrease achieved is one of most crucial data points for evaluating the performance of evaporative cooling systems. By measuring the difference between the DBT at the inlet (Tin) and outlet (Tout), or the saturation effectiveness (ε), we can determine the maximum temperature decreased that can be obtained in an adiabatic process. Saturation effectiveness can be expressed as the variation between the ambient air's DBT (Tin) and WBT ($T_{wb,in}$) [49]. The amount of moisture that the media may evaporatibly release into the air is what is meant by the term "Cooling Efficiency," which is another name for saturation effectiveness. And can be computed by applying Equation (3).

$$\varepsilon = \frac{T_{in} - T_{out}}{T_{in} - T_{wb,in}} \tag{3}$$

Cooling capacity (CC) is another helpful metric to describe cooling performance. The ability of the system to cool a certain airstream is better described by this parameter [49].

$$CC = \dot{m}_a \cdot C_{pa} \cdot (T_{in} - T_{out}) \tag{4}$$

Where: $\dot{m}_a$ is air mass flow rate in $\frac{kg}{s}$, and C_{pa} is the specific heat of air in $\frac{J}{Kg.K}$

To assess the energy consumption rate of air handling equipment by industry, the Energy Efficiency Ratio (EER) was established [18]. The energy efficiency ratio is expressed as the amount of thermal energy taken from the air for cooling purposes over watt of energy used.

$$E_{ER} = \frac{\Delta H}{P} = \frac{\text{Cooling Capacity}}{\text{Power consumed}} \tag{5}$$

Where: ΔH is change in enthalpy across the cooling pad and P is the electrical power input for the exhaust fan and water pump in kW [18].

5. Classification of Evaporative Cooler

Evaporative cooling system is broadly categorized as direct, indirect, and combined/hybrid evaporative cooling. Direct evaporative cooling systems are classified as active and passive depending on their driven mechanism and whether they are power-consuming or not. Indirect evaporative cooling systems are also classified as wet-bulb and sub-wet bulb systems depending on the heat exchange mechanism between the primary and secondary working fluid. The combined/hybrid evaporative cooling system is further classified as two-stage, three-stage, and multi-stage hybrid evaporative cooling system based on its working principle. Figure 2 illustrates the classification of evaporative cooling systems.

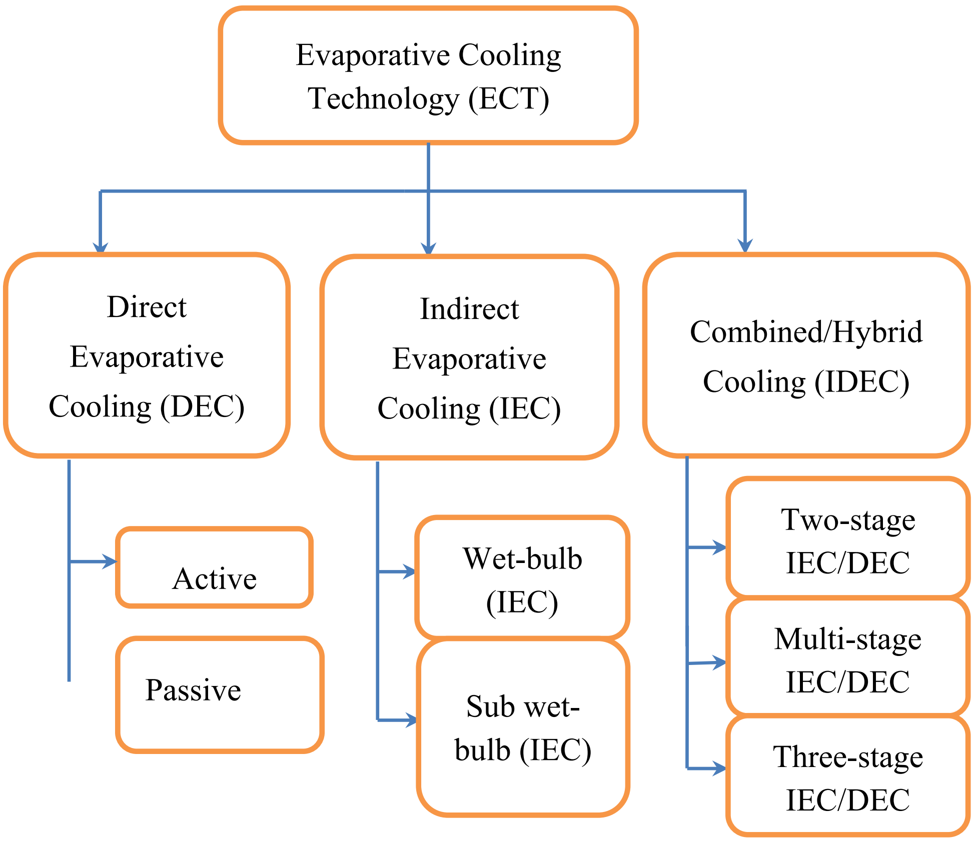

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Figure 2. The general classification of evaporative cooling systems.

5.1. Direct Evaporative Cooling (DEC)

The most basic and conventional kind of evaporative cooling is direct systems, where water and outdoor air come into direct contact. The technique is just cooling air by converting form of energy (sensible energy into latent energy). For hot and dry areas, direct evaporation cooling systems are appropriate. Relative humidity can rise to 80% in damp situations. Because of the potential for warping, corrosion, and mildew in sensitive materials, direct supply of such high humidity into building is not recommended [9]. DEC systems can be further subdivided into two categories: Passive DECs, which are naturally operated, and Active DECs, which run on electricity [9]. The active direct evaporative cooling systems are propelled by electrical systems for water and air circulation. However, when compared to vapor compression systems, active direct ECS are considered less energy-intensive systems with the possibility of saving up to 90% in energy [19].

Energy is not needed for the passive direct ECS to operate and utilize natural phenomena. Nevertheless, they might need pumps or fans with a modest capacity. The climate has an impact on this kind of system. This kind of device is said to be able to lower interior air temperatures by roughly 9 °C [20]. Figure 3 shows the schematic diagram for DEC systems.

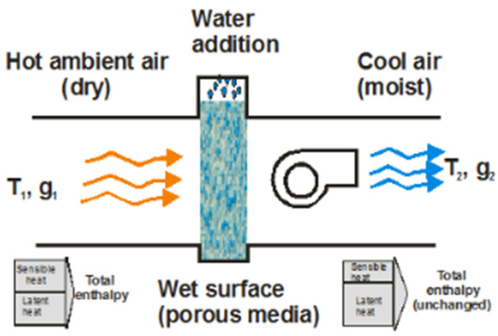

Figure 3. DEC Systems Schematic Diagram [40].

For arid as well as semi-arid climates, direct evaporative cooling can be taken as an energy effective air conditioning alternative [21]. The materials and construction qualities of commercialized evaporative cooling pads differ. The velocity of air, pad thickness, pad geometry and layout, and water flow rate are the most researched factors of evaporative cooling pad operation [21]. Typical performance indicators of the pad include its saturation effectiveness, temperature drop, the treated air's increased humidity, water evaporation and consumption, and cooling capacity [21].

Temperature variation and air relative humidity have a significant effect on the efficiency of evaporative cooling techniques compared with different roof heat gain reducing techniques. [22]. There are positive results when evaporative cooling systems are used in arid areas like BSk and BWh, but the benefits are modest in humid equatorial climates [22].

P. A. Dogramac [23] experimentally determined the performance of five new natural porous materials to see how well they performed when used for DEC systems in hot and dry areas. The materials consist of Cyprus Marble (CM), Ceramic Pipes (CP), Dry Bulrush Basket (DBB), Yellow Stone (YS), and Eucalyptus Fibers (EF) [23]. EF and CP were identified as the most potential candidates, with efficacy values ranging from 72% to 33% and 68% to 26%, cooling capacity varying between 0.13 kW and 0.71 kW, and 0.12 kW to 0.55 kW, with air velocities ranging from 0.1 to 1.2 m/s. YS was also considered a competitive material, with effectiveness and cooling capacity falling within the range of 46% to 22% and 0.08 kW to 0.48 kW, respectively, for similar air velocities.

Using experimental research, the effectiveness of direct evaporative cooling systems with and without dehumidifying pads was assessed and compared [24]. The suggested system's maximum ability to cool, efficiency, and Coefficient of Performance (COP) without the dehumidifying pad were 3.84 kW, 84.6 percent, and 16.1, respectively. Comparable values with the system operating with a dehumidifying pad were 3.2 kW, 71.4 percent, and 13.4 [24]. More water can evaporate into the surrounding air due to the decreased relative humidity, which leads to increased water usage. The total amount of water used on the experimental day was 8.93 L, resulting in an average daily water consumption of 0.99 L/h when the system is not equipped with a dehumidifying pad [24]. An average of 1.08 L/h water consumption was recorded during the experimental day when the suggested system was combined with a dehumidifying pad, for a total daily water usage of 9.73 L [24].

Two commonly used parameters for assessing the effectiveness of evaporative cooling pads are saturation efficiency and pressure drop [25]. According to A. Tejero-Gonzalez [25], future studies should take into account the impact of additional variables on the cooling efficiency of the DEC system, such as power requirement, water utilization, material decay, air quality, and the influence of water temperature and salinity.

5.2. Indirect Evaporative Cooling (IEC)

A significant benefit of IEC systems over DEC systems is the previous one use a method of cooling air by reducing sensible heat without altering its humidity. A standard IEC system consists of, a tiny fan, a heat exchanger, a pump, a water tank, and a water distribution line [9]. Figure 4 shows the typical diagram of an IEC system. The two common indirect evaporative cooling systems are wet-bulb temperature and sub-wet bulb (dew-point) temperature evaporative cooling systems [9].

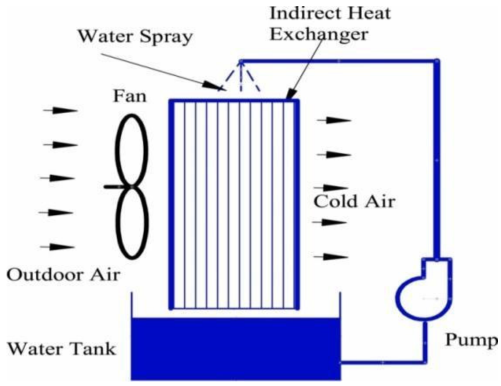

Figure 4. Schematic Diagram of IEC System [19].

5.2.1. Wet Bulb Temperature IEC

Heat exchange takes place via a heat-conductive plate in wet-bulb temperature IEC systems between primary and secondary operating fluids. Thus, no extra moisture is added up to the cooled air supply stream; the supply air is only subjected to sensible cooling. In contrast, the latent heat of vaporization is the mechanism via which heat is transferred between the working air and the water in wet channels [26–28]. Figure 5 shows the schematic structure and working principles of a typical wet-bulb temperature IEC system.

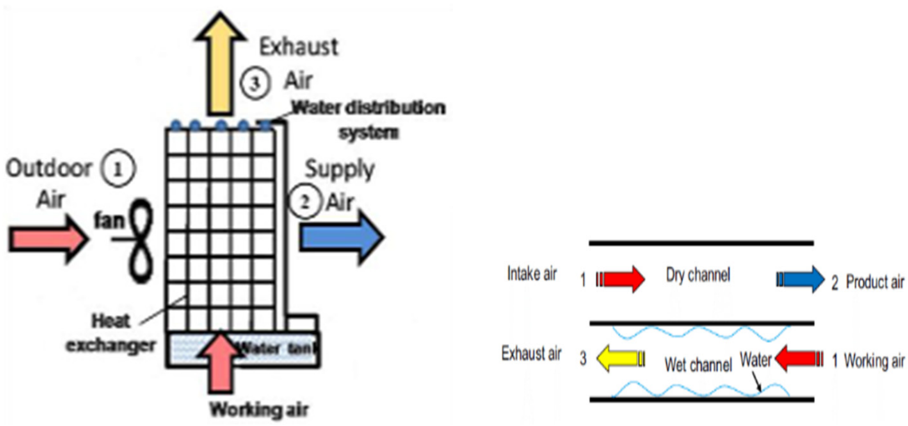

Figure 5. Schematic Structure and Working Principles of Wet bulb temperature IEC [9].

5.2.2. Sub-Wet Bulb Temperature IEC

Recent researches have focused on lowering air temperatures below the ambient air wet bulb temperature to enhance the indirect evaporative cooling system's cooling capacity [29].

Sub-wet bulb temperature IEC system also known as Maisotsenko cycle (M-cycle). This system combines evaporative cooling with a cross-flow multi-perforated flat plate heat exchanger. As illustrated in Figure 6, the secondary air must be pre-cooled in the dry channel before being redirected to pass through the wet channel. Consequently, the primary air temperature is lower than the wet-bulb temperature and is closer to the entering air's dew point temperature [9]. As compare to conventional heat exchangers, the M-cycle heat exchanger is 10–30% more effective [30].

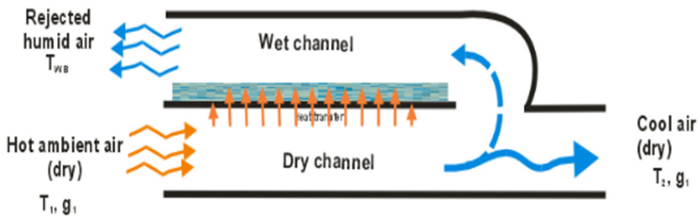

Figure 6. Schematic diagram of sub-wet bulb temperature IEC [31].

U. Sajjad et al. [32] examined the performance of advanced IEC systems, comprising Maisotsenko cycle coolers, dew point coolers, regenerative IECs, and conventional indirect evaporative coolers. According to this review work, evaporative material, air passage geometry, inlet air flow situation, and the system's configuration are essential factors to consider when designing an IEC system for greater efficiency and cooling capacity [32]. In the future, IEC systems may replace the conventional cooling systems used in buildings and other applications [32].

A parametric study was carried out to determine the performance of a cross-flow IEC using computational fluid dynamics [33]. According to this study, the humidity and temperature distribution of the suggested 3D model improved by 5.8% and 6.7% respectively, as compared to a 2D model [33].

T. Sun [34] analyzed the performance of new material on a tubular porous ceramic IEC using theoretical and experimental methods. A number of structural and operational factors were taken into account when doing the performance analysis, including the working/output air volume ratio, wall thickness, wet-bulb temperature reduction, and tube length and spacing. In conclusion, as compared to other parameters, the tube length significantly affects the cooling efficiency of IEC [34].

Experimental analysis in real climate conditions was carried out on dew point IEC, which comprises of a heat and mass exchanger built from a locally accessible polymer material, to see how effective it is [35]. The result shows that the performance of the dew point IEC system increases with the increase in the ambient temperature and decreases with the increase in the relative humidity of air [35]. The author suggests the proposed system can be used for residential cooling purposes [35].

The effectiveness of Regeneration Indirect Evaporative Cooling (RIEC) systems under variable inlet air conditions was examined using experimental and mathematical modeling [36]. The dew point effectiveness in this investigation is 0.91, indicating a considerable degree of cooling was accomplished [36]. The proposed system is also recommended for use as a model to examine the overall global behavior of RIEC [36].

The performance of combined/ hybrid cooling systems (IEC systems in combination with other cooling mechanisms) was examined experimentally for the application in hot-dry areas [37]. The outcomes indicate that the combination of IEC with thermal insulation and nocturnal radiative cooling had better cooling potential as compared to other possible combinations [37].

A new regenerative evaporative cooler performance was assessed using mathematical model and experiment conducted under carefully controlled laboratory environment [38]. The experimental

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result shows that the system is suitable for arid climates under typical ambient conditions because the temperature of cooled air supplied was 14°C less than the ambient air [38].

Parametric analysis was carried out to evaluate the effect of working air ratio, inlet temperature, and air passage length on the design of a dew point cooler [39]. The proposed system was designed for application in French and Algerian climate conditions. According to this study, dew point coolers can supply air at a temperature below that of the ambient wet-bulb temperature [39]. The result of this study shows that, there is a strong agreement between the simulated results and the experimental results in the literature review [39].

Experimental research was done to investigate the effectiveness of indirect evaporative cooling systems for the application in hot and dry areas [40]. The wet medium is made of porous/fired clay, and the working and supply air are arranged in counter flowing channels [40]. The result of this study demonstrates that the IEC would accomplish overall wet bulb effectiveness more than unity and a cooling capacity is about 27 W/m^2. Because of its performance, the system could be used in place of building air cooling units [40].

The effectiveness of a sub-wet bulb temperature IEC system was determined using computer modeling and validated with experiment tests to apply for building space cooling [41]. The result indicates that the proposed system may be able to replace conventional mechanical air conditioning systems in buildings in hot-dry areas [41].

5.3. Combined/Hybrid/ Evaporative Cooling System

Hybrid evaporative cooling systems integrate both IEC and DEC methods. DEC is highly effective but raises indoor humidity levels, whereas IEC is less effective but maintains constant humidity in the supplied air. Combining these two systems, or even integrating them with other cooling technologies, can achieve a blend of their respective advantages. This integrated approach is commonly referred to as a hybrid ECS [19]. The effectiveness of hybrid evaporative cooling systems ranges between 90% and 115% [19]. However, the complexity of the system and its high initial cost ate the main advantage [19]. There are two common types of combined systems: two-stage IDEC, three-stage IDEC and multi-stage IDEC.

5.3.1. Two-Stage IDEC

The two-stage evaporative cooling system produces colder air compared to single-stage system working alone. Due to its ability to maintain a more ideal range of indoor humidity, the two-stage systems often offer more comfort than conventional system [9]. In an advanced two-stage evaporative cooler, a variable speed blower circulates cool air using 100% outside air. Two-stage evaporative coolers can save energy usage by 60 – 75 percent compared to conventional air conditioning systems [42]. Figure 7 illustrates the schematic diagram of the two-stage IDEC system.

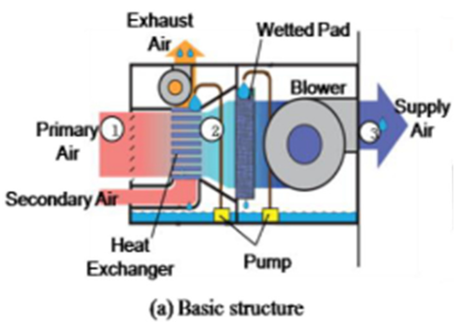

Figure 7. Schematic structure of two-stage IDEC [6].

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5.3.2. Three-Stage IEC/DEC

Three-stage IDEC systems consist of a two-stage IDEC system in combination with a cooling cycle. An IEC and/or DEC together with a solid desiccant dehumidification system can achieve a COP of around 20 [9]. By combining an IEC and a DEC together with a desiccant dehumidification system that provides sensible and adiabatic cooling, the system can be capable of achieving energy savings of 54%-82% over the conventional cooling systems [9]. Figure 8 illustrates the schematic diagram of solid desiccant and evaporative cooling systems.

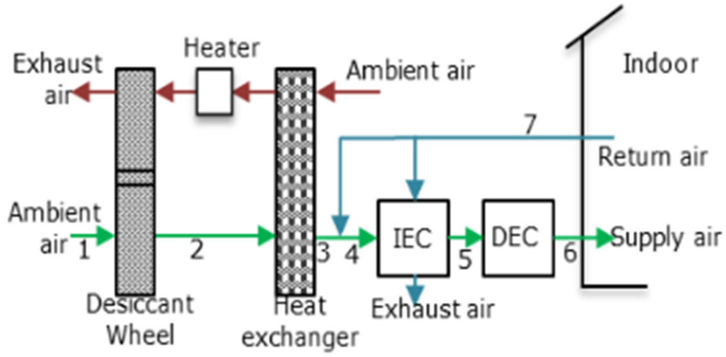
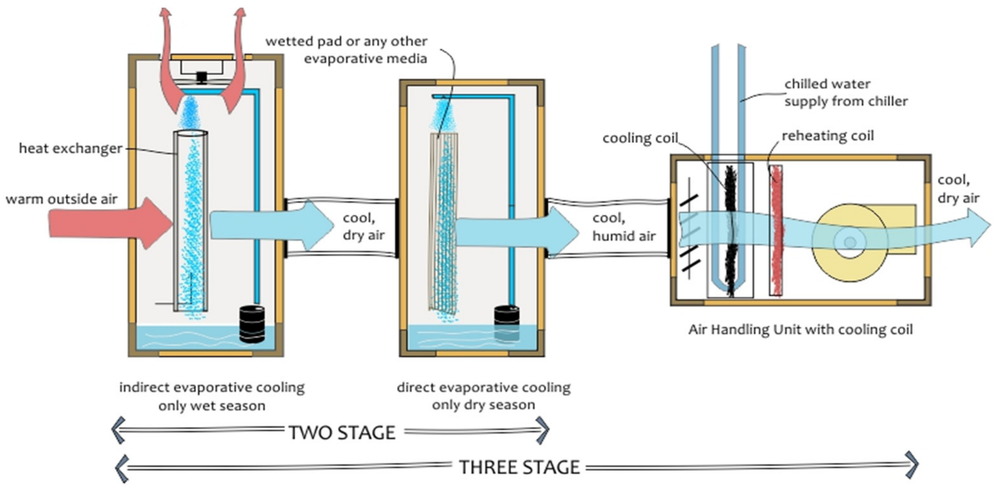


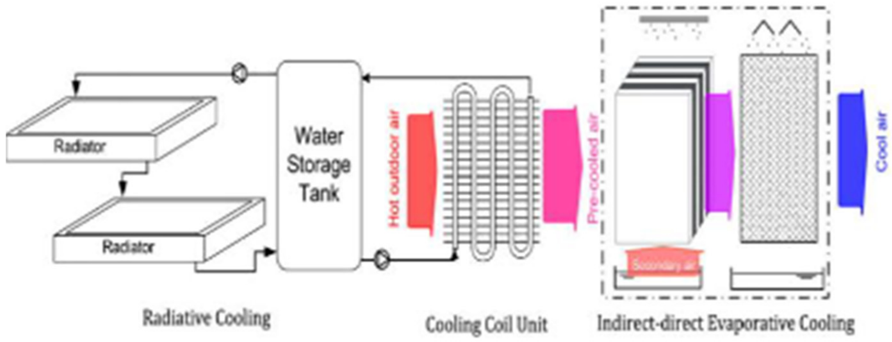
Figure 8. Schematic of solid desiccant and evaporative cooling systems [9].

5.3.3. Multi-Stage IDEC

Multi-stage IDEC is a combined system of a two-stage IDEC and multiple cooling cycles, as shown in Figure 9a. For example, a system that combines a two-stage IDEC system with nocturnal radiative cooling. A cooling coil of Multi-stage IDEC is more effective than two-stage evaporative cooling systems. The energy saving capacity of this system is range in 75-79% compared to mechanical vapor compression (MVC) systems [9]. Figure 9b illustrates the hybrid system of radiative cooling, cooling coil, and two-stage IDEC system.



(a)



(**b**)

Figure 9. a. Schematic diagram of a Multi-stage evaporative cooling system [47]. **b**. Hybrid system of radiative cooling, cooling coil, and two-stage IDEC system [9].

Q. Chen [43] reviewed the most recent research on the hybrid IEC-MVC system and compared its efficiency with standalone MVC cooling system. In addition, the paper explains the potential of this hybrid system for long-term energy savings under particular climate conditions. Furthermore, the author discussed the water consumption and economic feasibility of the proposed hybrid system [43]. Water consumption poses a significant challenge in arid regions experiencing severe water scarcity. The typical method to decrease water usage is by recovering the condensate from the mechanical vapor compression unit [43].

Theoretically evaluate the efficiency and water usage of a new hybrid system, which combines an IEC with an underground air tunnel [44]. The plan for the future involves replacing the vapor compression cooling cycle with this innovative hybrid system [44]. The proposed system's cooling performance is evaluated using finite difference full implicit method [44]. The simulation results of this study indicate the cooling efficiency is improved and the water consumption is highly reduced by connecting the underground heat exchanger to an IE cooler [44].

The performance of IEC systems integrated with the latent heat thermal energy storage (LHTES) is determined using thermodynamics analysis [45]. The modeling results show that the studied hybrid system can simultaneously dehumidify and pre-cool the ambient air in tropical regions. The surrounding air temperature can be lower by 6-10 ^{o}C and humidity ratio also reduced by 2-11g/kg of dry air within specific operating ranges [45].

The combined effectiveness of M-cycle counter-flow heat exchanger and a solar-assisted desiccant dehumidifier was conducted experimentally [46]. The solar collector efficiency and solar fraction of the hybrid solar thermal collector design were examined. The technological, economic, environmental, and climatic benefits of solar thermal system combined with other renewable energy dependent cooling techniques were discussed [46]. After evaluation, the suggested hybrid system's maximum cooling capacity is determined to be 4.6 kW [46].

6. Evaporative Roof Cooling System

The purpose of an evaporative roof cooling system is to lower the temperature of a roof within a specific range. In this system, the building's roof is utilized to expel heat. Heat is extracted from the building through water evaporation in evaporative roof cooling systems [48].

Roof cooling is one of the green cooling technologies, which can be constructed by applying an optimal water spray system and cooling water installation in direct evaporative cooling systems [49]. The domes' diameter and the cooling channel's dimensions considerably impact the thermal efficiency of passive DEC systems with domed roofs [50].

S. Sakdawattananon [51] studied numerically the performance of uncovered roof ponds, which is a type of passive IEC system with and without water flow. This research determines the impact of ambient temperature, solar radiation, and constant water evaporation on the thermal performance of uncovered roof ponds. The results indicated that an uncovered roof pond with a water depth of 0.2

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meters effectively prevented heat flow into the building. Additionally, a roof pond with water flow ranging from 0.1 to 0.4 meters was able to remove heat from the roof through water circulation [51].

The effectiveness of an IEC and rooftop sprinkler was determined with respect to temperature reduction and capacity of cooling [52]. According to the modeling results, the indirect evaporative cooler lowers the inside temperature by 9.2 °C, However, the temperature is only lowered by 4.4 °C by the rooftop sprinkler system. [52].

The cooling potential of an IEC system and a roof pond with wet fabric membranes and floating fiber (gunny bags) was experimentally tested in various actual environmental conditions and compared to each other to create an effective building model [53]. In hot-humid climates, the performance of all proposed systems is similar. But in hot-humid areas, the wet fabric device performs better in terms of thermal efficiency than other IEC systems. [53].

A.Sharifi [54], studied the effectiveness of roof pond cooling mechanisms for heating and cooling buildings. In comparison to other types of roof pond cooling systems, the study indicated that roof ponds with wet gunny bags, shaded roof ponds, vented roof ponds, and roof ponds with movable insulation were more successful [54]. Furthermore, the author's investigation revealed that the primary factors influencing the efficacy of roof ponds were weather, water depth, roof deck material, and insulating panel thickness. [54].

7. Conclusion

This work presents a review research on evaporative cooling systems, which may be utilized to cool buildings efficiently. The review shows that, when compared to mechanical vapor compression systems, evaporative cooling is more effective, economical, and energy-efficient. The air moisture content, air flow rates, and incoming air velocity all have a significant impact on the effectiveness of evaporative cooling. Moreover, the application area and the evaporative material's thickness affect an evaporative cooling system's performance. This review illustrate that evaporative cooling systems are mostly used in dry-hot climate conditions nowadays. The performance of evaporative cooling systems, particularly the M-cycle based dew-point IEC system have demonstrated higher efficiency values and more economical in terms of energy usage. However, combined IDEC systems have similar or even better performance. Recent studies concerning IEC based on M-cycle have shown considerable potential towards increasing the performance and cooling capacity of IEC systems for building air conditioning.

8. Future Direction

This review work investigate that there is few research activities on evaporative cooling systems in eastern Ethiopia and also eastern Africa as a whole. Most of these researches have focused on applying evaporative cooling systems for food storage and preservation rather than for buildings air conditioning. Due to the lack of research activities on evaporative cooling systems for building air conditioning applications in eastern Africa, this review considers research performed in regions with similar climates to East Africa. Regarding this, the author recommends researchers conduct a feasibility study on the use of evaporative cooling systems for air conditioning in eastern Ethiopia and throughout eastern Africa.

Author Contribution: Investigation, M.G.; resources, M.G.; writing-original draft preparation, M.G; Writing-review and editing, R.G. and A.M.

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