The need for low-humidity in mechanical applications and human comfort with the concept of Zero Humidity Added Air Cooler (ZHAC): A review

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Abstract— **This paperwork emphasizes the need for a lower humidity environment in both mechanical applications and human life, along with various ways to achieve it. Additionally, a concept of a zero humidity added air cooler that helps maintain a lower humidity level is proposed in this work. Humidity is one of the extrinsic properties that is generally ignored in the design, analysis, and operation of most mechanical systems [7]. However, if not controlled appropriately, it can have adverse effects. A brief description of conventional methods used to address this issue such as refrigeration-based dehumidification, desiccant dehumidification, ventilation with dry air, and membrane dehumidification for mechanical systems, as well as air conditioning with built-in dehumidification, exhaust fans, and evaporative air coolers for human comfort is also provided. Various types of evaporative air coolers are mentioned, which are applied for different purposes based on the need. Scientific data on how humidity affects human psychological behaviour and health is presented using genuine research articles. Similarly, the impact of humidity on mechanical systems whether beneficial or harmful is also discussed.**

Furthermore, the zero humidity added air cooler is described as a modified version of the normal evaporative air cooler that works in a different way with the aim of not increasing the humidity in the supplied air. A brief overview of the concept, method, working principle, and predicted results of the zero humidity added air cooler is included. Finally, a full comparison between traditional methods for achieving lower humidity and the zero-humidity added air cooler concept is discussed with how this modified system gives positive impact.

Index Terms— **Air Dehumidification, Evaporative Air Cooler, Humidity Control, Low Humidity Environment, Zero Humidity Added Air Cooler**

I. INTRODUCTION

Humidity, in simple terms, can be defined as the concentration of water vapor present in the air [15]. In highly accurate and precise project works, such as those involving vacuum environments and data storage components, this factor is taken into careful consideration. However, on a small scale or in less precise works, humidity is generally ignored. Despite this, it can adversely affect machines and systems if not controlled. For instance, in precise CNC machines, high humidity can lead to inaccurate machining. Similarly, in data storage devices like chips and hard disks, excessive humidity may result in the loss of functionality or permanent damage.

Moreover, the negative effects of humidity are not limited to mechanical devices. It can also significantly influence human psychological behavior and health. According to one research article, increasing the relative humidity from 50% to 70% at indoor temperatures of 26°C, 30°C, and 37°C causes noticeable discomfort [34]. Particularly at 37°C, individuals tend to experience anxiety and anger due to the combined effect of high temperature and high humidity [34].

In the present time, many dehumidifying systems are in use to reduce or maintain humidity at a constant level. Generally, we use air conditioners based on vapor compression systems. However, these systems release chlorofluorocarbons (CFCs), which are extremely detrimental to both the environment and human life. To maintain lower humidity in mechanical devices, techniques such as refrigeration-based dehumidification, desiccant dehumidification, ventilation with dry air, and membrane dehumidification are applied. Unfortunately, these systems often affect the environment adversely and are sometimes not efficient enough in performance.

To replace conventional air conditioners, people frequently use evaporative air coolers. However, they require water refilling after short intervals and may also make the human skin feel oily or sticky. Therefore, there is a growing need for a device that can overcome these challenges and function effectively without harming the environment. The Zero-Humidity Added Air Cooler is a type of modified evaporative air cooler designed to bridge this gap. Further details related to various dehumidifying devices currently in use, the effects of humidity on both man and machine, and the concept of the zero humidity added air cooler are described in this work.

II. IMPORTANCE OF HUMIDITY

As proposed earlier, a simple definition of humidity is the amount of water vapor in air [15]. For the purpose of

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research work, there are two main types of humidity that are considered. One is Specific humidity (Humidity ratio): This is the total mass of water vapor in a mixture of vapor and air per unit mass of dry air. For example, it is generally expressed as grams of water per kg of dry air. For a given barometric pressure it is a function of dew point temperature alone. Another type is Relative humidity (RH), (φ): This is the ratio of the partial pressure of water vapor in the mixture to the saturated partial pressure at the dry bulb temperature. Relative humidity accounts is expressed as a percentage [15].

Moisture is pervasive and is indispensable to life. For instance, a human body is composed of 70 % water. Maintaining a balance of water in the environment surrounding air and the human body is crucial. It controls all physiological processes and defines the occupant's well-being [12].

City	Average Ambient high temperature	Relative humidity
Hyderabad	32.2°C	56%
New Delhi	31.7°C	54%
Mumbai	31.8°C	75%
Chennai	33.1°C	70%
Kolkata	31.7°C	71%
Jodhpur	33.55°C	26%

Figure.1: Temperature and humidity in different cities of India [29]

As per the above mentioned table, in hot regions like Rajasthan, humidity level is low. While in cities near to ocean have higher humidity level such as Mumbai.

Humidity is one factor that is of concern in engineering practices and environmental control as well. In engineering, precautionary measures related to control of humidity is needed so that materials will not be damaged, since excessive humid conditions will lead to Corrosion of metals which include steel, iron, copper and others susceptible due to oxidation. This further becomes very important in aerospace, automotive and construction industries where the failure of materials can pose dire consequences. Moreover, humidity can greatly change the shape and size of materials, to include wood and composites which can expand or shrink due to moisture. This, indeed, is troublesome in CNC Machining due to the precision nature of these components. Even the smallest of size errors can lead to defective products or non-functional machines.

As for the general nature of the CNC machine and other equipment, their accuracy and proper functioning is put at risk when humidity is concern. The incautious use of moisture can result in dew formation within the machinery, which renders parts short circuited, electrically disassembled or eroded. It is noted that decrease in LED lights performance may result of too much humidity [1]. Furthermore, in hydraulic and pneumatic systems, effluent water from the body of the machine serves no useful purpose and in fact, makes matters worse by causing erosion and diminished effectiveness. This shows that lack of humidity control in instruments like data capturing systems, clean chambers and laboratories, which support higher performance machinery, will lead to restraining the usefulness of immense capabilities.

There are numerous properties of metals that can be affected by humidity. These include mechanical strength, adhesion, flowability, and magnetic field. It is very necessary to completely understand these phenomena to optimize metal performance in distinct environmental conditions.

Magnetic properties**:** Humidity can change some metal assemblies' magnetic properties. To exemplify this, in cyano-bridged metal complexes, water vapor can penetrate the lattice and change the geometric coordination of cobalt ions, altering the magnetic interaction between ferromagnetic and antiferromagnetic coupling [16].

Flowability in powder metallurgy: In additive manufacturing techniques, the flowability of metallic powder is very essential and is affected by humidity levels. When humidity levels change, a noticeable difference in water content in metal powder is observed. For example, in 316L and Ti6Al4V, molecular interactions are altered.

Mechanical strength in welded parts: Mechanical joints contain their own characteristics, which may be influenced by humidity. In aluminum 5052 joints, if humidity rises, it results in welding defects like porosity and weakened tensile as well as impact strength. However, if a moderate humidity level is maintained, such defects do not occur.

Adhesion strength: Humidity can affect metal film adhesion strength on substrates like polyphenylene sulfide (PPS). In a dry environment, adhesion bonding is strong, while in wet conditions, adhesion bonding may be lost [16].

Conversely, while humidity can negatively impact certain properties, it may also enhance specific functionalities in humidity-sensitive materials, suggesting a nuanced relationship between humidity and metal properties.

Furthermore, Friction and wear are ubiquitous in daily life. Under most circumstances, friction and wear come with energy consumption and material loss. In order to reduce friction and wear and thus save energy and resources, it is vital to understand the tribological properties of materials involved in such processes in ambient conditions. It is well known that tribological properties are not just intrinsic or inherent properties of materials, but are strongly dependent on working conditions. The working condition includes not only operating parameters (contact pressure, sliding speed, and counterpart materials), but also environmental factors (temperature, humidity, and atmosphere, among others). In ambient air, the impacts of environmental factors pertain to unlubricated or solid-lubricated conditions. Among all the factors mentioned above, humidity could be the easiest one to be ignored, because the adsorption of water is invisible and it is commonly believed that reactions between water and tribo-materials are normally self-limited only to the topmost surface at ambient temperatures. Or sometime, the physis or bed water molecules at the sliding interface are considered as a lubricant. Although reasonable based on common sense, it could be wrong if interfacial stress is involved. During the process of rubbing or sliding, water can react with the tribo-material due to normal load and shear stress, and further influence friction and wear behaviour [4].

As with other building systems, an HVAC system must control humidity to maintain indoor air quality, inhibit mold development, and ensure comfort.

Humidity is paramount in preserving health and comfort from an environmental standpoint. Indoor relative humidity levels should optimally be kept at 40 to 60 percent to avoid respiratory problems, skin dehydration, mold infestation, and allergen flourish [12].

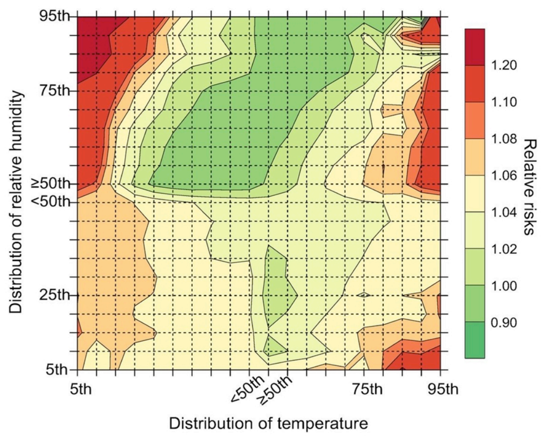

Figure.2: Relative risks during compound temperature-humidity events defined by 400 types of temperature and humidity combinations in China [21].

According to graph, when both values for humidity and temperature hover at or above the 95th percentile, relative risk increases considerably, exceeding the 1.2 mark as illustrated in the graph. Conversely, uncontrolled humidity and standard temperature systems are associated with lower risks that typically lie below one [21].

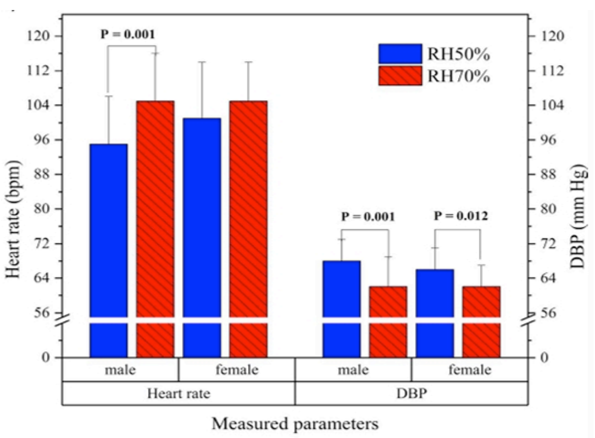

Figure.3: Effect on heart rate and DBP with change in humidity level [34].

As per one research conducted to analyse how physiological and sensation responses in humans are affected with an increase in indoor humidity level from 50% to 70% with respect to temperatures ranging from 26°C, 30°C, and 37°C. Initially, at 26°C and 30°C, there is no significant change noticed in human behaviour with the increase in humidity. Thermal comfort, air quality perception associated with Sick Building Syndrome (SBS), is normal because humidity is about 70%. Inversely, at 37°C, a considerable difference is noticed in thermal discomfort and physiological response, including elevated heart rate, respiration, and skin temperature, alongside a decrease in PNN50, which is a result of humidity above the standard upper limit [34].

Why dehumidify? : Focusing on the air-conditioning of buildings, I make these assumptions Since comfort is important, the air we supply should help us keep comfortable.

minimum supply of fresh, outdoor air is what is referred to as purge. collectors (key to delivery of a decent level of air quality) should not be excessively humid to ensure that indoor moisture production is balanced, the relative level from outside must stay compared with that of indoor air. But during summer, the humidity ratio outside is often higher than the in the level of moisture in the air [39].

III. Conventional Dehumidification Methods

A. Mechanical System-Oriented Methods:

Reliable, durable, and accurate behaviour of mechanical machines depends on them having the proper level of humidity. An excess of atmospheric moisture can cause metallic parts to rust, thermal systems to lose efficiency, sensitive electronics to malfunction, and sometimes result in the complete breakdown of precision applications. Most of the time, humidity control is not considered carefully when making or operating industrial machines. To deal with these problems, many dehumidification methods specifically developed for mechanical systems. Among these methods include using refrigeration, desiccants, dry air circulation, and membranes. Every technique uses a specific process, provides beneficial results, and has a few disadvantages as well as places where it can be put to use. Using suitable humidity control techniques helps ensure mechanical systems are not damaged by their environment, increasing how well and for how long they work.

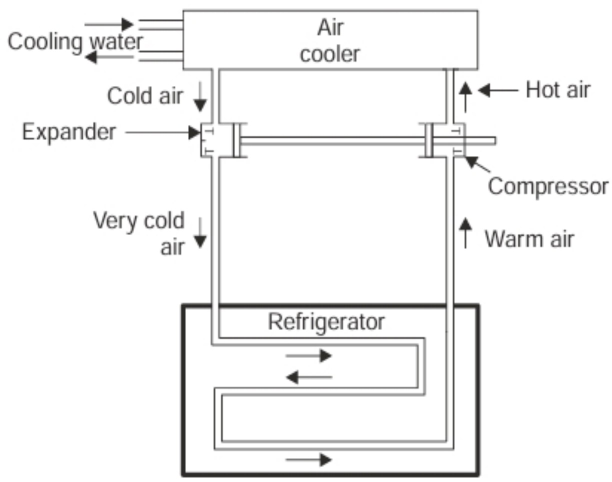

Figure.4: Vapor compression system [15].

1. Dehumidification using a refrigerator is widely chosen to control moisture when both cooling and lowering humidity are necessary. Condensation is the method used by the system. The air in the working area is brought into a dehumidifier or air conditioner, which then causes it to pass over a chilled evaporator coil. Cold air below the dew point makes the water vapor condense, and this collected liquid goes into a drainage pan or out a drain pipe. The air from the dehumidifier is then warmed a bit by a condenser coil before it is sent back into the room or the system for optimal comfort levels. Even though the use of this method is common in data storage rooms, precise machining, and factories, it has some drawbacks. A major problem is that running the compressors and fans all the time uses a lot of electricity. Also, systems that need refrigeration use gases such as CFCs and HFCs, which cause environmental damage and contribute to both global warming and the breakdown of the ozone layer. Regular maintenance on these systems is important to avoid clogs, refrigerant leaking, and reduced efficiency. Also, they do not usually perform well in cold conditions, where obtaining condensation is tough. Because there are problems with environmental and energy use, researchers and engineers are searching for new, and more sustainable techniques.

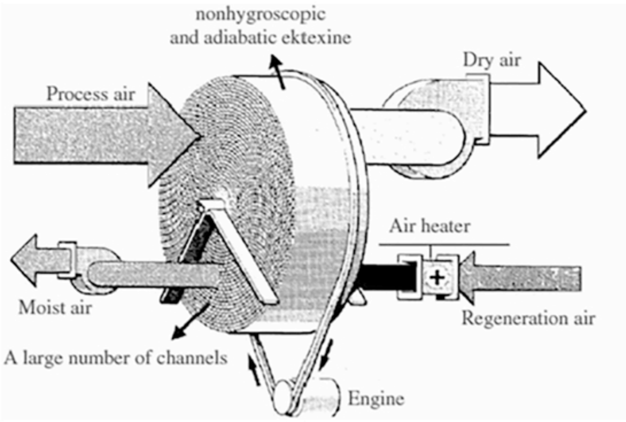

Figure.5: Desiccant dehumidification system [31].

2. Desiccant dehumidification removes water vapor from the air by using materials called desiccants that hold onto water well. Unlike refrigeration, desiccant systems extract moisture from the air by making contact with dry materials. The most common materials used to dry gases are silica gel, activated alumina, molecular sieves and lithium chloride. They are usually made as wheels, beds or packets through which air travels. Water vapor in the humid air is attracted by the dry air which carries it away. If the material becomes saturated, heating it will cause it to expel the water and be used again. It is especially productive in indoor areas with low heat or humidity, since standard refrigeration struggles in such conditions. Because of its excellent dryness, desiccant dehumidifiers are common in pharmaceuticals, food processing and electronic manufacturing industries. Desiccant systems continue to work well in a variety of conditions and can produce very little moisture. Such devices make use of thermal energy to recharge, so poorly controlled use of thermal energy can make operating them costlier. Modern systems generally make operations more efficient by linking desiccant wheels to energy recovery or by using hybrid models that add both refrigeration and desiccant parts. All in all, desiccant dehumidification is a great alternative because it is reliable and environmentally smart in situations where moisture must be controlled [31].

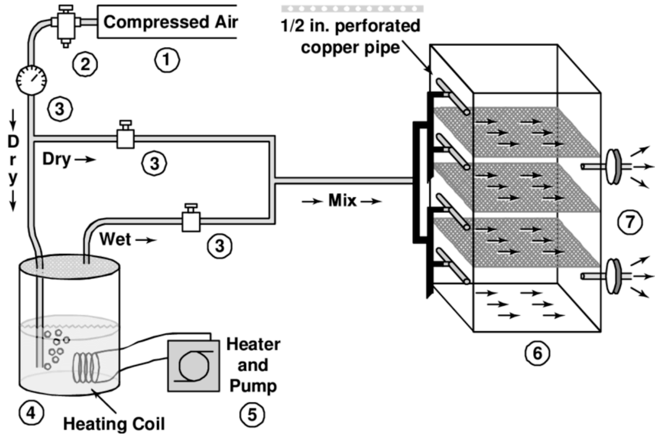

Figure.6: Dehumidification with dry air [Research Gate]

3. Replacing air within a room or system with air that contains less moisture is called ventilation with dry air and is a form of dehumidification. It's especially useful in small, remote or sealed spaces where regular dehumidifiers or chemicals are too hard to access. This way, dry air may be gathered from areas with a locationally low humidity or may be made dry through desiccant dryers before it enters the refrigeration system. With the dry air entering, it mixes with what's already humid, leading to a drop in overall relative humidity. The method is straightforward, uses little energy and works well if the outside air is very dry. However, it only works fully in enclosed spaces when there is great control over air exchange and if outdoor dry air can continue to be supplied without adding anything that isn't needed. Low-humidity is much more likely to be maintained in closed spaces, like control panels, clean rooms or storage containers, by dry air. Since dry air is hard to obtain when it's very humid, the method is less effective then and adding a conditioning step to the air also makes the system more complicated. Still, when used for some industrial and mechanical tasks that call for moderate humidity control, without the threat of harmful emissions and limited power use, these systems are low-cost and not difficult to manage.

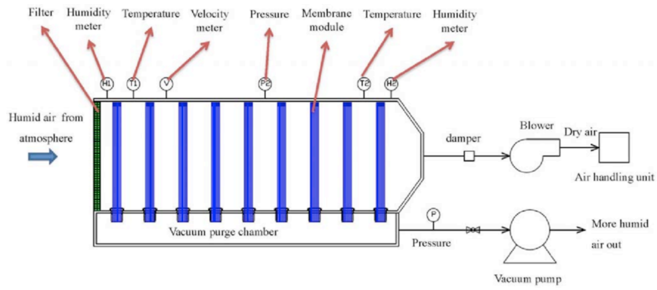

Figure.7: Membrane dehumidification system [Research Gate]

4. Membrane dehumidification relies on special membranes that allow water vapor to go one way and air to go another, so humidity is reduced without needing condensation or using chemicals. Gas exchange membranes are made so that only water or water vapor can pass across while all other gases such

as nitrogen and oxygen, are blocked from moving across. One main reason for separation is the gradient of pressure or concentration found across the membrane. In most cases, applying either a vacuum or dry purge gas to one membrane side draws moisture on that side through the membrane. The system is designed to use less energy, run quietly and not use chlorofluorocarbons, so it is easy to maintain. Membrane dehumidification suits electronic enclosures, storage of lithium batteries and pharmaceutical applications more than any other dehumidification method. Humidification control is important in gases being dried and is often needed in fuel cells. Their basic design and scalability make it possible for membrane systems to function both in compact portable equipment and large-scale factories. At the same time, the cost of purchasing membranes and their tendency to become contaminated may hold back their use in some industries. However, as better membranes and nanotechnology are developed, these devices can work longer and better, so their use for moisture control is becoming very attractive in today's systems.

B. Human Comfort-Based Methods:

This method centers on setting the proper humidity so that people inside feel both physically and psychologically comfortable. Each day, relative humidity helps us sense temperature, affects our comfort level and determines how healthy our indoor environment is. Too much humidity may result in being uncomfortable, sweaty, having irritated skin and occasional breathing issues. Too little humidity can make the skin dry, upset a person's eyes or throat and produce unwanted static electricity. Because of this, it's important to control humidity in homes, offices and other indoors spots, aiming for a level between 40% and 60%. For that reason, multiple humidity control devices and systems have been made specifically for people. These are air conditioners that dehumidify, exhaust fans and evaporative air coolers. Each system operates differently and is selected according to the climate, energy use, effect on the environment and the wishes of the person choosing it. While there are models that give you optimal control over temperature and humidity, others are mainly about ventilation or cooling which may raise the humidity. This section describe these methods in detail, highlight the principles behind them, their benefits, downsides and effects on human health and well-being.

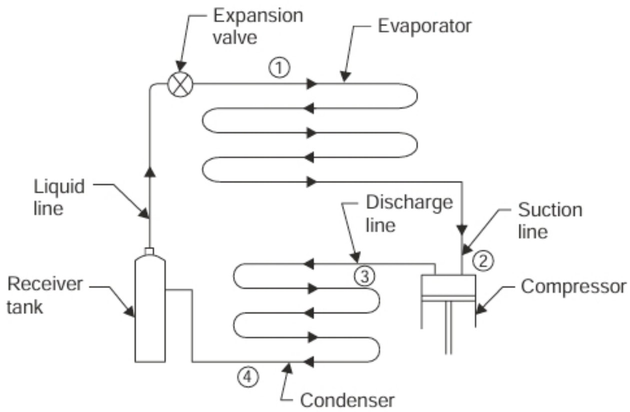

Figure.8: Air conditioning schematic diagram [15].

1. Air conditioning is the most popular and highly efficient way to manage temperature and humidity in indoor environments. The technique used is called the vapor compression refrigeration cycle which involves two circuits the refrigerant takes through the compressor, condenser, expansion valve and evaporator coil. When a warm, humid room is filled with relatively cold air from the evaporator coil, the refrigerant extracts heat from the air which cools it. Air moisture cools as it passes over the air conditioner coil and then falls into a drain which decreases the room's relative humidity. The dehumidifier function in these machines helps keep the air comfortable and safe in places with high humidity. Many current air conditioners provide a "dry mode" or a specific setting for removing more moisture than they cool. Even so, air conditioners are powerful at getting rid of humidity and present some limitations. A lot of regular AC systems rely on chlorofluorocarbons and hydrofluorocarbons as refrigerants and these are dangerous to the environment if they leak. They use a lot of electricity, so they are less efficient than many other humidity control approaches. During prolonged use in dry climates, some units may dry the air excessively which may cause skin, throat and breathing problems. However, people still choose air conditioners for indoor temperature control because they cool and dehumidify air which is what they are needed most.

2. Exhaust fans improve indoor air quality by pushing dirty, humid or old air from inside, making way for fresh air. By setting a negative pressure, they help decrease moisture, remove bad smell and capture

pollutants in the air. Exhaust fans are excellent at controlling moisture in places where humid air is created such as bathrooms, kitchens, laundry rooms and basements. When air is constantly removed and replaced by fresh air, the air gets drier. This stops mold growth, condensation and problems with the structure of your house due to excess moisture. Exhaust fans are attractive because they are both inexpensive to buy and easy to install, so mostly anyone can use them. So, how well they work is very much affected by how well the house is ventilated and how easy it is to provide fresh, dry air in place of humid air. In cases where the area is very sealed and ventilation is poor, exhaust fans may not correctly control the levels of humidity. Additionally, unlike air conditioners, they don't directly take away moisture or cool the air; they depend on having fresh air come in and out of the building. Still, exhaust fans are a good and efficient choice for reducing moisture indoors and making certain areas feel much more comfortable.

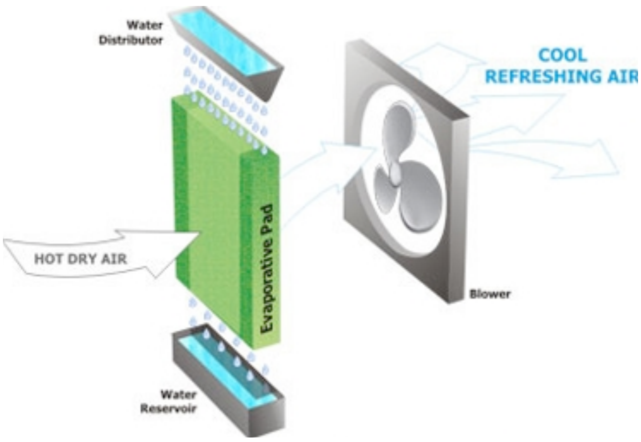

Figure.9: Evaporative air cooler diagram [36]

3. Evaporative air cooler also known as Swamp coolers are called that because they chill the air near them using evaporation, cooling the surrounding space. In these systems, the air is directed over pads or membranes which hold water and the water then evaporates, removing heat and adding humidity to the air. Since evaporators do not use refrigerants or compressors, they are better for both consumer budget and the environment than traditional air conditioners. There are mainly three types of evaporative cooling systems: ones that use direct flow, ones that use indirect flow and hybrid systems. Direct evaporative coolers lower the temperature by spraying water over the air which can add humidity and can be good for dry weather, yet is less useful when the atmosphere is humid. An indirect evaporative cooler uses a heat exchanger to lower the temperature of the air without adding moisture which is good where humidity is not wanted. Two approaches, direct and indirect cooling, are combined in a hybrid cooler for more effective temperature and moisture control. Although there are many good things about evaporative coolers, they have a few shortcomings. Since bacteria and scale can grow on cooling pads, user must constantly supply them with water and clean them regularly. Furthermore, in humid places, they don't help much since air cannot take on much more moisture and they can make rooms feel damp or sticky. In addition, the moisture put into the air by direct coolers has the potential to cause problems or harm for people and sensitive materials. Yet, evaporative coolers provide an affordable and environmentally friendly means of regulating temperatures and humidity where they are appropriate.

IV. TYPES OF EVAPORATIVE AIR COOLER

According to several studies conducted in the last decade, heating, ventilation, and air-conditioning (HVAC) systems are responsible for about 20% of energy consumption in buildings. Evaporative cooling technology presents an interesting solution to conventional cooling technologies based on vapor compression systems.

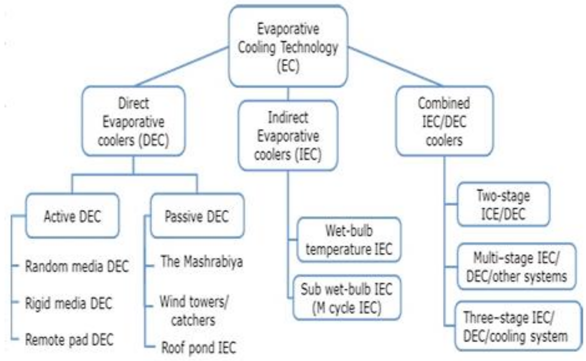

Figure.10: Classification of Air cooler [33].

Among the above types of air coolers mentioned in the flowchart, there are three widely used types. First and foremost, the direct evaporative air cooler is widely used in hot and dry climates by citizens. Then comes the indirect evaporative air cooler, and lastly, the combination of both systems, known as the Indirect-Direct Evaporative Cooler.

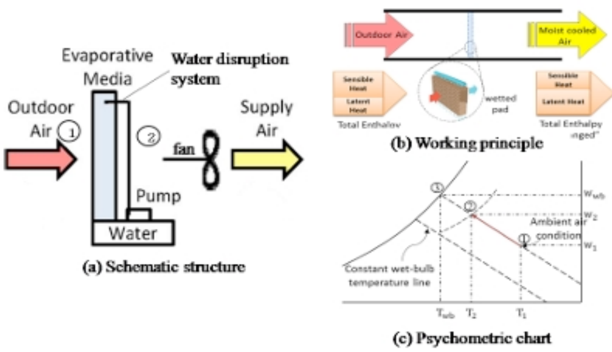

Figure.11: Direct evaporative air cooler (DEC) [33].

1. Direct Evaporative Cooling is one of many energy-efficient options. Direct evaporative cooling systems spray water vapor into the air to cool it as it loses heat to the water. As a result of this cooling, the

air temperature gets close enough to the wet-bulb temperature for there to be high cooling effectiveness. Yet, one big disadvantage of DEC is that indoor humidity goes up as the air becomes more humid during the process. These conditions can be uncomfortable where it's important to keep a stable humidity inside buildings or large areas. While DEC systems don't have to be complicated, they aren't commonly used in areas where humidity is too high. Although DEC systems are usually very effective, indoor moisture can lead to mold or other problems, mainly in humid regions.

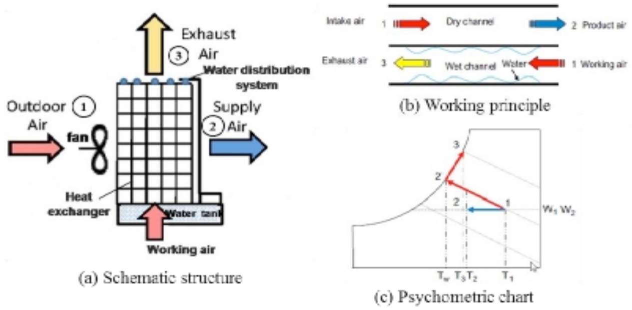

Figure.12: Indirect evaporative air cooler (IEC) [33].

2. Unlike with DEC, indirect evaporative cooling keeps indoor humidity levels stable because it doesn't put moisture into the air as it cools it. A heat exchanger is used to allow the outdoor air to flow over a dry area and be cooled by contact with evaporatively cooled water. The wet channel causes the passing water to evaporate and take up heat, but none of this water reaches the air coming in. It appears from the figures that IEC systems, particularly ones operating by the Maisotsenko cycle (M-cycle), show impressive effectiveness (ranging from 97% to 115%) and need just 2.5 to 3.0 liters of water for every kilowatt-hour. The M-cycle-based IEC systems may work well in areas with climate similar to many Greek cities, where controlling the use of energy and water is important. In addition, heat exchangers have been looked at from many angles, both in the classroom and in practical applications, by using different designs like cross-flow and counter-flow, all made from aluminum, polyethylene or other materials to support efficient heat and mass movement. Although they help save energy and control humidity, IECs usually work less effectively than direct evaporative systems but perform well when it comes to saving energy and maintaining cleaner, fresher air.

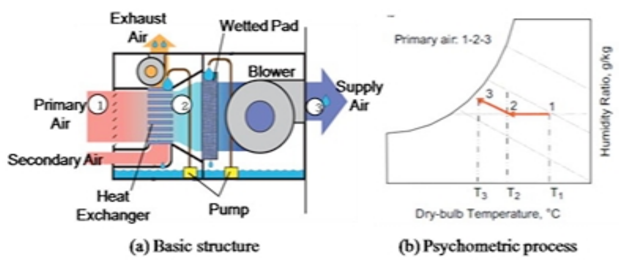

Figure.13: Integrated Indirect-Direct Evaporative Cooling (IDEC) [33].

3. Integrated Indirect-Direct Evaporative Cooling (IDEC) is used to capitalize on their strengths and address their weaknesses, the IDEC system blends both indirect evaporative cooling and direct evaporative cooling. Since DEC systems give cooler air and raise the humidity inside and IEC systems keep humidity consistent but have less powerful cooling effects, by combining both systems, the new one brings optimal results. Outdoor air first goes into an IEC in a typical two-stage IDEC which cools the air indirectly to lower the temperature but not change the humidity. Next, the air passes over a Direct Evaporative Cooler, where it cools as it evaporates water, but it gains some moisture too. As a result, the air circulating from the system is both colder and has a controlled moisture level. It is revealed by the data that two-stage IDEC systems are effective from 90% to 120% of the time, but consume more water by about 55%. In some cases, IDEC systems are built with three or more stages and add-ons such as solid desiccant units, cooling coils or nocturnal radiative coolers. These systems can help you save a lot on energy — up to 82% more than regular refrigerant cooling — and even provide better cooling performance than standalone evaporative systems. Coupling an IEC and DEC using desiccant dehumidification gives you both sensible cooling and control over humidity. Likewise, with nocturnal radiative cooling included, the cooling and energy performance of two-stage DEC-IEC systems improve and 75% to 79% less energy is used than in conventional MVC units. Although these systems have numerous benefits, the main problems are that they cost more to install and include sophisticated technology which has stopped more people from using them.

4. Dew point air cooler:
Unlike direct evaporative coolers, a dew point air cooler, cools air without adding moisture to it. The outside air is blown over a heat exchanger and cooled by the air from the evaporative cooler. The secondary stream gives up its heat through evaporation which cools the primary air in the heat exchanger but prevents the two streams from blending. For this reason, the main air is cooled to the dew point temperature, the temperature when moisture content is at maximum and dew appears yet it does not become more humid [37].

V. OTHER ATTEMPTS TO MAKE AIR COOLER MORE EFFECTIVE

1. In the paper called "Innovative Way to Decrease the Water Consumption of Direct Evaporative Air-Cooler," Jahidul Haque Chaudhuri, Rohan Deb and Jhinuk De describe an approach to increase how well DECs function in regions affected by water scarcity. Traditional DECs use a lot of water

for evaporation while cooling the air. In order to resolve this, the team used a method that capitalizes on the endothermic or cooling, feature of ammonium chloride (NH4Cl) salt which releases heat into its environment, cooling the water it is dissolved in. The coefficient is lowered by pumping the salt solution through honeycomb pads in the modified cooler. The pads help to cool air more efficiently than standard approaches, improving cooling while using less water. It was decided to use ammonium chloride instead of ammonium nitrite, due to its good cost-effectiveness and safety features. A salt-water separator is also included, using solar power to clean the ammonium chloride crystals. This improves the system's sustainability and cuts its running costs. Results from comparing the two designs revealed that the new approach not only improves cooling, but also saves water. With this method, water-scarce areas can get efficient cooling [32].

2. Dr. J.P. Yadav and Pankaj Sharma's paper "Performance Investigation of Modified Desert Cooler" examines how making changes to traditional desert coolers can improve their efficiency and ability to work well in many environments. They work best in dry and hot places because water evaporation is used for cooling the air. Even so, when it's humid outside, their performance suffers because the air's moisture can be uncomfortable. To combat this limitation, the authors designed a heating coil that could be incorporated into the main cooling pad. During hot days, the heating coil reduces moisture inside the room by raising the temperature of the cooled air a bit; in winter, it works like a blower to warm up the room. The new design found in experimental results helped cut down room temperature by 7°C and controlled humidity better, making the room more comfortable. In addition, the research reviewed cool pads made from wood wool, coconut coir, khus and modern cel-dek pads. The 90% cooling effectiveness of cel-dek pads is largely because of their superior water and air properties. From the study, we see that choosing the right materials and including innovative parts improves the effectiveness of desert coolers in many different climates [10].

VI. Concept of Zero Humidity Added Air Cooler

In a country like India, where the temperature in the majority of regions is high, citizens need some appliance that can provide low-temperature air so they can feel thermal comfort. There are many machines that are used to create an appropriate thermal comfort environment such as air cooler, mist fans, and air conditioners. Among all these appliances, air conditioner and air cooler both are widely chosen by people according to their requirements. In terms of money, purchasing and running air conditioner is more expensive in comparison to normal air cooler.

Additionally, an average price of air conditioners as of May 2025 is around 30,000 to 35,000. Then AC also consumes lot of electricity with added regular maintenance cost. Hence, lower-class or lower-middle-class person would like to go with air cooler that range in their budget and also provide thermal comfort at an appropriate level.

On the other hand, in compare of AC, air cooler has average price of 5,000 to 8,000 as of May 2025 which attract people to purchase. But there is one problem involved with this device, it makes air more humid so after a long use human skin feel like oily and sticky that recreate uncomfortableness. On top of that, air cooler requires regular filling of cold water that is very laborious. One of the main problem associated is it evaporates too much water so in country like India where in some regions water is a problem so it cannot make just sense.

Hence we require a solution that eliminate or make this problem very negligible. Zero Humidity Added Air Cooler is designed to fulfil this p(Law, 2018)urpose.

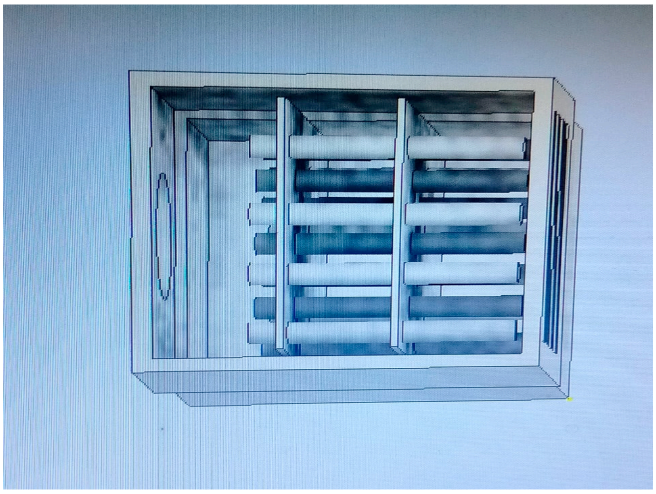

Figure.14: Zero Humidity Added Air Cooler (forecasted design)

Construction of the Zero Humidity Added Air Cooler involves a fan or blower, similar to the one used in conventional evaporative air coolers. Additionally, a pump is installed to supply and circulate water within the indoor body of the cooler. One of the main components that sets it apart from traditional models is the inclusion of heat-conductive hollow copper pipes. Furthermore, it contains regular components found in normal air coolers, such as a swing motor, swing blade, water level indicator, and controllers to adjust fan speed, operate the on/off function of the water pump, and switch the swing motor. The main body houses all these parts, and its base also serves as a water reservoir.

Modifications made in the evaporative air cooler include changes in arrangement and working principle. Unlike the conventional method of spraying water on a cooling pad made of grass or honeycomb material, this system sprays water on the outer surface of the copper pipes. A high-speed fan is installed at the front panel and draws air from the back-side vents. In between, hollow copper pipes are arranged in such a way that air flows through them from the environment to the user with the help of the cooler's fan.

As the working principle is quite understandable from the modification, let's elaborate further. Environmental air enters from the rear vents and passes through the copper pipes. Continuous circulation of water on the outer surface of these pipes causes them to cool down, as the water flows from a height and behaves like a mini cooling tower. Since the hot air comes into indirect contact with water—through direct contact with the walls of the copper pipes—it gets cooled, and the temperature of the air exiting through the fan is significantly reduced. Moreover, because there is no use of cooling pads, the quantity of water sprayed onto the copper pipes remains nearly equal to the amount stored in the reservoir.

Since copper pipes are known for their excellent heat conductivity, they work efficiently as heat exchangers and are able to cool a greater volume of air compared to a regular air cooler. Additionally, water loss is minimized to a negligible amount, making this system highly suitable for areas where water scarcity is a concern.

Comparative Analysis

Aspect	Evaporative air cooler	Zero Humidity Added Air Cooler
Purchasing cost	Average cost 5,000-8,000 [13].	Slight higher 7,500-10,500
Running cost	Operating cost is lower compare to air conditioner.	Operating cost is lower compare to air conditioner.
Consumption of electricity	Low power use in compare of air conditioner	Less power use in compare of evaporative air cooler as uses good quality fan
Working principle	Evaporate water to cool air by spraying on cooling pad.	Uses working principle of heat exchanger.
Humidity control	Humidity increases as water is directly coming in contact with supplied air.	Humidity is constant as water does not come in direct contact with air.
Water consumption	As water evaporate there is a water loss occur. [19]	Water loss is negligible as there is no direct contact.
Efficiency	Lower efficiency compare to air conditioner.	Higher efficiency compare to evaporative air cooler.
Maintenance	Regular maintenance is needed to clean cooling pad and clean water tub [40].	Very less periodic maintenance is needed to just clean copper pipes.
Air quality	May bacteria, dust and allergens are contained in water.	As there is no pad so air is of free from foreign material.
Thermal comfort	Initially good comfort environment is created but with time humidity destroy thermal comfort.	As the air is of low temperature and also humidity is not increasing so it provide more thermal comfort.
Climate suitability	Suitable for environment with less humidity such as kutch and rajasthan [40].	Suitable in all type of environmental condition.
Noise created	Fan and water pump create more noise	As motor and fan are of better quality they create less noise.
Components included	Basic fan, water pump and cooling pad.	Basic components with hollow copper pipes.
construction	Simple construction	Construction is complex dure to arrangement of copper pipes.
Environmental suitability	As water consumption is high hence not suitable for regions with water scarcity.	As water consumption is negligible hence suitable for regions with water scarcity.

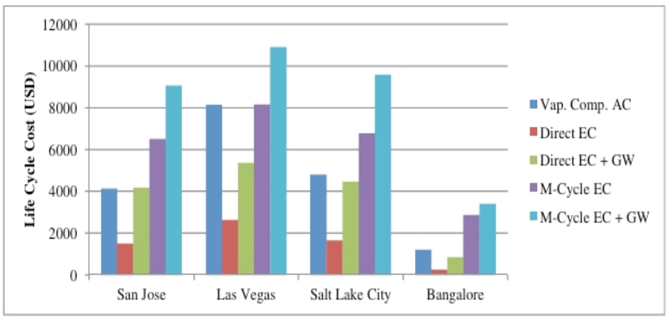

Figure.15: Total life-cycle cost of various colling technologies [17].

As mentioned in difference, using vapor compression system to get thermal comfort is way much expensive than evaporative air cooler. This stance is further proved by bar graph shown above that depicts life cycle cost of these equipment [17].

Why fan is preferred over air blower?

Air coolers rely on both air blowers and fans to move air, although they have different styles, air patterns and uses. The air blower typically draws air in from the sides, with a squirrel cage centrifugal mechanism and discharges it at a right angle. This pressure makes the air flow more accurately and drive it farther. Blowers are often found in air coolers that work in a compact or ducted way, where the air needs to be directed. Air coolers containing fans typically place blades in an axial configuration, making them blow air straight ahead as the blades spin. They move air more widely and in lower pressure levels than a regular blower. Air coolers that need to cool many areas tend to use these over those demanding stronger air blasts. Because fans run quietly and save energy, blowers deliver increased air to a focal point which is useful depending on how you need to cool your space [9].

VII. Conclusion

In conclusion, this paper has reviewed importance and the adverse effects of excess humidity on machines, electrical components and humans, pointing out that it requires efficient dehumidification. Several studies were examined to discover the effects of moisture on the performance of machines, how they corrode, affects energy efficiency and how good the components are at maintaining reliability. At the same time, the paper looked into how high humidity alters both humans' physiology and the surroundings, sometimes resulting in concerns about health and feeling uncomfortable inside. The ways air conditioning and dehumidification are done right now were studied and their brief description with limitation in using energy and operating in tropical climates were noted. Because of these difficulties, the concept of the Zero Humidity Added Air Cooler (ZHAC) was proposed, designed to cool the air and control humidity to regular level by using copper coils and other components. The ZHAC could increase mechanical efficiency, improve the comfort inside a home and stay environmentally friendly and energy-conscious. Even though it is not fully tested, it acts as a base for further development and advancements in climate control technology.

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