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ABACUS OF 04 ELEMENTS FOR DECISION MAKING IN HVAC SYSTEMS

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Abstract: With global warming and temperature increase, the global share of HVAC systems will move an estimated amount of US$ 167 billion by 2024, regardless of the make and models of equipment. In addition to traditional air conditioning systems, there is also the growth of unconventional systems (without compression cycle), such as evaporative systems, En-thalpics (Free Cooling) and geothermal systems. This article creates a diagram based on 4 natural elements: earth, fire, air and water to select the most interesting HVAC (Heating, Ventilation and Air-Conditioning) technology according to the characteristic of the region. The cities of Manaus and Foz do Iguaçu were analyzed, the solutions versus the number of hours for each one are very different, showing a more expressive advantage for the city of Foz do Iguaçu.
Keywords: HVAC, EUED, Free cooling, 04 elements, refrigeration.

INTRODUCTION

In a country with almost the entire area on the equator like Brazil, air conditioning is essential, in the same way, in other countries, due to society's needs for thermal comfort and the requirements for operating processes, the air conditioning are needed everywhere. There are air conditioning applications in Hotels, Commercial Buildings, Airports, Museums, Hospitals, Data-centers, Shopping Centers, Industrial Applications, Schools, Cinemas, Supermarkets and Churches.

ABRAVA (Brazilian Association of Refrigeration and Air Conditioning) includes the main manufacturers of air conditioning systems. This association participates in the main scientific researches and Brazilian works developed on this topic.

According to ABRAVA, the Brazilian central air conditioning market (in tons of refrigeration-generation, TR) has the evolution of the last 20 years shown in Figure 1 [1].

The growing demand for air conditioners is one of the most critical points in the current energy debate. Setting higher efficiency standards for cooling is one of the easiest steps governments can take to reduce the need for new plants, reduce emissions and reduce costs at the same time.

By 2050, about 2/3 of the world's households could have an air conditioner. China, India and Indonesia will together account for half of the total number [2].

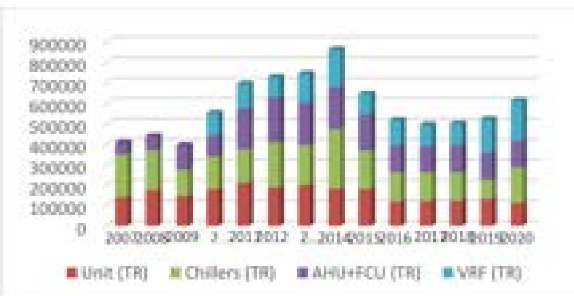

Figure 1– air conditioning market [1].

The number of equipment installed is growing at a time of financial crisis, as shown in the ABRAVA chart in Figure 2.

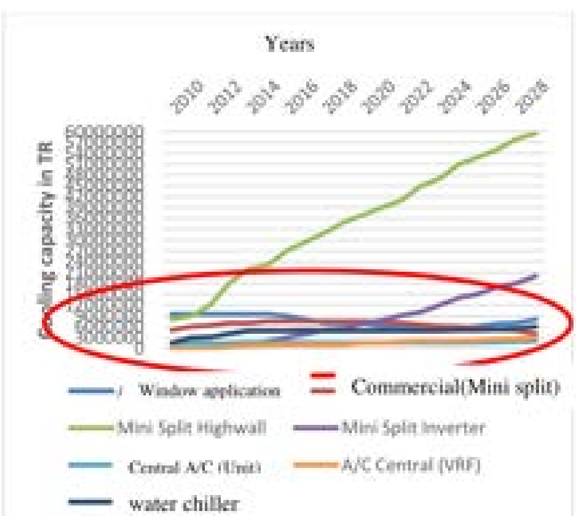

Figure 2 – A/C installation in Brazil in TR [1].

The technological solution of the evaporative system is suitable when the wet bulb temperature is low. Thus, this type of system seeks to approximate the value of the dry bulb temperature to the value of the wet bulb temperature, specifically Figure 3, it is a hybrid system of conventional air conditioning with evaporative Free Cooling system and automation with auto dampers -matic.

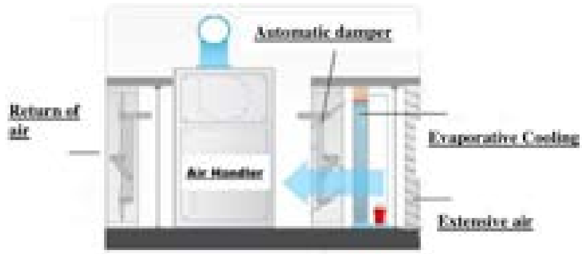

Figure 3 - Example of the evaporative system diagram (external air temperature between 16ºC and 25ºC or enthalpy below 12.5 kcal/kg)

Evaporative systems are divided into direct and indirect systems, as shown in figure 4. In direct evaporative systems, water is evaporated in contact with the air flow and there is an increase in absolute humidity in the supply. In indirect evaporative systems, the evaporated water is used to cool the air circulation indirectly, without adding absolute humidity to the insufflation. At Eurovent, direct evaporative equipment has the acronym DEC (Direct Evaporative Co-oling) and the indirect one is IEC (Indirect Evaporative Cooling) [3].

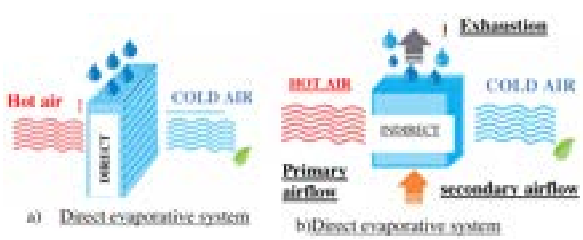

Figure 4 - Example of Direct and Indirect evaporative systems, adapted [4].

An evaporative cooler in a dry climate is more efficient than a traditional air conditioning unit with a compression cycle. In fact, the California Energy Commission claims that evaporative coolers can be 75% more economical than air conditioning. These coolers are also less expensive to install in many cases almost half the cost of an air conditioning unit, and some are powered only by solar energy. While an air conditioning unit recirculates the same air in a closed loop, evaporative coolers bring in fresh air, which is much healthier [5].

The number of installed evaporative cooling systems has increased all over the world due to its advantages over conventional systems, since this system has an enormous potential for use, despite a certain limitation in its performance, requiring a more rigorous analysis. [6].

The cooling process is only possible thanks to the interaction between heat transfer and mass transfer. The water absorbs heat from the air during evaporation and the heat is removed from the condensing steam. Prolonged free contact between water and air results in an equilibrium state in which normally the air will be saturated, the greater the amount of vapor in the air needed to saturate.

The function of the application of the evaporative cooling system is to make the evaporation occur in a controlled way, in order to obtain results that produce effects in terms of cooling, humidification and consequent improvement in the quality of the ambient air. Reaching the dew point, in this case, would be the limit of the evaporative principle (associating indirect and direct evaporative cascade), because at this moment the occurrence of evaporation ends. On the other hand, the lower the relative humidity, the faster evaporation occurs and the greater the degree of cooling that can be achieved [5].

Evaporative cooling is a well-known technique that provides good cooling results and is used in many applications, from residential, commercial, agricultural and institutional buildings to industrial applications such as spot cooling in power plants, foundries and friendly environments, as it uses only energy. natural as latent heat of water. The efficiency and effectiveness of evaporative cooling depends on the surrounding climatic conditions [7].

There are also technologies associated with traditional air conditioning, such as Free Cooling. In this technology, outside air is introduced internally to cool the room and an extraction is activated to discharge the heat, but always maintaining a positive equation between air inlet and air outlet. An example of the equipment and operation of the Free Cooling system is shown in Figure 5.

Figure 5 - Example of the Free Cooling system diagram (External air temperature between 10ºC and 16ºC).

Air conditioning and cooling systems account for about 40% of total electricity usage in data centers. Free Cooling is a promising technology that can lower the load ratio of the electric chiller and save cooling energy consumption accordingly, through full use of the natural Free Cooling source [8].

Geothermal alternatives are also an option to conventional systems. According to Egg & Howard, the word "geothermal" comes from the Greek "geo" (earth) and "terms" (heat) and is applied to the use of ground heat. There are basically two energetic applications of geothermal heat. One of them is electricity generation, typically maintained in large generation systems where water is introduced into the ground from high temperature geothermal areas, generating steam to drive

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turbines and generate electromotive power. Such installations only exist in places with high geothermal activity, such as some Asian and European countries. In the Philippines, for example, geothermal energy is responsible for 8,900 MW and represents 25% of the electricity generated [9]. The second way to use geothermal energy is to use the temperature at a constant value below the Earth's surface in Geothermal Heat Pumps (GHP). The geothermal heat source favors increased energy efficiency and can be used in urban building cooling systems, with energy savings ranging from 70% to 140% in winter, compared to air heat pumps. [10]. According to the EERE (Energy Efficiency & Renewable Energy) [11-12], an agency linked to the Department of Energy, a source of geothermal heat is an effective mechanism for energy efficiency and can be used in urban building cooling systems, pumps heat sources (land source or water source) achieving greater efficiency by transferring heat between a house and the ground or a nearby water source. Heat pumps are devices with simple operation and good thermal performance, characteristics that indicate great potential in the air conditioning market. Although more expensive to install, geothermal heat pumps have low operating costs because they take advantage of relatively constant ground or water temperatures. Geothermal (or ground source) heat pumps have some great advantages. They can reduce energy usage by 30% to 60% compared to conventional air conditioning and refrigeration systems [11]. For example, in the state of Paraná, winter and summer outdoor air temperatures versus geothermal temperatures at 2 meters below ground level are shown in Table 1 and Table 2, respectively, for various cities. Table 1 shows summer/winter temperature data for Paraná state and Table 2 also shows summer/winter temperatures but geothermal temperatures for Paraná state – Brazil [13].

Place/Cities	$T_{verão}$ (°C)	$T_{inverno}$ (°C)
Cascavel	35,1	3,4
Curitiba	30,9	2,4
Foz do Iguaçu	35,1	3,4
Guaratuba	33,0	7,5
Ipanema	33,0	7,5
Londrina	33,9	7,2
Maringá	33,9	7,2
Pinhais	30,9	2,4
Ponta Grossa	32,0	2,1
Toledo	34,9	2,4

Table 1 - Maximum outdoor summer temperature and minimum winter temperature for several cities in the state of Paraná [13].

Place/Cities	$T_{verão}$ (°C)	$T_{inverno}$ (°C)
Cascavel	22,9	16,0
Curitiba	22,1	18,1
Foz do Iguaçu	23,0	17,7
Guaratuba	22,9	18,2
Ipanema	23,0	18,3
Londrina	24,0	16,2
Maringá	23,0	17,9
Pinhais	20,9	17,0
Ponta Grossa	21,1	18,0
Toledo	23,0	17,7

Table 2 - Summer and winter geothermal temperature values for several cities in the state of Paraná [13].

Energy savings in data centers using geothermal heat source systems are likely to be greater, since for a temperature below 16°C, a direct geothermal air conditioning system can be implemented. Geothermal systems are divided into: Vertical Loop; Horizontal loops; loop ponds and lakes, open loop, as shown in figure 6 [14].

• Vertical Loop: This system requires less space, but they are longer in length and are buried deep in the ground. They are used for multi-storey housing projects, schools and large commercial buildings. For the vertical system, holes, approximately 4 inches in diameter, are drilled approximately 6 meters apart and 100 to 400 meters deep. In these holes, there are two tubes connected at the bottom with a U-shape to form a loop. Vertical handles are connected to a horizontal pipe (collector), placed in trenches and connected to the building's heat pump. They are more expensive.

• Horizontal Loop: This installation is more economical, takes up more space in width than the vertical system and more on the underground surface. The most common installation layout uses two pipes, one buried at two meters and the other at four meters, or two pipes placed side by side five meters into the ground, in a two-meter-wide trench. It must be ensured that there is enough space available for its installation. In suburban facilities, these are the most viable systems.

• Pond and lake loop: This system requires a water source close to your installation. Underground pipes run from the building to the water. The tubes are in the form of concentric coils so that the water does not freeze. Coils must only be placed in a water source that meets minimum volume, depth and quality criteria.

• Open Loop: This system needs a continuous supply of clean water that can be used to absorb heat from the water below ground. Therefore, bodies of water are used for the exchange of heat between fluids. This option is obviously practical only when there is an adequate supply of relatively clean water and all local codes and regulations relating to groundwater discharge are complied with.

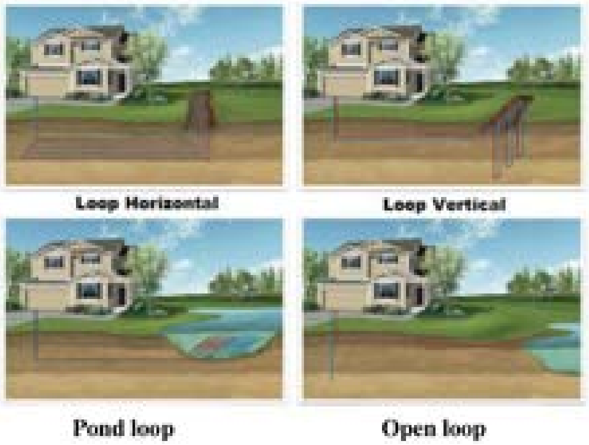

Figure 6 - Example of types of geothermal systems.

Despite the importance of air conditioning, and of so many alternative and/or complementary systems, the question is to develop a diagram that can help in the decision making of which alternative system is unstable to choose, according to the characteristics of the cities.

MATERIALS AND METHODS

The main objective is to generate tables of the new thermal performance and energy efficiency indices. The four natural elements used as a basis for defining the best solution for air conditioning are based on ancient knowledge (Figures 7-8). Empedocles (490 - 430 BC), on the other hand, taught that everything is made up of 4 "principles": earth, water, fire and air. This model was reformulated and defended by Aristotle, perhaps the greatest and most influential thinker in Western history. Plato renamed the four main elements and Aristotle used that term. Each element is characterized by two properties of natural opposites, hot-cold and dry [15].

Figure 7 - Four natural elements: earth, water, fire and air.

Figure 8 - Abacus involving the four elements: earth, water, fire and air.

Based on these principles, a diagram of technological solutions compatible with the characteristics of the climate was prepared, as shown in Figure 9.

Figure 9 - Conditions and solutions for air conditioning.

From Figures 7 and 8, Table 3 was developed. These results can be proposed in the form of a diagram (Figure 10) that refers to the predominant solutions regarding the characteristics of outdoor air, that is, the hygrothermal decision diagram based on in Aristotle's four elements.

Air temperature (°C)	Absolute humidity (g/kg)	Generic heat condition	Generic hygroscopic condition	AVAC SOLUTION
Over 20°C	Below 10 g/kg	Hot	Moist	Traditional cooling
	Below 10 g/kg		Dy	Evaporative System
Below 20°C	Over 10 g/kg	Cold	Moist	Geothermal System
	Below10 g/kg		Dry	Free Cooling

Table 3: Table of the four hygrothermal elements of decision making.

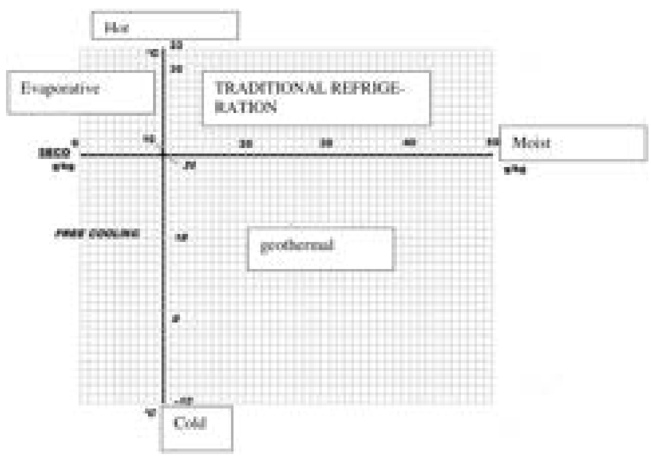

Figure 10 - Hygrothermal diagram based on Aristotle's four elements.

As can be seen in Table 3 from the diagram in Figure 10, it can be noted that:

1) In hot and humid weather, the best solution is refrigeration. The compression cycle with temperature below the dew point is the direct counterpoint to high temperature and absolute humidity.

2) In hot and dry climate, the best solution is the evaporative system. The evaporative system is the direct counterpoint to high temperature and low humidity.

3) In the cold and wet climate, the best situation is the geothermal system. Specifically, in this situation there is a humidity limit in a data center of up to 80%, and there is a need for cooling dehumidification. It is important to emphasize that rainy climates facilitate the exchange of geothermal heat, as they have greater thermal inertia, facilitating the exchange of heat. This is the example of the city of Curitiba, which has a temperate climate and good rainfall. The Köppen and Geiger classification [15] is CFB (temperate oceanic climate), with an average temperature of 17.1ºC. In Curitiba, in this case, it is cold and humid, which is very good for geothermal systems. "Geothermal closed-loop heat pumps work best in wet ground conditions as it improves heat transfer between the ground and the water pipeline. Poorly drained areas can provide additional horizontal loop piping."

4) In a cold and dry climate, the best solution is Free Cooling, as it has all the interesting characteristics of temperature and humidity to be implemented in a Datacenter, for example, even in 01 Call Center.

RESULTS AND DISCUSSIONS

According to the ASHRAE WEATHER Viewer, a city like Curitiba can have moments in any of the areas of the graph in Figure 10 [16].

As a solution, there is the EUED (Energy Usage Effectiveness Design) metric that uses the annual values of the dry bulb temperature associated with the coincident wet bulb temperature (data from the ASHRAE Weather Data Viewer, the same source to base the ASHRAE method), classified as [16]:

- Free Cooling - System that allows using the enthalpy characteristics of the outside air to acclimatize a room.
- Direct or indirect adiabatic cooling, which consists of cooling the ambient air using wet bulb temperature.
- Geothermal condensation system (ground source) as an option for a thermal bath to condense the refrigerant fluid.
- COP - Coefficient of performance, which is used to evaluate the relationship between the cooling capacities obtained and the work spent to obtain it.

Based on an average insulation temperature of 20 °C, in the EUED methodology, the following factors are used:

- When the outside air temperature is below 20 °C and the air enthalpy is below 42.797 kJ/kg, only Free Cooling will be used.
- When the temperature is between 15°C and 24°C and the enthalpy is from 42.7979 kJ/kg to 55.8233 kJ/kg, the evaporative system will be used.
- When the temperature is above 20 °C and the enthalpy is above 55.8233 kJ/kg, the system will normally be used under the following conditions:

1. Air inlet temperature between 24 °C and 27 °C, called COP1.
2. Air inlet temperature between 27.1 °C and 30 °C, called COP2.
3. Air inlet temperature between 30.1 °C and 33 °C, called COP3.
4. Intake air temperature above 33 °C in any condition, called COP4.

If geothermal temperature is available, it will be used to determine the COP, with a 4°C differential from the geothermal temperature.

To simulate the conditions of COP1, COP2, COP3 and COP4, a COOL-PACK software was used (initiated by condition 4 to simulate a standard isentropic coefficient to be able to identify the COP with the variation of the condensation temperatures). For the purpose of the condensation temperature, the air inlet temperature suggested in NBR 16255-2013 was added to 11 °C, with the conditions shown in Table 2, to assume an R410A refrigerant fluid. The results obtained with the software are described below for the cases COP4 to COP1 in descending order. For condensation systems for geothermal water, the value of 6 °C will be added to the water inlet temperature in the condenser [17]. Specifically, for geothermal systems, constant condensing temperature is used, Figure 11 shows the different case studies in the psychrometric graph.

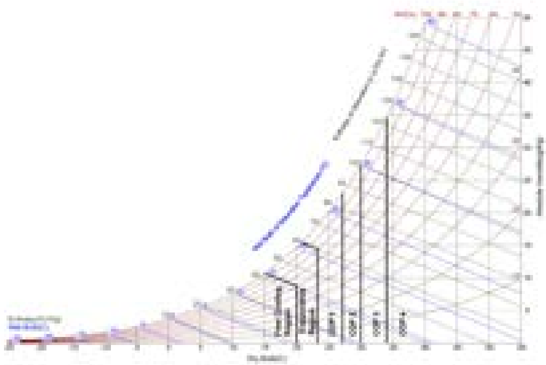

Figure 11 - Psychrometric chart with variation of case studies.

Using these factors, a simulation of the number of hours in each type of system was created using the Ashrae Weather Data Viewer [16], in two cities that have identical maximums.

EVAPORATIVE COOLING (EVAPORATIVO COOLING)

As it can be seen in the table, despite having identical maximums, the solutions versus the number of hours for each solution are very different, being much more advantageous for the city of Foz do Iguaçu.

CONCLUSION

A challenge for any designer is to achieve a NET Zero building, in this context the initial stage of the project is very important, and cannot be limited only to technological innovation, or from the inside envelope, issues of relief, geothermal, psychrometric history as well must be taken into account in the decision making of the systems to be implemented, it is very important to involve the air conditioning designer from the initial stage of the project, there is the French concept based on 06 steps that involve simplicity, compatibility, viable techniques, easy management, sustainability, with low cost [18] and the methodology of the 04 elements adheres to these principles.

The four natural elements are the basis for defining the best solution for air conditioning Empedocles (490 - 430 BC), on the other hand, taught that everything is formed by four "principles": earth, water, fire and air. Each element is characterized by two properties of natural opposites, hot-cold and dry.

The hygrothermal diagram of the 04 elements can be an interesting tool for the decision making of an air conditioning system, including a hybrid system with Free Cooling, evaporative and compression

Operating regime Regime de funcionamento	Foz de Iguaçu (Hours) Foz de Iguaçu [Horas]	Manaus (hours) Manaus [Horas]
Free Cooling	2069,77	0,41
Evaporativo Cooling	2851,63	4,42
COP1	2326,91	5787,75
COP2	842,60	1463,54
COP3	529,29	1127,60
COP4	139,78	376,25

Table 4_ Number of hours for each solution

refrigeration cycle as shown in the table, even having similar maxims to the advantage to use "free cooling" or evaporative systems.

Knowing the growth and the need for climate control in times of global warming, the diagram based on the four elements becomes an interesting source for deciding which is the best climate system.

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