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Optimum and Sustainable Cooling Technology Selection for Different Climatic Conditions

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Abstract: Global warming has led to rising electricity demands due to soaring cooling load, resulting in different technologies being implemented with renewable energy options. Renewable energy has been used to partially or fully operate these cooing systems through different technology routes in both conventional and hybrid modes. The feasibility of a particular cooling process is influenced by several technological, economic, environmental and other related factors. Selection of the appropriate route also requires consideration of external factors such as local weather, cooling load requirements and the potential of possible renewable energy. Multi-criteria decision analysis is a useful tool to systematically arrive at the right option from several possible options. This tool is used to assess the feasibility of eight technology routes for three different climatic conditions. Other than the direct cooling processes, two routes of renewable energy utilization, namely, the solar photovoltaic system and solar thermal system, are considered. The normalized decision matrix is established and weighted decision matrix is estimated, and the best solution and the worst solution values are obtained by using equations. This study is performed for three climatic zones under the Koppen classification, namely, the tropical maritime arid condition with average midday temperature from 40 to 45 °C, with two different relative humidity ranges, namely, dry area and maritime area. Additionally, the temperate continental climatic zone is analyzed for comparison. The results of this study will help decision makers to judiciously implement air conditioning systems in the above climatic zones. The distance of each waste treatment strategy from the overall best alternative treatment strategy and the overall worst alternative treatment strategy is obtained. Finally, the cooling strategies are ranked for the best option for the cooling mechanism to be adopted for the three climatic conditions.

Keywords: efficient refrigeration technology; multi-criteria decision analysis; hybrid refrigeration; solar refrigeration; refrigeration energy; TOPSIS

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1. Introduction

Building energy consumption for room cooling systems plays a predominant role in the energy economics of a country. Recent developments in compressor designs and the introduction of variable speed drives have substantially contributed to energy savings. The energy performance of these systems are primarily determined by the evaporator and condenser operating parameters. Prevailing weather conditions directly impact these parameters. Choosing the best among the different viable options is important. Vapor compression cooling technology continues to play a major role in spite of high energy consumption due to the advantages of high coefficient of performance, lower cooling temperature achievement and high condenser temperature endurance [1]. Vapor absorption cooling and thermo-electric cooling has recently reduced the prominence of vapor compression systems by replacing them for many cooling requirements. Evaporative cooling is limited to the achievable wet bulb temperature in a region and is suitable only for low humidity weather conditions. Vapor absorption cooling technology is being adopted on a large scale with the use of different heating sources, renewable as well as non-renewable, for supplying heat to the vapor generator. Thermo-electric cooling is used for localized cooling of electronic equipment.

Several methods have been adopted to improve the energy efficiency of cooling systems. Some of them focus on the end user by reducing the cooling load. This includes improvements in the building design or the insulation material [2]. More recently, many achievements have been reported in the cooling machinery. Hybridization of two or more cooling technologies have also been explored and viable options are being implemented for specific cooling requirements [3]. A selection scheme for choosing the best combination after considering the climatic zone is proposed. Five different cooling methods, namely, vapor compression-based cooling, absorption-based cooling, adsorption-based cooling, desiccant-evaporative and multi-evaporator cooling are considered. Hybridization of evaporative cooling with vapor compression cooling is one such example and they were tested both in series mode and parallel mode, wherein a 60% energy saving has been reported [4]. This study concludes that subjecting air to mist spray followed by water spray cooling and direct expansion using evaporator of vapor compression cooler gave the best result in terms of cooling performance. Parallel mode uses both the cooling systems simultaneously to cool the room, whereas series mode involves cooling the condenser of the vapor compression system using the evaporative cooling system. Hybridization of vapor compression systems with vapor absorption systems has also been explored by many researchers [5]. Here, the effect of evaporator pressure, condenser pressure, generator temperature and absorber temperature on the cooling performance is studied and the optimum performance under the combined operation is determined.

Renewable energy is utilized for cooling applications through different technology routes and has achieved notable success. Solar thermal or solar photovoltaic systems are used to energize cooling machines [6]. A numerical model with a vapor compression machine combined with a solar powered ejection cycle is developed and studied. Solar photovoltaic power is used to run the compressor and pumps of the vapor compression systems [7] and solar thermal energy is used in vapor absorption systems to supply heat to the generator [8]. It was estimated that 14 tons of carbon dioxide generation can be avoided by replacing conventional power with solar power in a 60 W vapor absorption cooling machine. Solar energy is also used for adsorption cooling systems and has been widely tested by researchers [9].

The different options available for cooling, as discussed above, make it clear that technology selection of the appropriate cooling method requires a scientific tool to analyze and determine the ideal choice. On the other hand, the existing cooling temperature, cooling load and condenser temperature as required by weather conditions make the selection more complicated. Multi criteria decision analysis is an ideal tool which has been successfully used in such situations. A substantial body of literature on multi-criteria decision making (MCDM) for selection of the optimal strategy for cooling under different climatic conditions has been reported. In order to have an energy efficient, sustainable, environmentally friendly and economic cooling method, one should evaluate the trade-offs between the benefits, opportunities, costs and risks of alternatives. There is a need to incorporate qualitative and quantitative multiple criterion to compare and assess and rank the alternative technologies. The qualitative evaluation methods are based on expert evaluation methods, safety check list methods, fault hypothesis analysis methods, etc., and the quantitative evaluation methods are based on exponential methods, probability methods, fuzzy synthetic evaluation methods, artificial neural network methods, etc. These methods not only have their own characteristics and feasibility, but also have some drawbacks.

Multi-criteria decision making has received attention from researchers and practitioners in evaluating, assessing and ranking alternatives across diverse industrial and non-industrial sectors. For example, to evaluate urban sustainable development in China [10]; to evaluate the strategies for sustainable energy planning [11]; to optimize renewable energy systems [12]. One of the principal objectives here is to adopt multi-criteria decision analysis methodology to compare and assess cooling options through different technology routes for three different climatic zones. The results of this study will help decision makers to choose the right technology under the right conditions, and different climatic zones can be tested using the similar procedure.

2. Methodology and Criteria

The performance assessment factors include environmental concerns, overall energy consumption, cost concerns, machine performance, ability to manage load variations from the supply side as well as the demand side and ergonomic concerns. In Table 1, the different criteria used are tabulated. When electrical or thermal energy is produced from fossil fuel or other biomass fuels, the emissions released and its quantity depend on the type of fuels and its combustion characteristics. For the purpose of analysis in this study, the emissions for natural gas-fired power production is taken during electrical energy usage unless alternate fuels are mentioned specifically. The ozone layer depletion potential (ODP) as well as the global warming potential (GWP) due to refrigerants that are used in the cooling machines are taken from literature and used in the analysis [13]. Noise is another major environmental concern, especially in vapor compression machines involving compressors.

Table 1. Criteria categories and their objectives.

Criterion Category		**j**	**Criterion Symbol, Name, and Criterion Objective**	**Units**
Environmental concerns	Emissions	1	C1: CO_2, minimization	*
		2	C2: CO, minimization	*
		3	C3: SO_2, minimization	*
		4	C4: NO_X, minimization	*
		5	C5: N_2O, minimization	*
		6	C6: HCL, minimization	*
		7	C7: NH_3, minimization	*
		8	C8: HF, minimization	*
		9	C9: Particulate matter, minimization	*
		10	C10: Dioxins/Furans, minimization	**
		11	C11:Poly-aromatichydrocarbons, minimization	***
		12	C12: Cadmium and thallium, minimization	***
		13	C13: Mercury, minimization	***
		14	C14: Other heavy metals, minimization	***
		15	C15: CH_4, minimization	****
	Refrigerant usage	16	C16: Ozone depletion potential of the leaked refrigerant, minimization	-
		17	C17:Global warming potential, minimization	-
	Noise	18	C18:Noise produced, minimization	dB/kW
Energy consumption	Electrical	19	C21: Cost of natural gas/diesel/Biomass used as fuel, minimization	USD/mm BTU
	Thermal	20	C22: Cost of heater used to supply thermal energy, minimization	USD/kW

Table 1. *Cont.*

Criterion Category		j	Criterion Symbol, Name, and Criterion Objective	Units
Cost concerns Investment and operating	Investment cost	21	C31: Electricity production plant cost, minimization	USD/kW
	Operating cost	22	C32: Operation and maintenance cost of the power production/heat supply unit, minimization	USD/kW-h
Machine performance	Evaporator temperature achievement	23	C41: Attainable cooling temperature, minimization	°C
	Condenser Split	24	C42: Condenser split, minimization	°C
	Reliability	25	C43: Reliability maximization	-
Ability to tolerate load variation	Fluctuating load	26	C52: Meeting the cooling load requirement, maximization	-
	Fluctuating energy supply	27	C52: Meeting the energy quality and supply requirement, maximization	-
Ergonomics	Spatial distribution components	28	C61: Improvement in appearance, maximization	-
Meeting Cooling load requirements/auxiliary needs	Meeting cooling requirement	29	C71: Difference between cooling demand and cooling produced, Minimization	kW
	Water requirement	30	C72: Water required for cooling, minimization	Kg/s per kW

* kg/Year for BLC of 1 kJ/h °C; ** ng/Year for BLC of 1 kJ/h °C; *** mg/Year for BLC of 1 kJ/h °C; **** g/Year for BLC of 1 kJ/h °C.

Initial investment costs and the operating cost of the cooling machines are proportional to the capacity and operating schedule. Technical performance of cooling machines is the achievable Coefficient of performance (*COP*), which again is a function of the evaporator and ambient temperatures in the case of vapor compression systems and the generator temperature as well in the case of vapor absorption machines. In the above table, the evaporator temperature and the condenser split (the temperature difference between the condenser and the ambient temperature) are taken as the criteria for determining machine performance.

3. Technology Options and Their Performance

The ASHRAE guidelines for recommended temperature for human comfort are 20 °C to 23.3 °C in winter and 22.2 °C to 26.6 °C in the summer. The guidelines recommend a relative humidity (RH) of 30% to 60% [14]. The capacity of the cooling system required depends on both the prevailing weather conditions and the building loss coefficient (BLC) and building operation. The different cooling methods analyzed in this study and the different concerns for performance assessment are explained below.

3.1. Vapor Compression Method

Vapor compression cooling is the most common method involving four basic components of the refrigeration cycle, namely, the compressor, condenser, expansion device and the evaporator. The process diagram is given in Figure 1a. The compressor pressurizes the refrigerant to high pressure and then the refrigerant is cooled in the condenser. The high-pressure liquid refrigerant is then expanded in the expansion valve and evaporates in the evaporator where the room cooling load occurs. HFC refrigerants such as R-134a has zero ODP but considerable GWP. Presently, the use of refrigerants such as hydrocarbons (HCs), hydro-fluoro-olefin (*HFO*), R744 (carbon dioxide), and environmentally safe nano-refrigerants can reduce both ozone depletion potential and global warming potential [15]. It has been found that replacing R-134a with R1234yf [16] had similar thermal performance and with better environmental benefits. The typical compressor is driven by electrical power and the specific power consumption varies from 0.33 kW/kW of cooling at a condenser temperature of 26 °C to 0.4 kW/kW of cooling at 40 °C condenser temperature [17]. High power consumption, especially during high ambient temperature conditions, because of high condenser temperatures, makes this method expensive to operate. Both the refrigerant used and the electrical power consumed have an ozone depletion effect as well as the global warming effect. Environmental concerns due to refrigerant leaks have been reduced by the replacement of hazardous refrigerants with eco-friendly refrigerants. Carbon dioxide emissions vary from as low as 300 kg/ton of refrigeration to 2500 kg/ton of refrigeration, depending on the type of machine used. Initial cost of vapor compression systems is around USD 570 per kW [18].

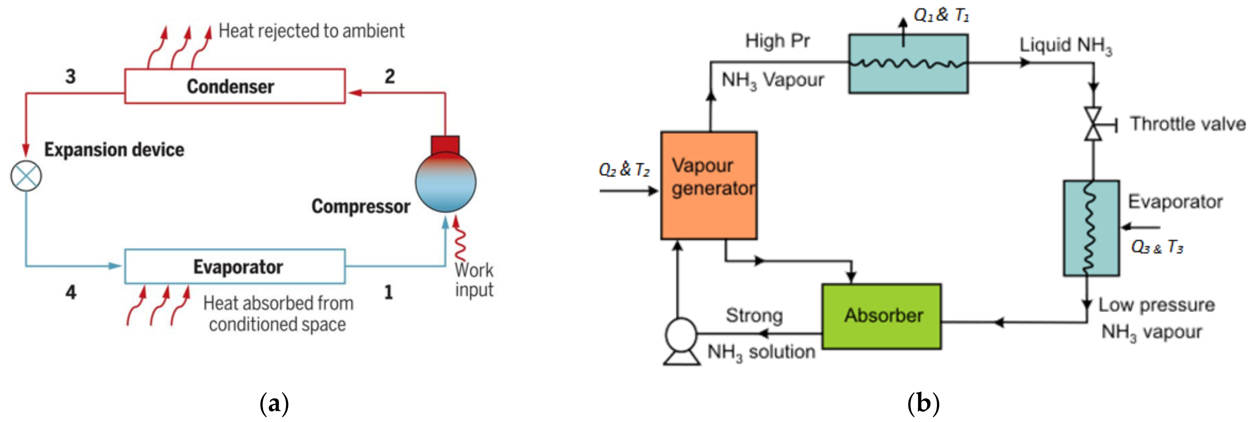

Figure 1. Technology options for cooling (**a**) Vapor compression cooling (**b**) Vapor absorption cooling.

3.1.1. Vapor Compression with Conventional Power Supply (VC1)

Grid power is used for driving the compressor and other accessories of vapor compression systems and different improvements in the energy efficiency of these systems have come up. Two of these are the variable frequency drives and variable refrigerant machines. In the case of variable frequency drives, the rotational speed of the compressor is varied as per the load variation in the room. In the case of the latter, the quantity of refrigerant evaporated in the evaporator is controlled. These methods have much more energy efficiency compared to the conventional vapor compression methods. Equation (1) is used to calculate the cooling load (Q_C) for a cooling energy, which depends on the cooling degree days (DD_C) for the location for the base temperature (T_b) and the building load coefficient (BLC). Equation (2) gives the refrigeration energy required (Q_R), which depends on the coefficient of performance. Equation (3) is used to calculate the actual grid energy (Q_E) consumed to meet the required cooling energy. The quantity of emissions produced by a natural gas power plant during the generation of the power used for cooling has been obtained from published literature [19–22]. After assuming the transmission efficiency (η_T) of 85% and efficiency of the drives (η_D) of 80%, the actual emission is determined and given in Tables 1–3. The refrigerant used is taken as R-134a and corresponding values of ODP and GWP are taken from the published data [23,24]. These systems are highly developed in terms of operational flexibility and ergonomics.

$$Q_C = 24 \sum_{i=1}^{N_H} \dot{q}_{h,i} = 24 \times BLC \times DD_C \times T_b \tag{1}$$

$$Q_R = \frac{Q_C}{COP} \tag{2}$$

$$Q_E = \frac{Q_R}{\eta_T \times \eta_D} \tag{3}$$

3.1.2. Vapor Compression with Photovoltaic Power Supply (VC2)

Solar PV can be used to replace either a part of or the total energy requirement for cooling in buildings. Extensive studies have been conducted with a partial energy substitution using PV panels to replace 30.7 percent of the electricity requirement of a cooling system and the payback period was found to be around 7 years [25].

$$A = \frac{P}{(I_t \times \eta_c)} \tag{4}$$

The above Equation (4) gives the area of collector required for supplying solar power to a cooling system for a given average value of solar radiation (I_t) and panel efficiency (η_c). For example, for a 3.51 kW cooling unit with a COP of 5 with an average solar radiation of 800 W/m^2 and a conversion efficiency of 15 percent, the area required would be 5.85 m^2. The carbon dioxide produced during the life cycle of a PV is 0.1 kg per kW-hour cooling [26]. The average installation cost of solar PV systems is USD 2500 per kW [27–29]. Other emissions in the form of heavy metals have been reported by several researchers, but they are not considered due to negligible quantity.

3.2. Vapor Absorption Method

The principle behind the absorption cooling process is separation and recombination of the refrigerant vapor from the absorbing fluid (refrigerant and absorbent) to create a cooling effect as shown in Figure 1b. Usually, absorption chillers fluid pair are either NH_3-H_2O (ammonia-water) or H_2O-LiBr (lithium bromide-water). In the former, water acts as the absorbent and ammonia acts as the refrigerant. In the latter, water acts as the refrigerant and lithium bromide is the absorbent. The refrigerant and absorbent are separated in the generator using external heat supplied by different methods as given below. The initial cost of vapor absorption systems is around USD 854.7 per kW [30].

3.2.1. Vapor Absorption with Conventional Fuel Firing (VA1)

Vapor absorption refrigeration systems can be operated using diesel oil-fired burners to supply the required quantity of heat. The oil can also be replaced with other fuels such as natural gas or other conventional fuels. The quantity of fuel required depends on the generator operating temperature and the cooling capacity. Theoretical generator temperature required depends on the *COP* of the system as below given in Equation (5).

$$COP = \left(\frac{T_e}{T_o - T_e}\right) \times \left(\frac{T_g - T_o}{T_g}\right) \tag{5}$$

Theoretical *COP* of a vapor absorption system with evaporator temperature (T_e) of 278 K, ambient temperature (T_o) of 320 K and generator temperature (T_g) of 363 K is calculated as 0.78. The temperatures assumed here are values occurring in summer conditions to maintain room temperatures at a comfortable level of 293 K (20 °C). In the present study, the fuel considered for firing is diesel for assessing emissions. The quantity of emissions is based on the combustion system after taking efficiency into account. The working fluid composition is ammonia and water.

Thermal power (P_T) required by a 3.51 kW cooling system is given below in Equation (6). The operating costs for a vapor absorption system are predominantly the fuel costs and are thus determined by the fuel cost and the heating value (*HV*) of the fuel. Conventional fuels are available at different costs (*FC*) and qualities which impact the operating costs. Annual operating cost (C_O) is given by Equation (7).

$$P_T = \left(\frac{3.51}{COP}\right) \tag{6}$$

$$C_O = \frac{P_T \times 3600 \times 365 \times FC}{HV \times \eta_C} \tag{7}$$

3.2.2. Vapor Absorption with Solar Thermal Energy (VA2)

Thermal power required by the vapor absorption cooling machines can also be supplied by solar thermal systems, which can be solar water heating systems or solar air heating systems. Solar water heating systems have higher efficiency among the above two but have the disadvantage of lower fluid outlet temperature. Solar air heating systems have lower efficiency but higher fluid outlet temperature, which makes it beneficial to increase the generator temperature and *COP* of the cooling system. The collector area (A_C) required to supply the thermal power is given by the following equation obtained from the Hottel Whillier Bliss modified as in below Equation (8). In this analysis, the solar air heater is taken as the energy source.

$$A_C = \frac{P_T}{F_R[(I_T \times \tau\alpha) - U_T(T_i - T_a)]} \tag{8}$$

The area of the collector is calculated based on the average daily solar radiation (I_T) received by the collector. F_R is the collector heat removal factor, $\tau\alpha$ is the collector transmissivity absorptivity coefficient, U_T is the overall heat transfer coefficient of the collector, T_i is the inlet fluid temperature and T_o is the ambient temperature. Costs of solar thermal collectors has an average value of USD 1300 per kilowatt [31,32]. No emissions are produced during the manufacture or operation of solar thermal collectors.

3.2.3. Vapor Absorption with Biomass Firing (VA3)

Biomass is used to supply the heat for the generator of the vapor absorption system using a combustion equipment which is designed as per the type of biomass available. Heating values of biomass vary from as low as 10,000 kJ/kg to 20,000 kJ/kg. Combustion efficiency of such systems is around 40 to 50 percent. Investment cost of a biomass combustion unit is about USD 632/kW. This includes the air handling system, fuel handling system and the flue gas handling equipment. Operating costs mainly consist of the fuel cost which varies widely with an average value of USD 8/kg [33].

3.3. Hybrid Cooling Methods

Hybrid cooling methods involve two or more cooling methods arranged in series mode or parallel mode. Series mode indicates using the cooling produced by one machine to cool the condenser of the second machine, which in turn is used to cool the room. The advantage of this method is its ability to achieve high *COP* in the primary machine due to low condenser temperature. The parallel mode of operation involves using two machines simultaneously to cool the room with both the machines having a condenser side exposed to ambient and evaporators exposed to the room. Three different options are considered for analysis in this research paper.

3.3.1. Hybrid Cooling with Vapor Compression System and Evaporative Cooling of Condenser (HC1)

In this method, the condenser of the vapor compression refrigeration system (as per the above-mentioned VC1 using an electrically driven compressor) is cooled using evaporative cooler in order to overcome the extreme temperature conditions experienced in desert climates in summer (Figure 2). This arrangement helps to improve the coefficient of performance of the vapor compression system and reduce the power consumption of the compressor. Evaporative cooling involves phase change of water during which the latent heat required for phase change produces the cooling effect. Such systems operate better in locations where ambient humidity is low. The evaporation rate is higher in such locations and the cooling effect is more. Coolers for normal household cooling applications consume about 400 to 700 Watts. The average investment cost of evaporative coolers is around USD 2000 for producing a cooling effect equivalent of kW. A maximum of 10 °C reduction in the condenser temperature reduced the specific power consumption by 0.085 kW/kW of cooling [34]. The effect of evaporative coolers is maximum in dry ambient conditions producing cooling up to 10 °C and moderate under humid conditions, producing a cooling of 5 °C. A 10 °C temperature reduction produces a 40% increase in *COP* and a 5% temperature reduction produces a 20% improvement in *COP*. The reduced energy consumption due to this condenser cooling is given by Equation (9).

$$Q_{RNew} = Q_R \times \frac{COP_{New}}{COP} \quad (9)$$

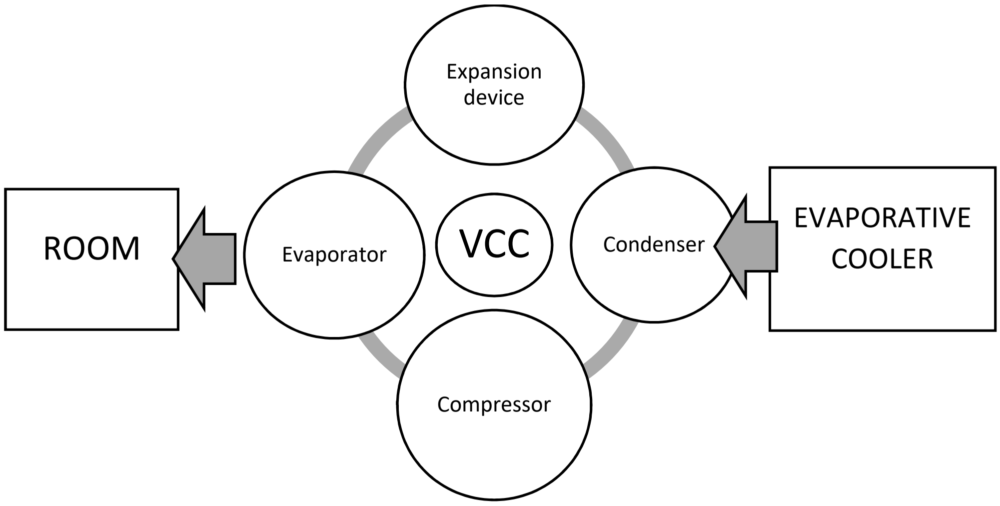

Figure 2. Vapor compression system with evaporative cooling of condenser.

3.3.2. Hybrid Cooling with Solar Vapor Absorption System and Evaporative Cooling of Condenser (HC2)

The heat required at the generator is supplied from a solar collector. A generator temperature from 80 to 100 °C is adequate to operate the system satisfactorily (refer below to Figure 3). However, the area of the collector required depends on the capacity of the cooling required. Solar air heaters have higher fluid outlet temperatures due to the lesser specific heat and density of the air used. However, the efficiency of solar air heating collectors is much lower than water heating collectors. There are different options for solar collectors, namely, water heating collectors, air heating collectors and collectors with reflectors or concentrators. Another important parameter that affects the system performance is the condenser temperature. The condenser of the vapor absorption system could be water cooled, air cooled or with evaporative cooling. In this study, evaporative cooling of condenser is used to analyze the system performance. Condenser cooling produces an improvement in the *COP* and decrease in the thermal energy requirement of the vapor absorption system [35]. Hence, the reduced electrical energy and the additional electrical supply required for the evaporative cooling are considered for assessment.

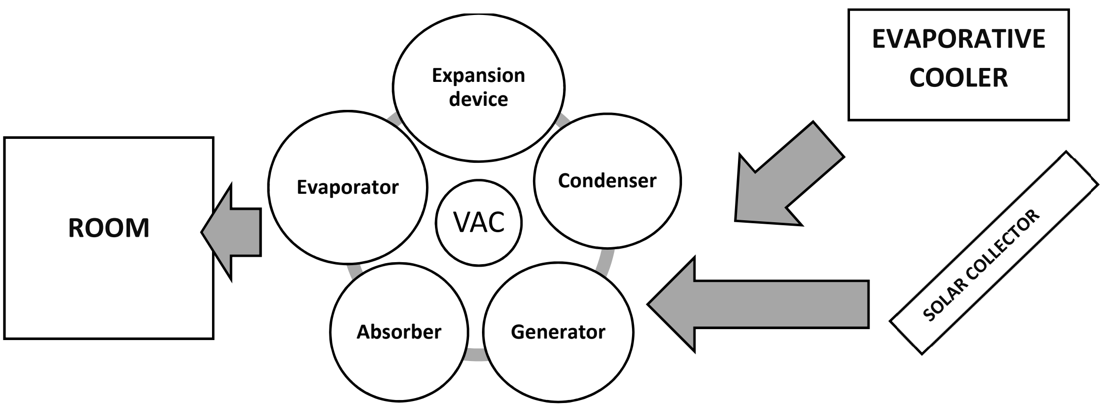

Figure 3. Solar vapor absorption system with evaporative cooling of condenser.

3.3.3. Hybrid Cooling with Combined Vapor Compression Cooling and Solar Vapor Absorption Cooling and Evaporative Cooling of Condenser (HC3)

This combination can help to substantially reduce electrical power consumption due to vapor compression cooling machines because the coefficient of performance of vapor compression coolers (VCC) is less during peak solar radiation hours. In contrast, solar collector-based VAC machines can deliver maximum output during this time due to high solar energy recovery (refer below to Figure 4). Hence, the peak load requirement and overall system capacity of VCC can be reduced by this type of arrangement. The cooling load in this case is assumed to be divided equally by the VCC and VAC cooling methods. The VCC is operated by conventional power and the VAC is operated by heat available from solar thermal collector. In this case, a solar heater is assumed to be the heat supply source. Further, evaporative coolers are used to cool the condenser of the VCC and VAC. Hence, the electrical power is used for two machines, namely, the VCC system and EC system.

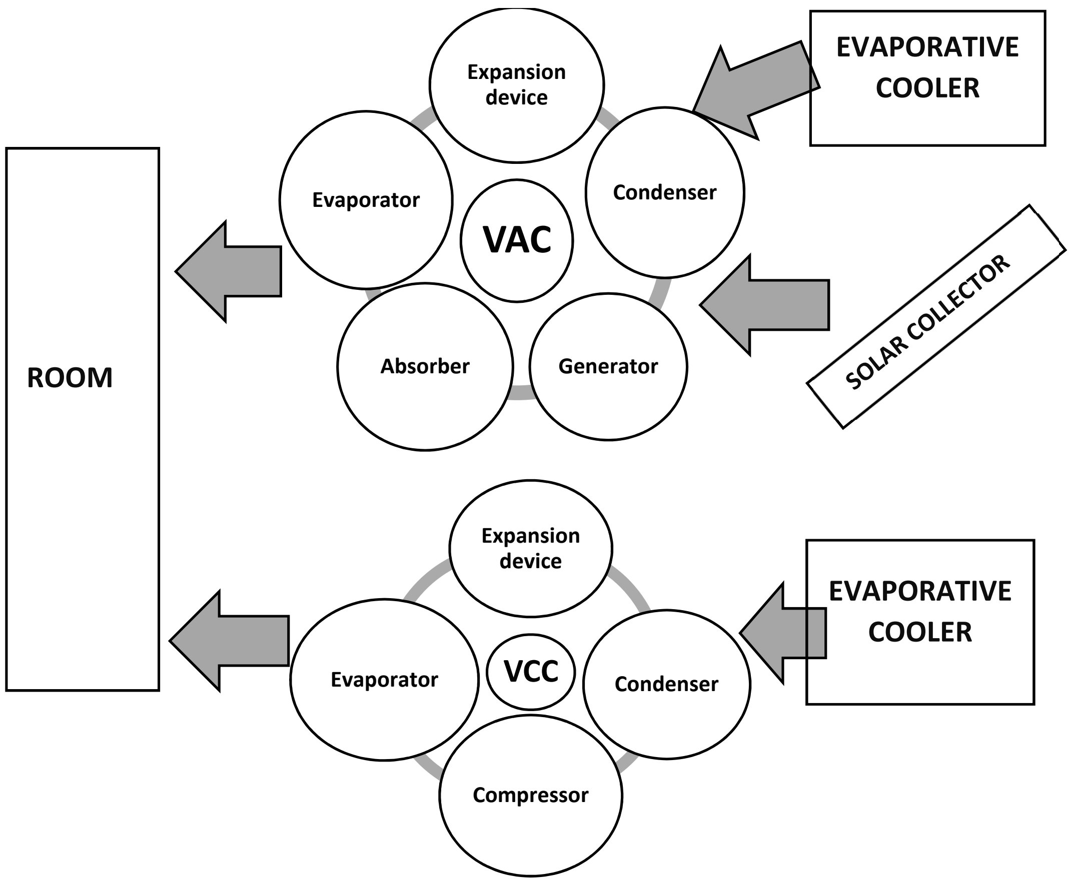

Figure 4. Combined Vapor compression cooling with solar vapor absorption cooling and evaporative cooling of condenser.

4. Cooling Climatic Zones

In this study, three types of climatic conditions are considered based on the solar radiation intensity, ambient temperature variation and the prevailing relative humidity. While solar radiation and ambient temperature influence the performance of solar collectors, the relative humidity and the ambient temperature data determine the cooling performance of the air conditioning systems.

4.1. Maritime Arid (BWhH) Climate Zone

This climate region has hot weather most of the year with highly intensive solar radiation and high humidity levels. Air conditioning machines operating in this situation have high latent heat load as well as sensible heat loads. However, the high level of solar radiations has the possibility of solar thermal collectors as well as solar photovoltaic systems extensively for energizing the air conditioning machines. Evaporative cooling does not work efficiently in this type of climate.

4.2. Dry Arid (BWhD) Climate Zone

This climate region has high solar radiation and hot weather most of the year, but low humidity levels. Hence, the latent heat load is much less compared to maritime region. However, the evaporative cooling machines produce effective cooling in this climate due to low wet bulb temperature.

4.3. Temperate Continental (Cfb) Climate Zone

This climate has moderate temperatures throughout the year as well as moderate humidity levels. Solar radiation intensity is less compared to tropical regions, because of which the solar collectors (thermal and photovoltaic) are less effective. Hence, larger collector area is required for supplying heat or electricity to the VAC or the VCC system.

5. Operating Schedule and Assumptions

The grid power option, conventional fuel option and the biomass heat supply option are assumed to be available on a 24 h basis. Solar option is assumed to be available for 8 h during which sunshine is considerable for operating the vapor absorption system as the average duration of sunshine in this considered climatic zone is 8.85 h [36]. Conventional fuel used is natural gas with associated emissions and cost factors. This fuel is selected due to the availability in the region [37]. Biomass fuel is composed of agricultural waste with associated emissions and cost factors [38]. The cooling load requirements in cooling degree days are taken from published data for the three different climate zones [39]. Three different cities are considered for this purpose, which are Riyadh, located in the interior region with dry conditions, Bahrain, located the coastal region and has humid conditions and London, which has moderate temperature and humidity conditions. The base temperature used to determine the cooling degree day for the above locations is 18.3 °C. The average annual cooling loads for summer conditions are taken. Equation (6) as presented above is used to calculate the energy requirement for cooling. The outdoor temperature is arid summer condition of 40 to 45 °C with a humidity of 15% for the arid dry climate and 60% for the arid maritime climate.

The different technology options, their operating time and the specifications are tabulated in Table 2 below. The refrigeration energy required for performing the cooling is calculated using above Equations (1)–(3) by assuming a *COP* of 5 which was based on performance of existing machines [40]. The cooling energy in the above equation is for Building load coefficient of 0.0027 W/K. Below, Tables 3–5 give the emissions produced for the three climate zones for the total seasonal heating energy required for each zone.

Table 2. Cooling Strategies and their Operating time and type of fuel used.

Cooling Strategies (i)	Description	Operating Hours
VC1	Vapor compression with conventional power supply	Full time on grid power
VC2	Vapor compression with photovoltaic power supply	8 AM to 4 PM—solar photovoltaic power 4 PM to 8 AM—grid power
VA1	Vapor absorption with conventional fuel firing	Full time on diesel thermal power
VA2	Vapor absorption with solar thermal heat supply	8 AM to 4 PM—solar thermal power 4 PM to 8 AM—diesel power
VA3	Vapor absorption with biomass fuel firing	Full time on biomass thermal power
HC1	Vapor compresion with evaporative cooling of condenser	Full time on grid power

Table 2. *Cont.*

Cooling Strategies (i)	Description	Operating Hours
HC2	Vapor absorption with evaporative cooling of condensser	Full time on diesel power plus grid power
HC3	Combined vapor compression and vapor absorption with evaporatively cooled condenser.	50% load from grid power for vapor compression system, 50% on diesel power for vapor absorption system, grid power for evaporative cooling system

Table 3. The data of evaluation criterions corresponding to cooling strategies for maritime arid climate.

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	VC2	VA1	VA2	VA3	HC1	HC2	HC3
1	242.44	145.24	198.36	115.71	119.02	173.17	141.69	117.09
2	7.38	4.31	6.04	3.52	3.62	5.27	4.31	3.56
3	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.02
4	0.05	0.03	0.04	0.02	0.02	0.04	0.03	0.02
5	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
6	0.37	0.21	0.30	0.17	0.18	0.26	0.21	0.18
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
9	22.44	13.09	18.36	10.71	11.02	16.03	13.11	10.84
10	0.68	0.40	0.56	0.32	0.33	0.49	0.40	0.33
11	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
12	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.02
13	0.56	0.33	0.46	0.27	0.27	0.40	0.33	0.27
14	0.76	0.44	0.62	0.36	0.37	0.54	0.44	0.37
15	27.31	15.93	22.34	13.03	13.41	19.51	15.96	13.19
16	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}
17	1300.0	758.33	1063.6	620.45	638.18	928.57	759.74	627.84
18	14.25	8.31	11.66	6.80	6.99	10.17	8.32	6.88
19	245.00	142.92	200.45	116.93	120.27	175.00	143.18	118.32
20	00.00	29.17	40.91	23.86	24.55	00.00	29.22	24.15
21	696.00	406.00	569.45	332.18	341.67	497.14	406.75	336.14
22	0.10	0.06	0.08	0.05	0.05	0.07	0.06	0.05
23	VG #	G	G	G	G	VG	G	VG
24	G	G	G	G	G	VG	VG	VG
25	P	G	A	A	A	P	G	A
26	G	A	A	A	A	VG	A	VG
27	G	G	G	A	A	VG	A	VG
28	VG	G	A	A	A	A	A	G
29	VG	G	G	A	G	VG	G	VG
30	2	2	1	1	1	1	1	0.32

Note: @ refer to above Table 1, * refer to above Table 2, and #: (VG: very good, G: good; A: average; P: poor).

Table 4. The data of evaluation criterions corresponding to cooling strategies for dry arid climate.

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	**VC2**	**VA1**	**VA2**	**VA3**	**HC1**	**HC2**	**HC3**
1	128.61	77.04	105.23	61.38	63.14	91.86	75.16	62.11
2	3.91	2.28	3.20	1.87	1.92	2.80	2.29	1.89
3	0.02	0.01	0.02	0.01	0.01	0.02	0.01	0.01
4	0.03	0.02	0.02	0.01	0.01	0.02	0.02	0.01
5	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
6	0.19	0.11	0.16	0.09	0.10	0.14	0.11	0.09
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
9	11.90	6.94	9.74	5.68	5.84	8.50	6.96	5.75
10	0.36	0.21	0.30	0.17	0.18	0.26	0.21	0.17
11	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
12	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01
13	0.30	0.17	0.24	0.14	0.15	0.21	0.17	0.14
14	0.40	0.24	0.33	0.19	0.20	0.29	0.24	0.19
15	14.49	8.45	11.85	6.91	7.11	10.35	8.47	7.00
16	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}
17	689.61	402.28	564.23	329.13	338.54	492.58	403.02	333.05
18	7.56	4.41	6.18	3.61	3.71	5.40	4.42	3.64
19	129.97	75.81	106.34	62.03	63.80	92.83	75.95	62.77
20	26.52	15.47	21.70	12.66	13.02	18.95	15.50	12.81
21	369.21	215.37	60.42	35.24	36.25	263.72	43.15	35.66
22	0.05	0.03	0.04	0.03	0.03	0.04	0.03	0.03
23	VG #	G	G	G	G	VG	G	VG
24	G	G	G	G	G	VG	VG	VG
25	VG	A	G	G	G	VG	A	VG
26	G	A	A	A	A	G	A	VG
27	G	G	G	G	G	VG	G	VG
28	VG	G	A	A	A	A	A	G
29	VG	G	G	A	G	VG	G	VG
30	0	0	0	0	0	0.16	0.16	0.16

Note: @ refer to above Table 1, * refer to above Table 2 and #: (VG: very good, G: good; A: average; P: poor).

Table 5. The data of evaluation criterions corresponding to cooling strategies for temperate continental climate.

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	**VC2**	**VA1**	**VA2**	**VA3**	**HC1**	**HC2**	**HC3**
1	128.61	77.04	105.23	61.38	63.14	91.86	75.16	62.11
2	3.91	2.28	3.20	1.87	1.92	2.80	2.29	1.89
3	0.02	0.01	0.02	0.01	0.01	0.02	0.01	0.01
4	0.03	0.02	0.02	0.01	0.01	0.02	0.02	0.01
5	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00

Table 5. *Cont.*

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	**VC2**	**VA1**	**VA2**	**VA3**	**HC1**	**HC2**	**HC3**
6	0.19	0.11	0.16	0.09	0.10	0.14	0.11	0.09
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
9	11.90	6.94	9.74	5.68	5.84	8.50	6.96	5.75
10	0.36	0.21	0.30	0.17	0.18	0.26	0.21	0.17
11	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
12	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01
13	0.30	0.17	0.24	0.14	0.15	0.21	0.17	0.14
14	0.40	0.24	0.33	0.19	0.20	0.29	0.24	0.19
15	14.49	8.45	11.85	6.91	7.11	10.35	8.47	7.00
16	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}
17	689.61	402.28	564.23	329.13	338.54	492.58	403.02	333.05
18	7.56	4.41	6.18	3.61	3.71	5.40	4.42	3.66
19	129.97	75.81	106.34	62.03	63.80	92.83	75.95	62.77
20	26.52	15.47	21.70	12.66	13.02	18.95	15.50	12.81
21	369.21	215.37	60.42	35.24	36.25	263.72	43.15	35.66
22	0.05	0.03	0.04	0.03	0.03	0.04	0.03	0.03
23	VG #	G	G	G	G	VG	G	VG
24	G	G	G	G	G	VG	VG	VG
25	VG	A	G	G	G	VG	A	VG
26	G	A	A	A	A	VG	A	VG
27	G	G	G	A	A	VG	A	VG
28	VG	G	A	A	A	A	A	G
29	VG	G	G	A	G	VG	G	VG
30	0	0	0	0	0	0.16	0.16	0.16

Note: @ refer to above Table 1, * refer to above Table 2 and #: (VG: very good, G: good; A: average; P: poor).

6. Cooling Strategy Evaluation: MCDM Approach and Its Application

In order to meet the objective of determining suitable weights of criterion and sub-criterion, it is necessary to minimize disorders and produce results in accordance with facts. In cooling climatic zone criterion evaluation, the entropy weight method by Shannon can be used to determine the system disorder degree. The smaller the entropy value is, the smaller the disorder degree of the cooling climatic zone criterion is. Here, in the paper, the entropy weight method is adopted to determine the weight of the criterion and sub-criterion related to cooling climatic zone evaluation.

The MCDM approach that can be applied when a set of alternatives cooling strategies is to be ranked according to a set of criteria reflecting the given climatic zone preferences. The adopted MCDM approach is straightforward and the concept permits the pursuit of best alternatives for each criterion depicted in a simple mathematical form, and the criteria weights are incorporated into the comparison procedures. Selected the alternative that is the closest to the ideal solution and farthest from the negative ideal alternative. For a given set of m alternatives (options) and n attributes/criteria and the score of each climate zone with respect to each criterion, refer to above Tables 2–4. The details of the cooling strategy evaluation using the MCDM approach are in the following section.

6.1. Structure of the Decision Matrix and Its Standardization

Suppose there are m cooling strategies and n evaluation criteria for the cooling climatic zone, where X_{ij} is the jth criterion's value in the ith cooling strategy. In order to eliminate the influence of criteria dimension on incommensurability, it is necessary to standardize criteria using the equations of relative optimum membership degree. To the maximum benefit of the criterion, the attribute value of the jth criterion in the ith cooling strategy can be standardized by using Equation (10) below, whereas for a minimization criterion, the attribute value of the jth criterion in the ith cooling strategy can be standardized by using Equation (11).

$$S_{ij} = \left[\frac{X_{ij} - \min_j X_{ij}}{\max_j X_{ij} - \min_j X_{ij}} \right] \tag{10}$$

$$S_{ij} = \left[\frac{\max_j X_{ij} - X_{ij}}{\max_j X_{ij} - \min_j X_{ij}} \right] \tag{11}$$

In the above Equations (10) and (11), S_{ij} is the standardized criterion value for the j^{th} criterion of the ith alternative cooling strategy); X_{ij} is the jth criterion's value for the i^{th} alternative cooling strategy; and (i = 1, . . . , m) and (j = 1, . . . , n). Supposing an evaluation set of multi-attribute decision making problems has the jth criterion's value in the i^{th} cooling strategy is X_{ij}, then the decision matrix is $X = [X_{ij}]m \times n$; refer to Table 6 below.

Table 6. Decision matrix for ith cooling strategy and jth criterion.

Evaluation Criterion (j)→ Alternative Cooling Strategies (i)↓	1	2	...	n
1	X_{11}	X_{12}	...	X_{1n}
2	X_{21}	X_{22}	...	X_{2n}
.	.	.	...	.
.	.	.	...	.
m	X_{m1}	X_{m2}	...	X_{mn}
Criterion Weight→	W_1	W_2	...	W_n

The standardization of all evaluation criteria for the given climatic zone, the structure of decision matrix is expressed as below in Equation (12).

$$S'_{ij} = \begin{bmatrix} S_{11} & S_{12} & \dots & S_{1n} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ S_{m1} & S_{m2} & \dots & S_{mn} \end{bmatrix} \tag{12}$$

After standardization of all evaluation criteria for all given cooling methods (refer to the above Equations (10)–(12)), the decision matrix is expressed for each cooling climatic zones type as here below in Tables 7–9.

Table 7. Standardized Decision matrix S'_{ij} for cooling maritime arid climatic zone.

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	VC2	VA1	VA2	VA3	HC1	HC2	HC3
1	0.000	0.767	0.348	1.000	0.974	0.547	0.795	0.989
2	0.000	0.795	0.347	1.000	0.974	0.547	0.795	0.990

Table 7. *Cont.*

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	VC2	VA1	VA2	VA3	HC1	HC2	HC3
3	0.000	1.000	0.500	1.000	1.000	0.500	1.000	1.000
4	0.000	0.667	0.333	1.000	1.000	0.333	0.667	1.000
5	0.979	1.000	0.000	1.000	0.500	0.980	0.993	0.987
6	0.000	0.800	0.350	1.000	0.950	0.550	0.800	0.950
7	0.972	1.000	0.000	1.000	0.500	0.967	1.000	0.983
8	0.875	1.000	0.000	1.000	0.500	0.963	0.958	0.960
9	0.000	0.797	0.348	1.000	0.974	0.546	0.795	0.989
10	0.000	0.778	0.333	1.000	0.972	0.528	0.778	0.972
11	0.023	1.000	1.000	1.000	1.000	0.000	0.770	0.385
12	0.000	1.000	0.500	1.000	1.000	0.500	1.000	1.000
13	0.000	0.793	0.345	1.000	1.000	0.552	0.793	1.000
14	0.000	0.800	0.350	1.000	0.975	0.550	0.800	0.975
15	0.000	0.797	0.348	1.000	0.973	0.546	0.795	0.989
16	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
17	0.000	0.797	0.348	1.000	0.974	0.547	0.795	0.989
18	0.000	0.797	0.348	1.000	0.974	0.547	0.795	0.989
19	0.000	0.797	0.348	1.000	0.974	0.547	0.795	0.989
20	1.000	0.287	0.000	0.417	0.400	1.000	0.286	0.410
21	0.000	0.797	0.348	1.000	0.974	0.547	0.795	0.989
22	0.000	0.800	0.400	1.000	1.000	0.600	0.800	1.000
23	1.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000
24	0.000	0.000	0.000	0.000	0.000	1.000	1.000	1.000
25	1.000	0.000	0.500	0.500	0.500	1.000	0.000	0.500
26	0.500	0.000	0.000	0.000	0.000	1.000	0.000	1.000
27	0.500	0.500	0.500	0.000	0.000	1.000	0.000	1.000
28	1.000	0.500	0.000	0.000	0.000	0.000	0.000	0.500
29	1.000	0.500	0.500	0.000	0.500	1.000	0.500	1.000
30	0.500	0.500	1.000	1.000	1.000	1.000	1.000	1.340

Note: @ refer to above Table 1, and * Refer Table 2 above.

Table 8. Standardized Decision matrix S'_{ij} for cooling dry arid climatic zone.

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	VC2	VA1	VA2	VA3	HC1	HC2	HC3
1	0.000	0.767	0.348	1.000	0.974	0.547	0.795	0.989
2	0.000	0.799	0.348	1.000	0.975	0.544	0.794	0.990
3	0.000	1.000	0.000	1.000	1.000	0.000	1.000	1.000
4	0.000	0.500	0.500	1.000	1.000	0.500	0.500	1.000
5	0.000	1.000	0.000	1.000	1.000	1.000	1.000	1.000
6	0.000	0.800	0.300	1.000	0.900	0.500	0.800	1.000
7	0.980	1.000	0.000	1.000	0.644	0.976	1.000	0.988

Table 8. *Cont.*

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	VC2	VA1	VA2	VA3	HC1	HC2	HC3
8	0.000	1.000	0.000	1.000	1.000	1.000	1.000	1.000
9	0.000	0.797	0.347	1.000	0.974	0.547	0.794	0.989
10	0.000	0.789	0.316	1.000	0.947	0.526	0.789	1.000
11	0.000	1.000	0.000	1.000	1.000	1.000	1.000	1.000
12	0.000	1.000	0.000	1.000	1.000	1.000	1.000	1.000
13	0.000	0.813	0.375	1.000	0.938	0.563	0.813	1.000
14	0.000	0.762	0.333	1.000	0.952	0.524	0.762	1.000
15	0.000	0.797	0.348	1.000	0.974	0.546	0.794	0.988
16	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
17	0.000	0.797	0.348	1.000	0.974	0.547	0.795	0.989
18	0.000	0.797	0.348	1.000	0.974	0.546	0.795	0.989
19	0.000	0.797	0.348	1.000	0.974	0.547	0.795	0.989
20	0.000	0.797	0.348	1.000	0.974	0.546	0.795	0.989
21	0.000	0.461	0.925	1.000	0.997	0.316	0.976	0.999
22	0.000	1.000	0.500	1.000	1.000	0.500	1.000	1.000
23	1.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000
24	0.000	0.000	0.000	0.000	0.000	1.000	1.000	1.000
25	0.000	1.000	0.500	0.500	0.500	0.000	1.000	0.000
26	0.500	0.000	0.000	0.000	0.000	1.000	0.000	1.000
27	0.500	0.500	0.500	0.000	0.000	1.000	0.000	1.000
28	1.000	0.500	0.000	0.000	0.000	0.000	0.000	0.500
29	1.000	0.500	0.500	0.000	0.500	1.000	0.500	1.000
30	1.500	1.500	1.500	1.500	1.500	1.420	1.420	1.420

Note: @ refer to above Table 1, and * Refer Table 2 above.

Table 9. Standardized Decision matrix S'_{ij} for cooling temperate continental climatic zone.

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	VC2	VA1	VA2	VA3	HC1	HC2	HC3
1	0.391	0.000	0.602	1.000	0.984	0.724	0.876	0.995
2	0.000	0.797	0.348	1.000	0.975	0.546	0.796	0.990
3	0.000	0.800	0.200	1.000	0.800	0.400	0.800	1.000
4	0.000	0.833	0.333	1.000	1.000	0.500	0.833	1.000
5	0.000	0.500	0.500	1.000	1.000	0.500	0.500	1.000
6	0.000	0.791	0.349	1.000	0.977	0.535	0.791	0.977
7	0.000	0.000	0.000	1.000	1.000	0.000	0.000	1.000
8	0.000	0.500	0.500	1.000	1.000	0.500	0.500	1.000
9	0.000	0.797	0.348	1.000	0.974	0.546	0.795	0.989
10	0.000	0.790	0.346	1.000	0.975	0.543	0.790	0.988
11	0.000	0.500	0.500	1.000	1.000	0.500	0.500	1.000

Table 9. *Cont.*

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	**VC2**	**VA1**	**VA2**	**VA3**	**HC1**	**HC2**	**HC3**
12	0.000	0.750	0.250	1.000	1.000	0.500	0.750	1.000
13	0.000	0.791	0.343	1.000	0.970	0.552	0.791	0.985
14	0.000	0.800	0.356	1.000	0.978	0.544	0.800	0.989
15	0.000	0.797	0.348	1.000	0.974	0.547	0.795	0.989
16	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
17	0.000	0.797	0.348	1.000	0.974	0.547	0.795	0.989
18	0.000	0.797	0.348	1.000	0.974	0.547	0.795	0.989
19	0.000	0.797	0.348	1.000	0.974	0.547	0.795	0.989
20	0.000	0.797	0.348	1.000	0.974	0.547	0.795	0.989
21	0.000	0.461	0.925	1.000	0.997	0.316	0.976	0.999
22	0.000	0.833	0.417	1.000	1.000	0.583	0.833	1.000
23	1.000	0.000	0.000	0.000	0.000	1.000	1.000	1.000
24	0.000	0.000	0.000	0.000	0.000	1.000	1.000	1.000
25	1.000	1.000	1.000	1.000	1.000	0.000	1.000	1.000
26	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27	1.000	0.500	0.500	0.000	0.000	0.500	0.500	0.500
28	1.000	0.500	0.500	0.500	0.000	0.500	0.500	0.000
29	1.000	0.500	0.500	0.000	0.500	1.000	0.500	1.000
30	1.500	1.500	1.500	1.500	1.500	1.380	1.380	1.380

Note: @ refer to above Table 1, and * Refer Table 2 above.

6.2. Estimation of Criterion Entropy Weights

The entropy weight represents useful information of the criterion related to cooling climatic zone evaluation. Note that higher the entropy weight of the evaluation criterion, the more important the criterion and vice versa. Whereas the entropy weight E_j of the the jth criterion of the ith alternative cooling strategy is determined by Equation (13). Subsequently, based on E_j of the jth criterion, W_j, the criterion entropy weights, is determined by using Equation (14).

$$E_j = -\frac{\sum_{i=1}^{m}[S_{ij} \times \ln(S_{ij})]}{\ln(m)} \quad (13)$$

$$W_j = \frac{1 - E_j}{\left[1 - \sum_{j=1}^{n} E_j\right]} \quad (14)$$

Using standardization of all evaluation criteria, W_j an entropy weight of the jth criterion is determined by Equations (13) and (14). Obtained E_j values for each climatic zones and for irrespective of climatic zone the overall entropy weights for each evaluation criterion are presented here below in Table 10.

Table 10. E_j entropy weight values for criterion related to cooling climatic zone.

Evaluation Criterion (j) @	Cooling Climatic Zone			Average Weight
	BWhH	**BWhD**	**Cfb**	
1	0.0299	0.0267	0.0298	0.0288
2	0.0302	0.0270	0.0292	0.0288

Table 10. *Cont.*

Evaluation Criterion (j) @	Cooling Climatic Zone			Average Weight
	BWhH	BWhD	Cfb	
3	0.0357	0.0398	0.0275	0.0343
4	0.0278	0.0236	0.0302	0.0272
5	0.0395	0.0398	0.0255	0.0349
6	0.0295	0.0262	0.0289	0.0282
7	0.0393	0.0358	0.0430	0.0394
8	0.0372	0.0398	0.0255	0.0342
9	0.0302	0.0269	0.0291	0.0288
10	0.0295	0.0266	0.0290	0.0284
11	0.0362	0.0398	0.0255	0.0338
12	0.0357	0.0398	0.0288	0.0347
13	0.0307	0.0270	0.0290	0.0289
14	0.0301	0.0261	0.0292	0.0285
15	0.0302	0.0269	0.0291	0.0288
16	0.0450	0.0398	0.0430	0.0426
17	0.0302	0.0270	0.0291	0.0288
18	0.0302	0.0270	0.0291	0.0288
19	0.0302	0.0270	0.0291	0.0288
20	0.0205	0.0270	0.0291	0.0255
21	0.0302	0.0302	0.0326	0.0310
22	0.0311	0.0317	0.0306	0.0311
23	0.0450	0.0398	0.0430	0.0426
24	0.0450	0.0398	0.0430	0.0426
25	0.0263	0.0276	0.0430	0.0323
26	0.0404	0.0357	0.0430	0.0397
27	0.0310	0.0276	0.0211	0.0266
28	0.0357	0.0317	0.0211	0.0295
29	0.0263	0.0236	0.0255	0.0251
30	0.0410	0.0928	0.0983	0.0774

Note: @ refer to above Table 1.

6.3. Normalization of the Decision Matrix

In order to eliminate the influence of criteria dimension and its variation range on cooling strategy evaluation results, it is necessary to normalize the original matrix to ensure that all the attributes are equivalent and the same format, then the normalized decision matrix is R_{ij} is obtained using Equation (15) below. After normalization of all evaluation criteria for all given cooling methods the decision matrix is expressed for each cooling climatic zones type as here below in Tables 11–13.

$$R_{ij} = \frac{X_{ij}}{\sqrt{\sum X_{ij}^2}} \tag{15}$$

Table 11. Normalized decision matrix R_{ij} for cooling maritime arid climatic zone.

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	VC2	VA1	VA2	VA3	HC1	HC2	HC3
1	0.5284	0.3165	0.4323	0.2522	0.2594	0.3774	0.3088	0.2552
2	0.5298	0.3094	0.4336	0.2527	0.2599	0.3783	0.3094	0.2556
3	0.5443	0.2722	0.4082	0.2722	0.2722	0.4082	0.2722	0.2722
4	0.5361	0.3216	0.4288	0.2144	0.2144	0.4288	0.3216	0.2144
5	0.0189	0.0000	0.8940	0.0000	0.4470	0.0176	0.0063	0.0120
6	0.5361	0.3043	0.4346	0.2463	0.2608	0.3767	0.3043	0.2608
7	0.0248	0.0000	0.8937	0.0000	0.4468	0.0298	0.0000	0.0149
8	0.1109	0.0000	0.8872	0.0000	0.4436	0.0333	0.0370	0.0351
9	0.5297	0.3090	0.4334	0.2528	0.2601	0.3784	0.3095	0.2559
10	0.5284	0.3108	0.4351	0.2486	0.2564	0.3807	0.3108	0.2564
11	0.6326	0.0000	0.0000	0.0000	0.0003	0.6474	0.1488	0.3981
12	0.5443	0.2722	0.4082	0.2722	0.2722	0.4082	0.2722	0.2722
13	0.5287	0.3116	0.4343	0.2549	0.2549	0.3777	0.3116	0.2549
14	0.5316	0.3077	0.4336	0.2518	0.2588	0.3777	0.3077	0.2588
15	0.5298	0.3090	0.4333	0.2528	0.2601	0.3785	0.3096	0.2559
16	0.3536	0.3536	0.3536	0.3536	0.3536	0.3536	0.3536	0.3536
17	0.5297	0.3090	0.4334	0.2528	0.2601	0.3784	0.3096	0.2558
18	0.5297	0.3090	0.4334	0.2528	0.2601	0.3783	0.3096	0.2559
19	0.5297	0.3090	0.4334	0.2528	0.2601	0.3784	0.3096	0.2558
20	0.0000	0.4071	0.5710	0.3330	0.3426	0.0000	0.4078	0.3371
21	0.5297	0.3090	0.4334	0.2528	0.2601	0.3784	0.3096	0.2558
22	0.5270	0.3162	0.4216	0.2635	0.2635	0.3689	0.3162	0.2635
23	0.2085	0.4170	0.4170	0.4170	0.4170	0.2085	0.4170	0.2085
24	0.4170	0.4170	0.4170	0.4170	0.4170	0.2085	0.2085	0.2085
25	0.4588	0.2294	0.3441	0.3441	0.3441	0.4588	0.2294	0.3441
26	0.3841	0.2561	0.2561	0.2561	0.2561	0.5121	0.2561	0.5121
27	0.3560	0.3560	0.3560	0.2374	0.2374	0.4747	0.2374	0.4747
28	0.5443	0.4082	0.2722	0.2722	0.2722	0.2722	0.2722	0.4082
29	0.1890	0.3780	0.3780	0.5669	0.3780	0.1890	0.3780	0.1890
30	0.5525	0.5525	0.2763	0.2763	0.2763	0.2763	0.2763	0.0884

Note: @ refer to above Table 1, and * Refer Table 2 above.

Table 12. Normalized decision matrix R_{ij} for cooling dry arid climatic zone.

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	VC2	VA1	VA2	VA3	HC1	HC2	HC3
1	0.5284	0.3165	0.4323	0.2522	0.2594	0.3774	0.3088	0.2552
2	0.5293	0.3087	0.4332	0.2532	0.2599	0.3791	0.3100	0.2559
3	0.4851	0.2425	0.4851	0.2425	0.2425	0.4851	0.2425	0.2425
4	0.5669	0.3780	0.3780	0.1890	0.1890	0.3780	0.3780	0.1890
5	0.7071	0.0000	0.7071	0.0000	0.0000	0.0000	0.0000	0.0000

Table 12. *Cont.*

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	VC2	VA1	VA2	VA3	HC1	HC2	HC3
6	0.5236	0.3031	0.4409	0.2480	0.2756	0.3858	0.3031	0.2480
7	0.0186	0.0000	0.9416	0.0000	0.3353	0.0223	0.0000	0.0112
8	0.7071	0.0000	0.7071	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.5297	0.3089	0.4335	0.2528	0.2599	0.3783	0.3098	0.2559
10	0.5276	0.3078	0.4397	0.2491	0.2638	0.3810	0.3078	0.2491
11	0.7071	0.0000	0.7071	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.5345	0.2673	0.5345	0.2673	0.2673	0.2673	0.2673	0.2673
13	0.5378	0.3047	0.4302	0.2510	0.2689	0.3764	0.3047	0.2510
14	0.5250	0.3150	0.4332	0.2494	0.2625	0.3807	0.3150	0.2494
15	0.5298	0.3090	0.4333	0.2527	0.2600	0.3784	0.3097	0.2560
16	0.3536	0.3536	0.3536	0.3536	0.3536	0.3536	0.3536	0.3536
17	0.5297	0.3090	0.4334	0.2528	0.2601	0.3784	0.3096	0.2558
18	0.5297	0.3090	0.4334	0.2529	0.2600	0.3785	0.3096	0.2559
19	0.5298	0.3090	0.4334	0.2528	0.2600	0.3784	0.3096	0.2558
20	0.5297	0.3090	0.4334	0.2529	0.2600	0.3785	0.3096	0.2559
21	0.7219	0.4211	0.1181	0.0689	0.0709	0.5156	0.0844	0.0697
22	0.4951	0.2970	0.3961	0.2970	0.2970	0.3961	0.2970	0.2970
23	0.2085	0.4170	0.4170	0.4170	0.4170	0.2085	0.4170	0.2085
24	0.4170	0.4170	0.4170	0.4170	0.4170	0.2085	0.2085	0.2085
25	0.1741	0.5222	0.3482	0.3482	0.3482	0.1741	0.5222	0.1741
26	0.3841	0.2561	0.2561	0.2561	0.2561	0.5121	0.2561	0.5121
27	0.3560	0.3560	0.3560	0.2374	0.2374	0.4747	0.2374	0.4747
28	0.5443	0.4082	0.2722	0.2722	0.2722	0.2722	0.2722	0.4082
29	0.1890	0.3780	0.3780	0.5669	0.3780	0.1890	0.3780	0.1890
30	0.0000	0.0000	0.0000	0.0000	0.0000	0.5774	0.5774	0.5774

Note: @ refer to above Table 1, and * Refer Table 2 above.

Table 13. Normalized decision matrix R_{ij} for cooling temperate continental climatic zone.

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	VC2	VA1	VA2	VA3	HC1	HC2	HC3
1	0.4469	0.5964	0.3659	0.2138	0.2199	0.3193	0.2613	0.2155
2	0.5297	0.3092	0.4334	0.2529	0.2599	0.3784	0.3095	0.2558
3	0.5188	0.2882	0.4611	0.2306	0.2882	0.4035	0.2882	0.2306
4	0.5413	0.2952	0.4429	0.2460	0.2460	0.3937	0.2952	0.2460
5	0.5669	0.3780	0.3780	0.1890	0.1890	0.3780	0.3780	0.1890
6	0.5291	0.3097	0.4323	0.2516	0.2581	0.3807	0.3097	0.2581
7	0.4472	0.4472	0.4472	0.0000	0.0000	0.4472	0.4472	0.0000
8	0.5669	0.3780	0.3780	0.1890	0.1890	0.3780	0.3780	0.1890
9	0.5297	0.3090	0.4335	0.2528	0.2601	0.3784	0.3096	0.2558
10	0.5303	0.3099	0.4339	0.2514	0.2583	0.3788	0.3099	0.2548

Table 13. *Cont.*

Evaluation Criterion (j) @	Alternative Cooling Strategies (i)							
	VC1 *	**VC2**	**VA1**	**VA2**	**VA3**	**HC1**	**HC2**	**HC3**
11	0.5669	0.3780	0.3780	0.1890	0.1890	0.3780	0.3780	0.1890
12	0.5090	0.3181	0.4454	0.2545	0.2545	0.3818	0.3181	0.2545
13	0.5312	0.3095	0.4350	0.2510	0.2593	0.3764	0.3095	0.2551
14	0.5308	0.3086	0.4321	0.2531	0.2593	0.3796	0.3086	0.2562
15	0.5297	0.3090	0.4334	0.2529	0.2601	0.3784	0.3096	0.2559
16	0.3536	0.3536	0.3536	0.3536	0.3536	0.3536	0.3536	0.3536
17	0.5297	0.3090	0.4334	0.2528	0.2601	0.3784	0.3096	0.2558
18	0.5297	0.3090	0.4334	0.2528	0.2601	0.3784	0.3096	0.2558
19	0.5297	0.3090	0.4334	0.2528	0.2601	0.3784	0.3096	0.2558
20	0.5297	0.3090	0.4334	0.2528	0.2601	0.3784	0.3096	0.2558
21	0.7219	0.4211	0.1181	0.0689	0.0709	0.5156	0.0844	0.0697
22	0.5406	0.3056	0.4231	0.2586	0.2586	0.3761	0.3056	0.2586
23	0.2236	0.4472	0.4472	0.4472	0.4472	0.2236	0.2236	0.2236
24	0.4170	0.4170	0.4170	0.4170	0.4170	0.2085	0.2085	0.2085
25	0.3536	0.3536	0.3536	0.3536	0.3536	0.3536	0.3536	0.3536
26	0.4500	0.3375	0.3375	0.3375	0.3375	0.3375	0.3375	0.3375
27	0.4815	0.3612	0.3612	0.2408	0.2408	0.3612	0.3612	0.3612
28	0.4815	0.3612	0.3612	0.3612	0.2408	0.3612	0.3612	0.2408
29	0.1890	0.3780	0.3780	0.5669	0.3780	0.1890	0.3780	0.1890
30	0.0000	0.0000	0.0000	0.0000	0.0000	0.5774	0.5774	0.5774

Note: @ refer to above Table 1, and * Refer Table 2 above.

6.4. Determine Best and Worst Cooling Strategy for a Given Criterion

Multiply each element of the above normalized decision matrix by its associated entropy weight W_j; the decision matrix is obtained using Equation (16) below.

$$V_{ij} = W_j \times R_{ij} \tag{16}$$

The outcome of above Equation (16) results in the set of best and worst solutions, and are obtained using Equations (17) and (18), respectively.

$$\begin{gathered} V^{+} = \text{Best soultion} = \left\{V_1^{+}, \ldots V_j^{+}, \ldots\ V_n^{+}\right\} \\ \text{In Equation (14) } V_j^{+} = \text{maxi}\left(V_{ij}\right) \text{ if j } \in \\ \text{maximization criteria; mini}\left(V_{ij}\right) \text{ if j } \in \text{minimization criteria} \end{gathered} \tag{17}$$

$$\begin{gathered} V^{-} = \text{Worst soultion} = \left\{V_1^{-}, \ldots V_j^{-}, \ldots\ V_n^{-}\right\} \\ \text{In Equation (15) } V_j^{-} = \text{mini}\left(V_{ij}\right) \text{ if j } \in \\ \text{minimization criteria; maxi}\left(V_{ij}\right) \text{ if j } \in \text{maximization criteria} \end{gathered} \tag{18}$$

6.5. Determine the Closeness to Ideal Solution for Each Alternative Cooling Strategy and Ranking the Alternative

For a given alternative cooling strategy, its distance from the best ideal cooling strategy is obtained using Equation (19).

$$D_i^{+} = \sqrt{\sum\nolimits_j \left(V_j^{+} - V_{ij}\right)} \tag{19}$$

For a given cooling strategy, its distance from the worst ideal cooling strategy is obtained using Equation (20) below.

$$D_i^- = \sqrt{\sum_j \left(V_j^- - V_{ij}\right)} \tag{20}$$

For a given cooling strategy, its closeness to ideal cooling strategy is obtained using Equation (21) below.

$$C_i = \frac{D_i^-}{D_i^+ - D_i^-} \tag{21}$$

In the above Equation (21), C_i value ranges between one and zero. The alternative cooling strategy i with maximum positive value of Ci is ranked number one.

Thus, the decision matrix of three cooling climatic zone and corresponding eight cooling strategies and 30 evaluation criterions are established according to the data in Table 7 above. The normalized decision matrix is established and the weighted decision matrix is estimated (refer to above Table 9), and the best solution and the worst solution values are obtained by using Equations (17) and (18).

7. Results and Discussion

Refer to Tables 3–5 above, which give the results of the different factors for selection among the eight different technology options using Equations (1)–(8). The various emissions produced due to the different technology options are listed in items 1–15. Values are entrusted for all the emissions for comparison purposes. Calculations performed as per the assumptions in Section 5 and operating times as given in Table 2. It can be seen that the maximum carbon dioxide is produced by fully grid powered VC1 systems due to the emissions produced in the power plant. Additionally, the losses due to transmission and the efficiency of the machines involved contribute to the high energy usage and consequently the emissions. In the case of VC2, a part of the electrical power consumption is substituted by solar energy for a fraction of the time. Hence, in this case, the carbon dioxide emission is reduced due to the use of solar energy. Absorption refrigeration system running on diesel oil as represented by VA1 has further reduced carbon dioxide emission because of the direct firing. It is also inferred that use of cleaner fuels can bring down the emissions further. When the absorption systems are supplied heat from solar thermal heaters as in VA2, we have the situation of minimum emission production because solar thermal heaters are the most environmentally friendly thermal heat sources. Biomass-powered vapor absorption systems (VA3) are used with agro-industrial as well as agricultural waste and the emissions produced by these systems are lesser, due to the fact that the fuel is a renewable source. Evaporative coolers which are used to cool the condensers of vapor compression (HC1) and vapor absorption systems (HC2) have enhanced COP due to low condenser temperatures. Hence, the power consumed is less. However, the electrical energy used to drive the cooler fan is to be accounted for. In the case of combined vapor compression and vapor absorption system with condenser cooling, the vapor absorption system is assumed to be driven by solar energy and hence the emissions are very low in this case. All the other emission parameters give a similar trend. Using normalized decision matrix and weighted decision matrix (refer to above Table 9) the best solution and the worst solution values are obtained by using Equations (17) and (18). The corresponding best cooling strategies and the worst cooling strategies for each criterion for given climatic zones are obtained and presented here below in Table 14.

Table 14. Best V^+ and worst V^- solution for each criterion for climatic zones using corresponding E_j entropy weight values.

Evaluation Criterion (j) @	Cooling Climatic Zone											
	Maritime Arid (BWhH)				Dry Arid (BWhD)				Temperate Continental (Cfb)			
	V+	**Best Cooling Strategy ***	**V−**	**Worst Cooling Strategy ***	**V+**	**Best Cooling Strategy**	**V−**	**Worst Cooling Strategy**	**V+**	**Best Cooling Strategy**	**V−**	**Worst Cooling Strategy**
1	0.0075	VA2	0.0158	VC1	0.0067	VA2	0.0141	VC1	0.006	VA2	0.017	2
2	0.0076	VA2	0.0160	VC1	0.0068	VA2	0.0143	VC1	0.007	VA2	0.015	VC1
3	0.0097	VC2,VA2,VA3/HC2, HC3	0.0194	VC1	0.0096	VC2,VA2,VA3/HC2, HC3	0.0193	VC1, VA1, HC1	0.008	VA2, HC3	0.018	VC1
4	0.0060	VA2,VA3,HC3	0.0149	VC1	0.0045	VA2,VA3, HC3	0.0134	VC1	0.007	VA2,VA3, HC3	0.015	VC1
5	0.0000	VC2,VA2	0.0353	VA1	0.0000	VC2,VA2,VA3,HC1, HC2,HC3	0.0281	VC1, VA1	0.007	VA2,VA3, HC3	0.020	VC1
6	0.0073	VA2	0.0158	VC1	0.0065	VA2,HC3	0.0137	VC1	0.007	VA2	0.015	VC1
7	0.0000	VA2,VA2,HC2	0.0351	VA3	0.0000	VC2,VA2,HC2	0.0337	VA1	0.000	VA2,VA3, HC3	0.018	VC1, VC2,VA1, HC1, HC2
8	0.0000	VC2,VA2	0.0330	VA1	0.0000	VC2,VA2,VA3,HC1, HC2,HC3	0.0281	VC1,VA1	0.006	VA2,VA3, HC3	0.019	VC1
9	0.0076	VA2	0.0160	VC1	0.0068	VA2	0.0143	VC1	0.007	VA2	0.015	VC1
10	0.0073	VA2	0.0156	VC1	0.0066	VA2, HC3	0.0140	VC1	0.007	VA2	0.015	VC1
11	0.0000	VC2,VA2	0.0234	HC1	0.0000	VC2,VA2,VA3,HC1, HC2,HC3	0.0281	VC1, VA1	0.006	VA2,VA3, HC3	0.019	VC1
12	0.0097	VC2,VA2,VA3, HC2,HC3	0.0194	VC1	0.0106	VC2,VA2,VA3,HC1, HC2,HC3	0.0213	1,3	0.009	VA2,VA3, HC3	0.018	VC1
13	0.0078	VA2,VA3, HC3	0.0162	VC1	0.0068	VA2,HC3	0.0145	VC1	0.007	VA2	0.015	VC1
14	0.0076	VA2	0.0160	VC1	0.0065	VA2,HC3	0.0137	VC1	0.007	VA2	0.015	VC1
15	0.0076	VA2	0.0160	VC1	0.0068	VA2	0.0143	VC1	0.007	VA2	0.015	VC1
16	0.0159	VC2,VA2,VA3, HC2,HC3	0.0159	VC1	0.0141	VC2,VA2,VA3,HC1, HC2,HC3	0.0141	1,3	0.015	VA2,VA3, HC3	0.015	VC1,VC2
17	0.0076	VA2	0.0160	VC1	0.0068	VA2	0.0143	VC1	0.007	VA2	0.015	VC1
18	0.0076	VA2	0.0160	VC1	0.0068	VA2	0.0143	VC1	0.007	VA2	0.015	VC1
19	0.0076	VA2	0.0160	VC1	0.0068	VA2	0.0143	VC1	0.007	VA2	0.015	VC1
20	0.0000	VC1,HC1	0.0117	VA1	0.0068	VA2	0.0143	VC1	0.006	VA2	0.014	VC1
21	0.0076	VA2	0.0160	VC1	0.0021	VA2	0.0218	VC1	0.002	VA2	0.022	VC1

Table 14. *Cont.*

Evaluation Criterion (j) @	Cooling Climatic Zone											
	Maritime Arid (BWhH)				Dry Arid (BWhD)				Temperate Continental (Cfb)			
	V^+	Best Cooling Strategy *	V^-	Worst Cooling Strategy *	V^+	Best Cooling Strategy	V^-	Worst Cooling Strategy	V^+	Best Cooling Strategy	V^-	Worst Cooling Strategy
22	0.0082	VA2, VA3, HC3	0.0164	VC1	0.0094	VA2,HC3	0.0157	VC1	0.008	VA2, VA3, HC3	0.017	VC1
23	0.0094	VC1,HC16,HC3	0.0188	VC2,VA1, VA2,VA2, HC2	0.0083	VC1,HC1,HC3	0.0166	VC2,VA1, VA2, VA2, HC2	0.010	VC1,HC1, HC2, HC3	0.019	VC2,VA1,VA2,VA3
24	0.0094	HC1,HC2,HC3	0.0188	VC1,VC2,VA1, VA2,VA2, HC2	0.0083	HC1 HC2,HC3	0.0166	VC1, VC2,VA1 VA2, VA2	0.009	HC1,HC2,HC3	0.018	VC1, VC2,VA1,VA2,VA2
25	0.0121	VC1,HC1	0.0060	VC2, HC2	0.0144	VC2,HC2	0.0048	VC1,HC1,HC3	0.011	HC1,HC2,HC3	0.011	VC2,VA1,VA2
26	0.0207	HC1,HC3	0.0103	VC2,VA1,VA2, VA3,HC2	0.0183	VA3, HC3	0.0092	VC2,VA1,VA2, VA3,HC2	0.018	VC1	0.013	HC1,HC2,HC3
27	0.0147	HC1,HC3	0.0074	VA2,VA3,HC2	0.0131	VA3, HC3	0.0066	VA2,VA3,HC1	0.013	VC1	0.006	VA2, VA3
28	0.0194	VC1	0.0097	VA1,VA2,VA3, HC1,HC2	0.0172	VC1	0.0086	VA1,VA2,VA3, HC1,HC2	0.014	VC1	0.007	VA3, HC3
29	0.0050	VC2,HC1,HC3	0.0149	VA2	0.0045	VC1,HC1,HC3	0.0134	VC2	0.005	VC1,HC1,HC3	0.014	VA2
30	0.0036	HC3	0.0226	VC1, VC2	0.0000	VC1, VC2, VA1, VA2, VA3	0.0536	HC1, HC2, HC3	0.000	VC1,VC2VA1, VA2,VA3	0.045	HC1,HC2,HC3

Note: @ refer to above Table 1, and * Refer Table 2 above.

The best and worst cooling strategies for different climatic zones are given in above Table 14. It can be seen that under maritime arid climate zone, VA2 cooling technology has best performance in about 20 out of the 30 criteria. This is attributed to the reduced environmental damage due to solar thermal heating as well as minimized operating costs. At the same time, VC1 gives the worst performance in 20 out of the 30 criteria. This is attributed mainly due to environmental damages due to conventional electrical energy used as well as the cost of operation. It is also notable that VAVAEC cooling technology shows best performance in 10 criteria. Under dry arid conditions, VA2 gives the best performance in 201 criteria but, again, the worst performance in five criteria. HC3 cooling shows the best performance for 17 criteria while the VC1 method shows the worst performance in 18 criteria. Under temperate continental condition, VA2 gives the best performance for 23 criteria while HC3 is the best for 13 criteria. Again, VC1 is also the worst performer in this climatic zone.

As can be seen from Table 15, evaluation ranks of the eight cooling methods for the different cooling methods for three climatic zones indicate different rankings for different climatic zones. As seen in Figure 5a, while the HC3 method demonstrates the best performance in the maximum number of cases and ranks first for the Maritime Arid zone as well as the ranking irrespective of the climate, VA2 ranks fist for the Dry Arid zone and VA3 ranks first for the Temperate Continental zone. Overall, VA2 cooling gives the best performance, which is accredited mainly to low emissions and low cost of operation. Similar trend happens in the case of average entropy weight (Figure 5b) Vapor compression systems both with and without condenser cooling show the worst overall performance.

Table 15. Climatic zones, cooling strategies and their ranks using corresponding E_j entropy weight values.

Cooling Strategy (i)↓	Cooling Strategies Ranking for Maritime Arid Climatic Zone							
	Based on BWhH Entropy Weight				Based on Average Entropy Weight			
	D_i^+	D_i^-	C_i	Rank	D_i^+	D_i^-	C_i	Rank
VC1 *	0.0470	0.0608	0.5639	7	0.0545	0.0578	0.5148	7
VC2	0.0293	0.0707	0.7066	4	0.0425	0.0665	0.6099	5
VA1	0.0683	0.0299	0.3043	8	0.0660	0.0337	0.3382	8
VA2	0.0254	0.0739	0.7441	2	0.0274	0.0722	0.7246	2
VA3	0.0383	0.0525	0.5782	6	0.0384	0.0533	0.5815	6
HC1	0.0312	0.0666	0.6810	5	0.0317	0.0661	0.6757	4
HC2	0.0247	0.0696	0.7377	3	0.0275	0.0682	0.7128	3
HC3	0.0170	0.0742	0.8131	1	0.0170	0.0767	0.8190	1
Cooling Strategy (i)↓	Cooling Strategies Ranking for Dry Arid Climatic Zone							
	Based on BWhD Entropy Weight				Based on Average Entropy Weight			
	D_i^+	D_i^-	C_i	Rank	D_i^+	D_i^-	C_i	Rank
VC1 *	0.0628	0.0650	0.5085	7	0.0588	0.0599	0.5044	7
VC2	0.0208	0.0854	0.8043	2	0.0221	0.0780	0.7794	2
VA1	0.0662	0.0580	0.4669	8	0.0636	0.0503	0.4417	8
VA2	0.0210	0.0882	0.8077	1	0.0221	0.0814	0.7867	1
VA3	0.0230	0.0842	0.7857	3	0.0244	0.0760	0.7570	3
HC1	0.0590	0.0646	0.5227	6	0.0514	0.0620	0.5469	6
HC2	0.0567	0.0689	0.5487	5	0.0486	0.0667	0.5785	5
HC3	0.0546	0.0722	0.5693	4	0.0462	0.0704	0.6036	4

Table 15. *Cont.*

Cooling Strategy (i)↓	Cooling Strategies Ranking for Maritime Arid Climatic Zone							
	Based on BWhH Entropy Weight				Based on Average Entropy Weight			
	D_i^+	D_i^-	C_i	Rank	D_i^+	D_i^-	C_i	Rank
VC1 *	0.0471	0.0592	0.5569	5	0.0485	0.0480	0.4977	6
VC2	0.0312	0.0637	0.6711	3	0.0309	0.0538	0.6352	3
VA1	0.0336	0.0623	0.6493	4	0.0338	0.0517	0.6045	4
VA2	0.0179	0.0738	0.8046	2	0.0183	0.0660	0.7833	2
VA3	0.0166	0.0735	0.8161	1	0.0175	0.0655	0.7887	1
HC1	0.0643	0.0273	0.2977	8	0.0539	0.0282	0.3435	8
HC2	0.0614	0.0380	0.3822	7	0.0504	0.0382	0.4312	7
HC3	0.0573	0.0497	0.4647	6	0.0456	0.0510	0.5279	5
Cooling Strategy (i)↓	Cooling Strategies Ranking Irrespective of Climate Zone							
	Based on Average Entropy Weight				Based on Uniform Weight to All Criterion			
	D_i^+	D_i^-	C_i	Rank	D_i^+	D_i^-	C_i	Rank
VC1 *	0.0589	0.0185	0.2387	8	0.0479	0.0210	0.3046	8
VC2	0.0481	0.0325	0.4034	6	0.0294	0.0354	0.5463	6
VA1	0.0423	0.0253	0.3743	7	0.0386	0.0193	0.3329	7
VA2	0.0195	0.0586	0.7503	2	0.0202	0.0480	0.7034	2
VA3	0.0273	0.0464	0.6293	3	0.0199	0.0452	0.6945	3
HC1	0.0380	0.0337	0.4700	5	0.0279	0.0340	0.5492	5
HC2	0.0369	0.0365	0.4973	4	0.0258	0.0371	0.5900	4
HC3	0.0161	0.0525	0.7646	1	0.0102	0.0493	0.8286	1

Note: * Refer Table 2 above.

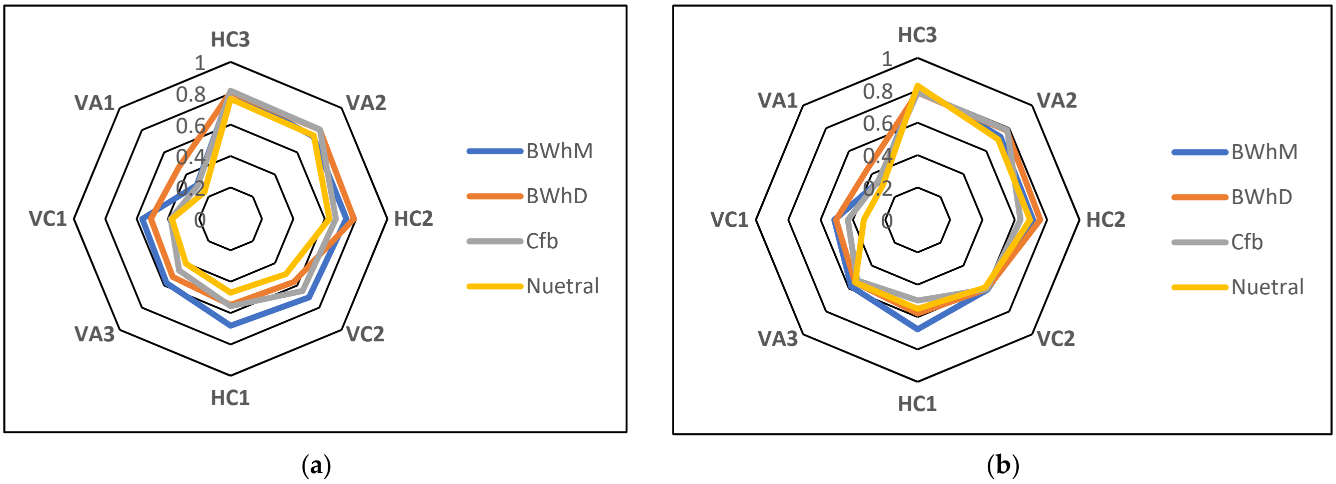

Figure 5. The ranking for the four different conditions (**a**) Based on the entropy weight for the climate (**b**) Based on average entropy weight.

Thus, selection of the technology option for a particular climatic condition for a location is one of the most challenging problems when it comes to overall energy economics and environmental benefit. This has become more complex, incorporating dynamically incorporating changing cooling requirements and external conditions. It is observed that experts are having diverse preference weights for the evaluation criterion for different locations. Thus, decision makers need to select the most suitable cooling option in order to achieve the desired global energy output with minimum cost and specific application ability. This paper mainly focuses on the selection of the best cooling option for meeting cooling requirements using TOPSIS. The entropy weight and TOPSIS method, which have high resolution and a simple calculation process, could objectively evaluate the cooling technologies. This approach is different as compared to the other known approaches. Here, the approach incorporates the fuzzy nature of decision-making. It synthesizes the preference relationships for each alternative to produce the desired outranking relationship between the entire alternative cooling strategies. A sensitivity analysis can also be performed to see the effect of the variation in the importance that is assigned to objective criteria.

8. Conclusions

A multi criterion evaluation system using TOPSIS was performed to evaluate the most suitable cooling technology among eight different alternatives for three different climate conditions.

a. Three types of weather conditions, namely, maritime arid conditions, dry arid conditions and temperate continental weather condition as per Koppen classification was considered for this study.
b. The cooling technology applied for this analysis includes vapor compression cooling with conventional grid power, vapor compression with conventional grid power and solar photovoltaic power, vapor absorption cooling with diesel firing, vapor absorption with solar thermal heater, vapor absorption with biomass firing, vapor compression with evaporative cooled condenser, vapor absorption with evaporative cooled condenser and combined vapor compression/vapor absorption cooling with evaporative cooled condenser.

Different measurable factors were used in the analysis for cooling options. Exhaustive calculations using the relevant equations as well as from existing published literature was used for generating the data for analysis. A comparative study to find the effectiveness of the TOPSIS method was performed and it was demonstrated the TOPSIS results are reliable and are more in accordance with reality. The results of the study indicate that the rankings were different for three different climatic conditions.

a. Vapor absorption system with solar heating and combined vapor compression–vapor absorption with evaporative condenser cooling were chosen as the best and second best option when the rankings were considered. This is attributed mainly to low investment cost of 35.66 USD /kW and CO_2 emissions, which are 62.11 kg/year in the case of HC3 method in tropical arid dry weather conditions. These was the best options for maritime arid weather condition as well as dry arid weather condition because of lower condenser temperature and application of solar power for power generation which produced lesser environmental damage. This is also attributed to the lower energy cost and the renewable power.
b. When the analysis was conducted for the case of climate independent condition, hybrid cooling with combined vapor compression cooling and solar vapor absorption cooling and evaporative cooling of condenser was found to rank first in performance.
c. In the case of continental temperate weather conditions, biomass-fired vapor absorption was found to be the best option. This is attributed to low cooling loads which were easily manageable by biomass power. These results can be used for policy makers to choose the appropriate technology in the above climatic zones to achieve energy efficiency and sustainable development.

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performed by Z.K. and A.U.R. Project administration and funding management was performed by Z.K. Both authors have read and agreed to the published version of the manuscript.

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