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Evaporative cooling efficiency according to climate conditions

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Abstract

The present paper evaluates Evaporative Cooling (EC) strategy efficiency, in which water is used as coolant. Based on this premise, the EC is a very interesting strategy to take into account in greenhouse gas reduction. Spain, as a European country and Kyoto protocol signatory, must reduce its emissions. The research is centered on Evaporative Cooling potential and its efficiency in the Spanish country. Starting from the climatic geographic classification considered by the Spanish Building Efficiency Rules & Regulations, a first approach to comfort potential improvement is done for the Spanish country using EC strategies. These results are the first step to evaluate EC strategies efficiency according to a geographic location. In a second step, it is calculated hourly comfort improvement for each geographic location using EC during daytime hours, when cooling is needed. With the detailed hourly evaluation it is obtained comfort improvements percentages and it is evaluated which type of EC strategy is needed in each case.

Keywords: Evaporative Cooling, Energy Efficiency, potencial cooling, water, coolant

1. Introduction

Spain as a Protocol signatory of the Climatic Change Framework Agreement (Kyoto Protocol) it is committed to reduce for 2012 greenhouse gas emissions. The European Union committed to reduce mean total greenhouse emissions in an 8% (from 1990 reference) during 2008-2012 period. Each European country had different certain limits depending on economic and environmental variables according to the

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established “load charge” for each country. Spain had a limit of +15% (with 1990 reference). [1].

According to the 2011 edition “Spain greenhouse gas stock list” [2], emissions evolution since 1990 is the one showed in the following figure (Fig.1). In 2009 Spain was in +26,8% of emissions. To achieve Kyoto Protocol, GHG emissions reduction is nowadays a main target for Spain.

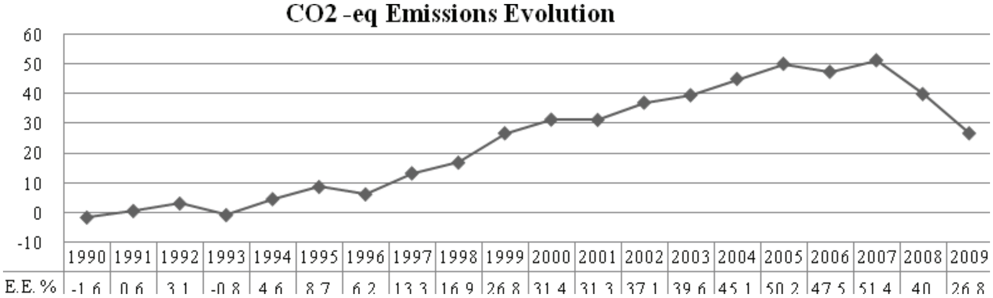


Fig.1. CO_2 Emissions Evolution.

In addition, world energy consumption has been rising too fast for the last years, with its associated environmental impacts. Buildings Energy Consumption (Residential and Commercial) reach figures between 20% and 40% in developed countries, exceeding other sectors (Table 1). This is related, amongst other things, to the increasing demand for building services and comfort levels. Among building services, the HVAC systems use near the 50% of building energy consumption [3]. Reducing HVAC demand will suppose Energy and Economic savings and therefore CO_2 emissions reductions.

Table 1. Weight of buildings energy consumption.

Final Energy Consumption (%)			
Country	Commercial	Residential	Total
USA	18	22	40
UK	11	28	39
EU	11	26	37
Spain	8	15	23
World	7	16	24

Evaporative cooling systems have been used as passive air conditioning in architecture since long time ago. The determining factors that define the effectiveness of these systems are: exterior conditions (linked to weather conditions), interior conditions (depending on comfort requirements) and architecture design.

Focusing on a country like Spain with a mild climate, the potential energy saving using passive air conditioning strategies can reach very good Energy savings figures. EC, with water as coolant, is an interesting strategy to take into account to reduce GHG emissions and therefore reduce environmental impact.

Solar gains in winter are easily predictable with Irradiance data, but EC loads are not so easily quantifiable. Moreover EC is not applicable at any climate; a previous particularized study of climate conditions of the geographic location is needed. For this purpose we developed a “Climatic Analysis Methodology” focused on calculating percentages of extended comfort using Direct or Indirect Evaporative Cooling (DEC & IEC).

2. Methodology

2.1. Evaporative Cooling process and Classification

The Evaporative Cooling (EC) is based on an air temperature reduction by means of an adiabatic process. During this psychrometric process water changes its phase from liquid to vapor. The energy needed for this change (vaporization latent heat: 2501 kJ/kg, at 0ºC and 610Pa) is taken from the air mixture itself, reducing air temperature and rising air humidity. Total energy balance maintains constant [4].

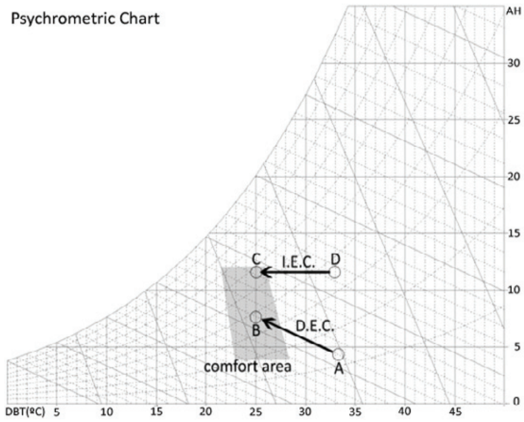


Fig. 2: (a) Psychrometric chart, with Direct and Indirect Evaporative Cooling (DEC&IEC) processes represented.

EC can be classified according to its psychrometric process and air moisture content variation after it. Direct Evaporative Cooling (DEC) is when the environment is cooled directly by water vaporization, while Indirect Evaporative Cooling (IEC) is when the environment is cooled by a cold element (cooled at the same time by water vaporization). Heat exchange is produced here by radiation, convection and conduction transfers (Fig 2a).

While in DEC air moisture content rises up, temperature decreases. In IEC process air moisture content stays constant during temperature decreasing. In addition, effectiveness in DEC is much higher than in IEC due to there are less energy looses in the whole process, because the energy needed in the vaporization is taken from the same environment. Besides, in IEC there are other energy exchanges in between and, consequently, energy losses.

The main restriction DEC has is air moisture content. In climates with high Relative Humidities (RH,%), more than 50-60%, cooling capacity goes down. In addition, there are maximum and minimum RH limits for indoor environments established by Spanish Rules & Regulations, 70% maximum and 30% minimum [5]. On the contrary, IEC is a better strategy on climates with high RH.

Besides these two main evaporative processes there can be countless intermediate ones. In fact, most of EC processes are going to be a mixture of DEC and IEC ones.

2.2. Climatic geographic areas definition

EC Efficiency is going to depend on weather conditions of a specific geographic location. At this point, it is needed a national climatic classification according to geographic areas to establish a gradation of EC strategies effectiveness depending on the building location.

Nowadays, there is a Climatic Geographic Classification for the national region, established by the Spanish Building Construction Rules & Regulations, Código Técnico de la Edificación [6]. The present research study is based on these Climatic geographic areas to facilitate comprehension of the charts and final results given at the end by any professional used to the Spanish R&R.

In the Spanish Building Construction R&R [6] the Climatic Geographic Classification is based on the provincial capital, but not to the whole provincial geographic area. That is to say, this Classification must be used as a reference guide; taking into account that a specific climatic analysis is needed if the location to study is not the capital, because geographic and climatic differences in the same provincial area can be quite big.

Definitively, 52 geographic locations have been analyzed according to the mentioned R&R [6]. National area is divided into 5 climatic areas (from A to E), divided into 4 groups (from 1 to 4). (Fig 3)

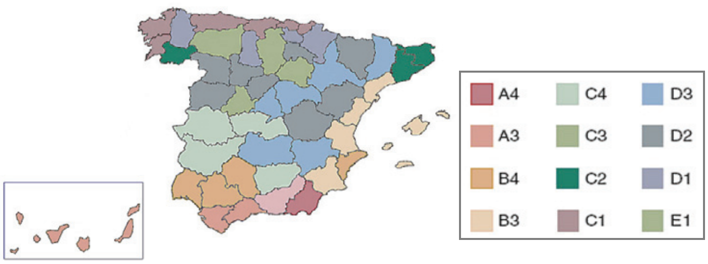


Fig. 3: Climatic geographic areas (according to Spanish Rules & Regulations).

For this research analysis the Weather Data Base used is the one registered by the U.S. Department of Energy (DOE). It is a Data Base international recognized. For Spain the files are named SWEC (Spanish Weather Energy Calculations) that comes from the State Meteorological Agency (Agencia Estatal de Meteorología, AEMET).

The inconvenience founded in this Data Base is that not all the Meteorological Observatories are coincident with the ones at provincial capitals. This must be considered for the following efficiency analysis it is going to be developed in the present paper.

2.3. Climatic data base analysis of each geographical location

At this point the 52 locations of the DOE Data Base are evaluated. Average hourly monthly data is analyzed and represented in a psychrometric chart. In this chart are also represented comfort area, DEC extended comfort area and IEC extended comfort area (Fig. 4).

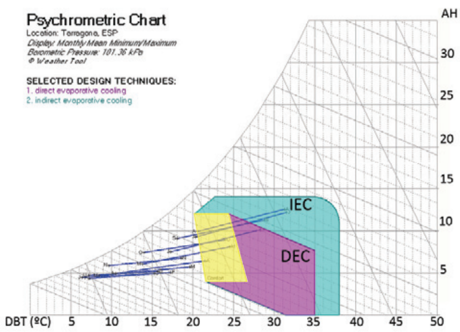


Fig. 4: Psychrometric Chart for Tarragona city, with months and DEC & IEC comfort areas represented (comfort and extended comfort).

2.4. Comfort and extended comfort data

From the psychrometric chart of each geographic location, it is calculated annual comfort and DEC and IEC extended comfort percentages (Fig 5 a, b). With these figures of potential comfort improvement using EC strategies, a first approach to the suitability or not in using EC systems can be made.

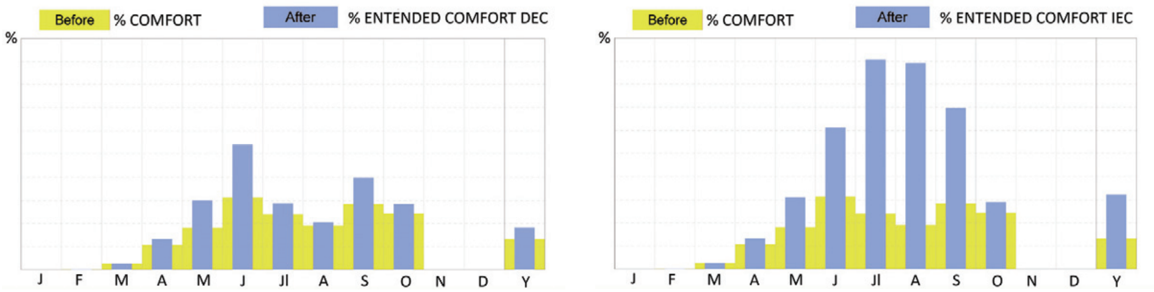


Fig. 5: (a) Comfort percentages and DEC extended comfort percentages graph for Tarragona. (b) Comfort percentages and IEC extended comfort percentages graph for Tarragona.

2.5. Data leak and Final Rating

Once potential comfort improvement percentages for the 52 geographic locations are calculated for the whole year, it is possible to remove the ones with little potential improvement. To obtain a more precise improvement comfort percentages, it is needed a more accurate hourly weather analysis. Therefore, in this second analysis, it is only take into account from May to September, months in which cooling is needed. New percentages for DEC and IEC strategies, obtained from this second evaluation, are shown in the following figures (Fig 6). Moreover, the four months average is calculated to give a rate to each geographic location. To the general rating it has been given a final grade of “drops”, where the higher percentages have a “5 drops” mark and the lower ones a “1drop” mark.

This final ranking of potential comfort improvement for different geographic locations using DEC & IEC strategies has been represented on the following maps as well (Fig. 7 a, b).

3. Analysis and evaluation of three geographic locations.

To be more precise on the definition of the potential comfort improvements and determine efficiency of using EC systems, a specific study of the concrete geographic location is needed. Furthermore, potential energy savings can be calculated from this more precise study as well.

For the present paper it has been chosen three different geographic locations with different potential comfort improvements percentages (calculated before): Seville (B4), Tarragona (B3) and Toledo (C4). The methodology followed has been: Firstly analyze the psychrometric chart with months and comfort areas representation. Secondly, analyze hourly temperatures and humidities to obtain time-ranges in which to apply EC strategies. With these time-ranges, comfort percentages calculations are carried out (extended DEC and IEC comfort).

Finally, it is obtained the number of hours of comfort period, extended comfort period putting into practice DEC and IEC systems and no-comfort period. In following Figures (Fig. 8 a, b, c) the nomenclature used is the following: “COMFORT” is for time in comfort with no additional strategies, “COMFORT WS” is comfort percentage with strategies,” No-Comfort” is for time out of comfort area (even applying DEC and IEC strategies), “DEC” is for extended comfort with Direct Evaporative Cooling strategy, “IEC” is for extended comfort with Indirect Evaporative Cooling strategy.

			Average (%) May/Sep	Rating
DIRECT EVAPORATIVE COOLING	B4	Córdoba	29	💧💧💧💧
		Huelva	15	💧
		Sevilla	19	💧💧
	C2	Orense	17	💧
	C3	Granada	28	💧💧💧💧
	C4	Badajoz	29	💧💧💧💧
		Cáceres	33	💧💧💧💧💧
		Jaén	28	💧💧💧💧
		Toledo	34	💧💧💧💧💧
	D1	Pamplona	19	💧💧
	D2	Cuenca	24	💧💧💧
		Huesca	24	💧💧💧
		Logroño	19	💧💧
		Salamanca	21	💧💧
		Segovia	20	💧💧
		Teruel	20	💧💧
		Valladolid	23	💧💧💧
		Zamora	19	💧💧💧
	D3	Albacete	26	💧💧💧💧
		Ciudad Real	25	💧💧💧
		Guadalajara	22	💧💧💧
		Lérida	23	💧💧💧
		Madrid	21	💧💧
		Zaragoza	23	💧💧💧

			Average (%) May/Sep	Rating
INDIRECT EVAPORATIVE COOLING	A3	Las Palmas	28	💧💧💧
		Cádiz	39	💧💧💧💧💧
		Málaga	32	💧💧💧💧
		Melilla	33	💧💧💧💧
		Tenerife	26	💧💧💧
	A4	Almería	38	💧💧💧💧💧
	B3	Castellón	31	💧💧💧💧
		Murcia	25	💧💧💧
		Tarragona	34	💧💧💧💧💧
		Valencia	15	💧
	B4	Alicante	31	💧💧💧💧
		Huelva	20	💧
		Sevilla	22	💧💧
	C2	Barcelona	20	💧
		Gerona	15	💧

Fig. 6. DEC and IEC comfort improvement percentages and final rating.

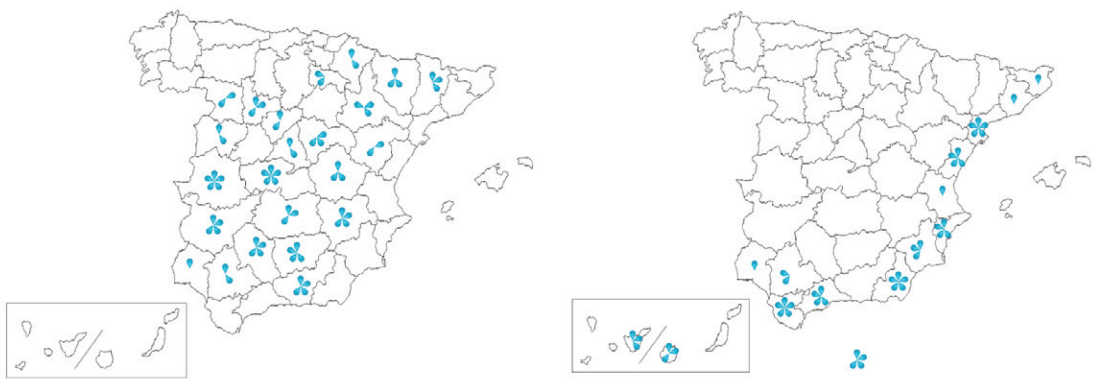
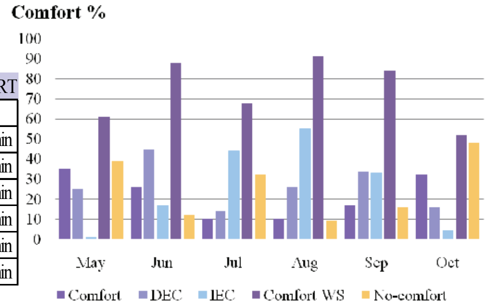


Fig. 7. (a) DEC potential comfort improvement percentages. (b) IEC potential comfort improvement percentages.

The comfort percentages (COMFORT, COMFORT WS, No-Confort, DEC and IEC) for the three specific locations of Seville, Tarragona and Toledo, can be also represented in the following bar charts (Fig. 8 a,b,c). These charts give a more visual interpretation of the same data, where the differences between percentages are more easily interpreted.

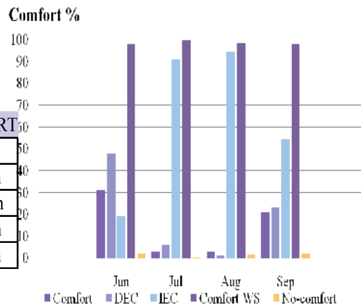
PERCENTAGE CALCULATION [08:00-23:00, SEVILLA]

	COMFORT		DEC		IEC		COMFORT WS		NO-COMFORT	
	%	hours	%	hours	%	hours	%	hours	%	hours
MAY	35	5h 15min	25	3h 45 min	1	0h 9min	61	9h 9 min	39	5h 51min
JUN	26	3h 54min	45	6h 45min	17	2h 33min	88	13h 12 min	12	1h 48min
JUL	10	1h 30min	14	2h 6min	44	6h 36min	68	10h 12 min	32	4h 48min
AUG	10	1h 30min	26	3h 54min	55	8h 15min	91	13h 39 min	9	1h 21min
SEP	17	2h 33min	34	5h 6min	16	2h 24min	84	12h 36 min	16	2h 24min
OCT	32	4h 48min	16	2h 24min	4	0h 36min	52	7h 48 min	48	7h 30min



PERCENTAGE CALCULATION [10:00-22:00, TARRAGONA]

	COMFORT		DEC		IEC		CONFORT WS		NO-COMFORT	
	%	hours	%	hours	%	hours	%	hours	%	hours
JUN	31	3h 43min	48	5h 46min	19	2h 17min	98	11h 46min	2	14min
JUL	3	7min	6	43min	90,8	10h 53min	99,8	12h	0,2	1,5min
AGO	2,9	20min	1,1	8min	94,5	11h 20min	98,5	11h 50min	1,5	11min
SEP	21	2h 31min	23	2h 46min	54	6h 29min	98	11h 46min	2	14min



PERCENTAGE CALCULATION [10:00-22:00, TOLEDO]

	COMFORT		DEC		IEC		CONFORT WS		NO-COMFOR	
	%	hours	%	hours	%	hours	%	hours	%	hours
JUN	21	2h 31min	74	8h 53min	3	22min	98	11h 46min	2	14min
JUL	1	7min	78	9h 22min	19	2h 17min	98	11h 46min	2	14min
AGO	3,5	25min	84,5	10h 8min	11	1h 19min	99	11h 53min	1	7min
SEP	23	2h 46min	74	8h 53min	1	7min	98	11h 46min	2	14min

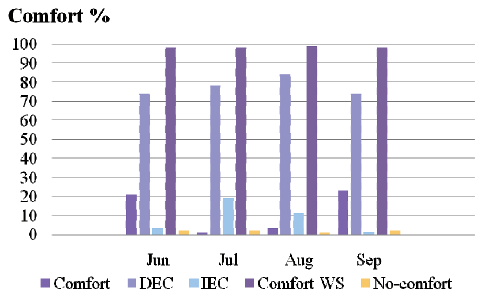


Fig. 8. (a) Comfort and comfort improvements percentages (DEC & IEC) for Seville location. (b) Comfort and comfort improvements percentages (DEC & IEC) for Tarragona location. (c) Comfort and comfort improvements percentages (DEC & IEC) for Toledo location.

4. Conclusion

Evaporative Cooling efficiency depends directly on geographic location. The graphics shown in the present paper are the result of a methodology developed to evaluate if it is worthy to apply this systems according to weather conditions.

In the previous DEC & IEC efficiency maps, it is well represented how DEC is more efficient in continental climates (with less Relative Humidity) while IEC is more efficient in the Mediterranean coast locations, with higher Relative Humidity and higher temperatures. In the Atlantic coast temperatures are not so high in warm months to need evaporative cooling strategies.

These maps are a first approach to the potential comfort improvement percentages, to give specific figures of efficiency and potential energy savings it is needed a particular weather analysis as it has been developed for Seville, Tarragona or Toledo. The methodology developed can be applied in any geographic location according to its weather conditions.

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