Contents lists available at ScienceDirect





Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Comparative study of the conventional types of heat and mass exchangers to achieve the best design of dew point evaporative coolers at diverse climatic conditions

Check for updates

Ali Sohani, Hoseyn Sayyaadi*, Negar Mohammadhosseini

Optimization of Energy Systems' Installations Lab., Faculty of Mechanical Engineering-Energy Division, K.N. Toosi University of Technology, P.O. Box 19395-1999, No. 15-19, Pardis St., Mollasadra Ave., Vanak Sq., Tehran 1991 943344, Iran

ARTICLE INFO

Keywords: Best heat and mass exchanger Dew-point (M-cycle) indirect evaporative coolers Life-cycle cost analysis Multi-objective optimization Thermal comfort conditions Water consumption

ABSTRACT

The objective of this research is a comparative analysis of various kinds of heat and mass exchangers of dew point indirect evaporative cooler. Considering three key performance parameters of an evaporative cooler, namely life-cycle cost, annual water consumption and the annual average of the coefficient of performance as objective functions, the best design of two popular types of the dew-point evaporative cooler (counter-regenerative and cross configurations) for employing in small-scale residential buildings was found through a multi-objective optimization approach. Both operational and geometric characteristics of the coolers were selected as the design (decision) variables while proper constraints such as thermal comfort were imposed. Afterward, between the optimized counter-regenerative and cross configurations, the foremost one was selected for representative cities of four diverse groups within the Köppen-Geiger climate classification system. It was found that in very hot and dry areas, the counter-regenerative configuration was the ideal choice while in other investigated climates, using cross configuration was a better alternative. Moreover, the results showed that in comparison to the base case conditions by using the best-optimized configurations, 64.4, 86.4, and 1039.0% improvements in life-cycle cost, the annual water consumption, and the annual average of the coefficient of performance were achieved, respectively.

1. Introduction

During recent years, dew point indirect evaporative cooling system (DPIEC) has occupied an important role in air-conditioning system technologies. The system was originally patented and developed by Valery Maisotsenko [1-3]. Therefore, the system is also known as the Maisotsenko (M-cycle) indirect evaporative cooling system [4,5]. Maisotsenko (M-cycle) indirect evaporative coolers (MCIECs) not only provide the supply air temperature below the wet-bulb close to dew point temperature by the highest efficiency but also consume much lower electricity than the similar vapor compression systems [6]. Additionally, MCIECs are an environmental option for the conventional vapor compression system [7]. Providing cooled air without adding moisture and wet-bulb effectiveness of higher than 100% could be counted as the main advantages of MCIECs compared to direct evaporative cooling systems (DECs) and other indirect evaporative cooling systems (IECs) [8]. There are different versions of the air flow arrangement in the M-cycle heat and mass exchangers [9]. Fig. 1a represents a counter-flow regenerative heat and mass exchanger with partial extraction of air (also known as regenerative heat and mass exchanger). Moreover, Fig. 1b shows a cross-flow heat and mass exchanger. Each of these illustrated figures is one of the different types of air flow arrangement. Counter-flow regenerative and cross-flow M-cycles (CoFRMC and CrFMC) are the major popular developed kinds of heat and mass exchangers of MCIECs [10].

There have been two main approaches by which the performance of MCIECs has been analyzed: conducting experiments and developing analytical or numerical models. Conducting experiments is a method in which the researchers have performed a number of experiments and then they have reported and interpreted the results [11–14]. For instance, Xu et al. [11] investigated the performance of an innovative CoFRMC, in which high-quality wet material layer and intermittent water distribution system were employed. In another study, Kashif Shahzad et al. [12] tested an integrated cooling system which composed of solid desiccant and CrFMC. Moreover, Duan et al. [13] found the potential of electrical energy saving of a CoFRMC at diverse climatic conditions of China using an experiment-based evaluation. Khalid et al. [14] also studied the performance of a CrFMC under low inlet air

* Corresponding author. E-mail addresses: alisohany@yahoo.com, asohani@mail.kntu.ac.ir (A. Sohani), sayyaadi@kntu.ac.ir (H. Sayyaadi).

https://doi.org/10.1016/j.enconman.2017.12.042

Received 1 November 2017; Received in revised form 29 November 2017; Accepted 12 December 2017 0196-8904/ © 2017 Elsevier Ltd. All rights reserved.

Energy Conversion and Management 158 (2018) 327-345

$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	Nomencl	ature	PWF	present worth factor	
$ \begin{array}{rcl} AACC & the annual average of coefficient of performance & RLSHS & the ratio of low speed to the high speed of the fan AACC & the annual average of cooling capacity (W) & T & temperature (C) & temperature (C) & temperature (C) & soft computing and statistical techniques for order preference by similarity to ideal so-third or a soft computing and statistical techniques for order preference by similarity to ideal so-third or a soft computing and statistical techniques for order preference by similarity to ideal so-third or a soft computing and statistical techniques for order preference by similarity to ideal so-third or a soft computing and statistical techniques for order preference by similarity to ideal so-third or a soft computing and statistical techniques for order preference by similarity to ideal so-third or a soft computing and statistical techniques for order preference by similarity to ideal so-third or a soft computing and statistical techniques for order order order order order order for the state state order orde$			RFMP	retailer's profit	
AACCthe annual average of cooling capacity (KW)Ttemperature ('C)AADPthe annual average of dew-point efficiencyTOPSIStechnique for order preference by similarity to ideal so- lutionAWCannual water consumption (m ³ year ⁻¹)Tmean radiant temperature ('C)Ccost (\$)SCSTsoft computing and statistical techniques c_p constant pressure specific heat ($lkg^{-1}K^{-1}$)SHfin static head (lPa)COFRMCconstant pressure specific heat ($lkg^{-1}K^{-1}$)SHfin static head (lPa)COFRMCconstant pressure specific heat ($lkg^{-1}K^{-1}$)SHfin static head (lPa)COFRMCconstant pressure specific heat ($lkg^{-1}K^{-1}$)SHfin static head (lPa)COFthe coefficient of performanceWARworking ait to total inlet air ratioCOFRMCcros-flow regenerative Maisotsenko (M-cycle) indirectWARworking ait to total inlet air ratioCOFRMCcros-flow regenerative Maisotsenko (M-cycle) indirectWARworking ait to total inlet air ratioDFIECdevoloritwarethe size of a component of the system whose cost is de- termined based on thatDFIECdey point Indirect evaporative cooling systemsoft airif athe fraction of time in an hour in which CoFRMC or bardbardbardbardbardbardf.athe fraction of trase income at the end of system life span to the initial costfrf.ainfation ratein ininlet airf.ainfation rate<	AACOP	the annual average of coefficient of performance	RLSHS	the ratio of low speed to the high speed of the fan	
AADP AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND AND<	AACC	the annual average of cooling capacity (kW)	T	temperature (°C)	
AWC antificial neural network Intion AWC antificial neural network Terms andiant temperature (°C) C cost (\$) SCST soft computing and statistical techniques c_C cost (\$) SRH fan static head (Pa) CC costing capacity (W) SRH fan static head (Pa) CoBRMC conter-flow regenerative Maisotenko (M-cycle) indirect V velocity (m s ⁻¹) COP the coefficient of performance WAR working air to total inlet air ratio COP coss-flow regenerative Maisotenko (M-cycle) indirect W cost witch (m) COP the coefficient of performance WAR working air to total inlet air ratio COP exporative cooler War the system obsec cost is de-termined based on that DH hydraulic diameter (m) years the system si life span (years) DEC diver exporative cooler stripts termined based on that FPEC electrical power consumption (W) barr air EPEC electrical power consumption (W) barr fan fag the fraction of time in an hour in which CoFRMC or barr barr fag the fraction of reside income at the end of system life span to in inite air ratio fan statia taid </td <td>AADP</td> <td>the annual average of dew-point efficiency</td> <td>TOPSIS</td> <td>technique for order preference by similarity to ideal so-</td>	AADP	the annual average of dew-point efficiency	TOPSIS	technique for order preference by similarity to ideal so-	
$ \begin{array}{cccc} AWC & ansata water consumption (m3 year-1) & T & mean radiant temperature (C) \\ cost (s) & SCT & soft computing and statistical techniques \\ c_{p} & constant pressure specific heat (J kg-1 K-1) & SH & fan static head (Pa) \\ CC & cooling capacity (W) & SRM & the stepwise regression method \\ CFRMC & cooler width (m) & V & velocity (ms-1) \\ evaporative cooler & W & cooler width (m) \\ CPMC & coofficient of performance & WAR & working air to total inlet air ratio \\ evaporative cooler & V & velocity (ms-1) \\ evaporative cooler & W & cooler width (m) \\ CFRMC & consention of the system whose cost is de- \\ d & discount rate & vaporative cooler & V & the size of a component of the system whose cost is de- \\ d & discount rate & vaporative cooling system \\ DPLC & direct evaporative cooling system & Scripts \\ EPC & electrical power consumption (W) \\ FW & external work (W m-2) & air \\ f_{am} & the fraction of time in an hour in which CoFRMC or \\ GrADH & fraction of time in an hour in which CoFRMC or \\ f_{amate} & the fraction of time in an hour in which CoFRMC or \\ f_{amate} & the fraction of time in an hour in which CoFRMC or \\ f_{amate} & the fraction of time in an hour in which CoFRMC or \\ f_{amate} & the fraction of time in an hour in which CoFRMC or \\ f_{amate} & the fraction of time in an hour in which CoFRMC or \\ f_{amate} & the fraction of time in an hour in which CoFRMC or \\ f_{amate} & the fraction of resel income at the end of system life span \\ to the initial cost & up on the difference \\ f_{amate} & the fraction of time in an hour in which CoFRMC or \\ f_{amate} & the fraction of time in an hour in which CoFRMC or \\ f_{amate} & the fraction of time in an hour in which CoFRMC or \\ f_{amate} & the fraction of time in a hour in which CoFRMC or \\ f_{amate} & the fraction of time in a hour in which CoFRMC or \\ f_{amate} & the fraction of time in a hour in which CoFRMC or \\ f_{amate} & the fraction of time in a hour in which CoFRMC or \\ f_{amate} & the fraction of time in the system whose cot i$	ANN	artificial neural network		lution	
Ccost (\$)SCSTsoft computing and statistical techniques c_p constant pressure specific heat (J kg $^{-1}$ K $^{-1}$)SHfan static head (Pa)CCCcoulter-flow regenerative Maisotsenko (M-cycle) indiretVvelocity (ms $^{-1}$)COPthe coefficient of performanceWARworking air to total inlet air ratioCFMCcross-flow regenerative Maisotsenko (M-cycle) indiretWCwater consumptionCPFMCcross-flow regenerative Maisotsenko (M-cycle) indiretWCwater consumptionCPFMCcross-flow regenerative cooling systemSriftthe size of a component of the system whose cost is determined based on thatDFECdew point indiret (m)yearsthe system's life span (years)DFECexternal work (W m $^{-2}$)airairaffairairbasef_mthe fraction of time in an hour in which CoFRMC orbasebase conditionf_mthe fraction of time in an hour in which CoFRMC orbasebasef_mthe fraction of time in an hour in which CoFRMC orbasebasef_mthe fraction of time in an hour in which CoFRMC orbasebasef_mthe fraction of time in an hour in which CoFRMC orin initialf_mthe fraction of time in an hour in which CoFRMC orbasef_mthe fraction of time in an hour in which CoFRMC orin initialf_mthe fraction of resole income at the end of system life spandpdwdy channel (m)inintel airf_m </td <td>AWC</td> <td>annual water consumption $(m^3 year^{-1})$</td> <td>$\overline{T_r}$</td> <td>mean radiant temperature (°C)</td>	AWC	annual water consumption $(m^3 year^{-1})$	$\overline{T_r}$	mean radiant temperature (°C)	
$\begin{array}{ccc} c_{1} & \mbox{constant pressure specific heat (J kg^{-1} K^{-1}) & SH & fan static head (Pa) & \\ CC & \mbox{constant pressure specific heat (J kg^{-1} K^{-1}) & SH & fan static head (Pa) & \\ CPRMC & \mbox{constant presentative Maisotsenko (M-cycle) indirect & volume volume (Pa) & \\ columer-flow regenerative Maisotsenko (M-cycle) indirect & W & \mbox{colity (n s^{-1})} & \\ columer-flow regenerative Maisotsenko (M-cycle) indirect & W & \mbox{colity air to total inflet air ratio & \\ corse-flow regenerative Maisotsenko (M-cycle) indirect & W & \mbox{water consumption & } & \\ corse-flow regenerative Maisotsenko (M-cycle) indirect & W & \mbox{water consumption & } & \\ water consumption & WAR & \mbox{water consumption & } & \\ W & \mbox{discont rate (m) & yars & \mbox{the system's life span (years) & } & \\ DHC & \mbox{direct evaporative cooler & } & \\ DHC & \mbox{direct evaporative cooling system & \\ SCripts & \mbox{eternal work (W m^{-3}) & \mbox{arian indirect evaporative cooling system & \\ GPC & \mbox{eternal work (W m^{-3}) & arian indirect evaporative cooling system in hear in a in a fraction of time in an hour in which CoFRMC or fan & \mbox{arian back on the end of system life span & \mbox{arian back on the end of system life span & \mbox{arian back on the end of system life span & \mbox{arian back on the end of system life span & \mbox{arian back on the end of system life span & \mbox{arian back on the end of system life span & \mbox{arian back on the end of system life span & \mbox{arian back on the end of system life span & \mbox{arian back on the system second back on the end & \mbox{arian back on the system second back & \mbox{arian back &$	С	cost (\$)	SCST	soft computing and statistical techniques	
	Cn	constant pressure specific heat $(J kg^{-1} K^{-1})$	SH	fan static head (Pa)	
CoFRMCevaporative cooler V velocity (m s ⁻¹)CPH CPH conserior coefficient of performance WA cooler width (m)CPHMCcross-flow regenerative Maisotsenko (M-cycle) indirect evaporative cooler W cooler width (m)CPHMCcross-flow regenerative Maisotsenko (M-cycle) indirect evaporative cooler W water consumptionDr.discount rate X the size of a component of the system whose cost is de- termined based on thatDr.hydraulic diameter (m)yearsthe system's life span (years)DECdirect evaporative coolerScriptsPPECelectrical power consumption (W)alrairEWexternal work (W m ⁻²)alrair f_{end} the fraction of time in an hour in which CoFRMC or GrEPKC is onbasebase f_{end} the fraction of reade income at the end of system life span to the initial costdbdry bulb f_{ende} the height of dry channel (m)ininitialgap 1inflation rateOoperatingHcooler height (m)frfriction h_e conductive heat transfer coefficient (W m ⁻² K ⁻¹)O I_a insulation (m ² K W ⁻¹)au I_a insulation (m ² K W ⁻¹)wa I_b conductive heat tr	с́с	cooling capacity (W)	SRM	the stepwise regression method	
evaporative coolerWcooler width (m)COPthe coolerWARworking air to total inlet air ratioCOPcross-flow regenerative Maiotsenko (M-cycle) indirectWARworking air to total inlet air ratioCMCevaporative coolerXthe size of a component of the system whose cost is determined based on thatDifdirect evaporative cooleryearsthe size of a component of the system whose cost is determined based on thatDifdirect evaporative cooleryearsthe size of a component of the system whose cost is determined based on thatDifdirect evaporative cooleryearsthe size of a component of the system whose cost is determined based on thatFPTECdeve point indirect evaporative coolerscriptsscriptsFWCelectrical power consumption (W)airairairFWeternal work (W m ⁻²)airairairfonthe fraction of time in an hour in which CoFRMC or to initial costboardboardfonthe fraction of resale income at the end of system life span to the initial costin initialgenthe height of dry channel (m)ininitialforcooler height (m)frfrictionhcooler height (m)frfrictionhcooler height (m)frfrictionhinflation ratefrfrictionforcooler height (m)frfrictionhinflation ratefrfrictionfinflation ratefrfr	CoFRMC	counter-flow regenerative Maisotsenko (M-cvcle) indirect	V	velocity $(m s^{-1})$	
COPthe coefficient of performanceWARworking air to total inlet air ratioCrFMCcross-flow regenerative Maisotsenko (M-cycle) indirectWCwater computionddiscount rateWCwater component of the system whose cost is determined based on that D_{II} hydraulic diameter (m)yearsthe system's life span (years)DECdirect evaporative coolerScriptsDFIECetertical power consumption (W)ScriptsEWexternal work (W m ⁻²)airairair f_{on} the fraction of time in an hour in which CoFRMC or CrFAC is onbase f_{reade} the fraction of sale income at the end of system life span to the initial costingapthe height of dry channel (m)ingapthe height of dry channel (m)inhcooler height (m)frh_ccoovercive heat transfer coefficient (W m ⁻² K ⁻¹)0iinflation rate01iinflation rate01iconductive heat transfer coefficient (W m ⁻¹ K ⁻¹)relativeichannel length (m)sasupply airkconductive heat transfer coefficient (W m ⁻¹ K ⁻¹)waterkconductive heat transfer coefficient (W m ⁻¹ K ⁻¹)vaterkconductive heat transfer coefficient (W m ⁻¹ K ⁻¹)waterkconductive heat transfer coefficient (W m ⁻¹ K ⁻¹)waterkconductive heat transfer coefficient (W m ⁻¹ K ⁻¹)waterkconductive he		evaporative cooler	W	cooler width (m)	
CrFMCcross-flow regenerative Maisotsenko (M-cycle) indirect evaporative coolerWCwater consumption D_{IL} discount rate X the size of a component of the system whose cost is de- termined based on that D_{IL} direct evaporative cooler X the size of a component of the system whose cost is de- termined based on that D_{ILC} direct evaporative cooler $Scripts$ $Scripts$ EPC electrical power consumption (W) air air EW external work (W m ⁻²) air air f_{on} the fraction of time in an hour in which CoFRMC or $GrefNC is on$ $base$ base condition $board$ f_{on} the fraction of creale income at the end of system life span to the initial cost db dry bulb f_{reale} the fraction of creale income at the end of system life span to the initial cost I initial initial gap the height of dry channel (m)inin let air I $GMDHF$ group method of data handling type neural network fan fan fr I_{c} insulation ($m^2 K^{-1}$) O operating i inflation rate O operating I_{c} insulation ($m^2 K^{-1}$) O operating i inflation rate PE purchase of equipment k conductive heat transfer coefficient (W m ⁻¹ K ⁻¹) $relative$ k conductive heat transfer coefficient (W m ⁻¹ K ⁻¹) $relative$ k conductive heat transfer coefficient (W m ⁻¹ K ⁻¹)	COP	the coefficient of performance	WAR	working air to total inlet air ratio	
evaporative cooler tegentre to introduction (un plane) interest of a component of the system whose cost is determined based on that point indirect evaporative cooler interest of a component of the system whose cost is determined based on that point indirect evaporative cooler interest of a component of the system whose cost is determined based on that point indirect evaporative cooler interest of a component of the system whose cost is determined based on that point indirect evaporative cooler interest of a component of the system whose cost is determined based on that point indirect evaporative cooler interest of a component of the system whose cost is determined based on that point indirect evaporative cooler of the fraction of time in an hour in which CoFRMC or correctly form of time in an hour in which CoFRMC or correctly base into a fract of the fraction of resale income at the end of system life span to the initial cost in the initial cost in the the height of dry channel (m) in the fraction of resale income at the end of system life span to the height of dry channel (m) in the height of dry channel (m) in the fract in fraction of mesale income (S) in the fract in fraction of mesale income (S) in the fract in transfer coefficient (W m ⁻¹ K ⁻¹) in the fract income (S) in the fract income (S) in the fract income (S) in the fract income is supply a ir set income (S) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg s ⁻¹) in the mass flow rate (Mg	CrFMC	cross-flow regenerative Maisotsenko (M-cycle) indirect	WC	water consumption	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0.1.1.10	evaporative cooler	X	the size of a component of the system whose cost is de-	
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	d	discount rate		termined based on that	
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	D ₁₁	hydraulic diameter (m)	vears	the system's life span (years)	
Diffect dew point indirect evaporative cooling systemScriptsEPC EPC electrical power consumption (W)airairEW external work (W m ⁻²)airairfor for the fraction of time in an hour in which CoFRMC or CrFMC is on to the fraction of resale income at the end of system life span to the height of dry channel (m)basefor forableclothing surface area factordbdry builbforablethe fraction of resale income at the end of system life span to the initial costininlet airgapthe height of dry channel (m)ininlet airGMDHgroup method of data handling type neural networkfanfanHcooler height (m)frfrictionh_cconvective heat transfer coefficient (W m ⁻² K ⁻¹)Ooperating in the first yeariinflation rateO1operating in the first yearI_ainsulation (m ² K W ⁻¹)rel relativeLchannel (m)sasu supply airLchannel length (m)sasu supply airLCClife-cycle cost (\$)thermostat thermostatmmetabolic rate (W m ⁻²)wwaterMmetabolic rate (W m ⁻²)Qoutine towing airQvolumetric flow rate of required fresh air (m ³ h ⁻¹)AdifferencePpressure (Pa)gminol loss coefficientPApressure (Pa)gminol loss coefficientPApressure (Pa)grelative humidity (kg _{moisture} kg _{dry ai}	DFC	direct evaporative cooler	years	the system s me span (jears)	
$ \begin{array}{llllllllllllllllllllllllllllllllllll$	DPIEC	dew point indirect evaporative cooling system	Scripts		
Breeexternal work (W m ⁻²)airair f_{ont} the fraction of time in an hour in which CoFRMC or CrFMC is on f_{calle} $base$ basebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebasebase <td>EPC</td> <td>electrical power consumption (W)</td> <td>ourpu</td> <td></td>	EPC	electrical power consumption (W)	ourpu		
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	EW	external work (Wm^{-2})	air	air	
	f	the fraction of time in an hour in which CoEPMC or	hase	hase condition	
$ \begin{array}{cccc} Grand b & dry bulb \\ for d & dry bulb \\ fresale \\ fresa$	Jon	CrEMC is on	base	board	
$ \begin{aligned} \int_{result}^{d} & \text{chorms surface factor of the end of system life span to the fraction of resule income at the end of system life span to the initial cost & I initial \\ gap the height of dry channel (m) & in inlet air \\ GMDH group method of data handling type neural network fan fan \\ cooler height (m) & fr friction \\ h_c & \text{convective heat transfer coefficient (W m-2 K-1) & O operating in the first year \\ I inflation rate & O1 operating in the first year \\ I_d & insulation (m2 K W-1) & out outlet (product) air \\ I_k & resale income ($) & PE purchase of equipment \\ k & \text{conductive heat transfer coefficient (W m-1 K-1) & rel relative \\ L & channel length of the channel & sensible \\ LCC & life-cycle cost ($) & thermostat thermostat \\ m & metabolic rate (W m-2) & wa working air \\ M & metabolic rate (W m-1) & Qa & working air \\ MCIEC & Maisotenko (M-cycle) indirect evaporative cooler \\ NSGA-II & non-dominated sorted genetic algorithm 2 & Greek symbols \\ Q & volumetric flow rate (m3 h-1) & Qa & difference \\ P & pressure (Pa) & g & efficiency \\ PMV & predicted mean vote \\ PAG & water vapor partial pressure (Pa) & g & efficiency \\ PMV & predicted mean vote \\ PDF & Pareto optimal frontier \\ PAG & volumetric flow rate of required fresh air (m3 h-1) & Qa & difference \\ P & pressure (Pa) & g & efficiency \\ PMV & predicted percentage dissatisfied (%) & p & relative humidity (%gmoisture kgdry air-1) \\ \end{array} $	f	clothing surface area factor	dh	dry hulb	
$ J_{restrict} \text{difference} I I \text{difference} I I I I I I I I I $	J _{cl} f	the fraction of resale income at the end of system life span	dn	dew point	
gapthe height of dry channel (m)inGMDHgroup method of data handling type neural networkfanfanHcooler height (m)frfrictionh_cconvective heat transfer coefficient (W m ⁻² K ⁻¹)Ooperatingiinflation rateO1operating in the first yearI_dinsulation (m ² K W ⁻¹)outoutlet (product) airI_Rresale income (\$)PEpurchase of equipmentkconductive heat transfer coefficient (W m ⁻¹ K ⁻¹)relrelativeLchannel length (m)sasupply airL*dimensionless length of the channelsensiblesensibleLCClife-cycle cost (\$)thermostat thermostatmthe mass flow rate (kg s ⁻¹)waworking airMCIECMaistenko (M-cycle) indirect evaporative coolerGreek symbolsNSGA-IInon-dominated sorted genetic algorithm 2Greek symbolsQvolumetric flow rate of required fresh air (m ³ h ⁻¹) Δ differencePpressure (Pa) ζ minor loss coefficientPApredicted mean vote ν kinematic viscosity (m ² s ⁻¹)POFPareto optimal frontier ρ density (kg m ⁻³)PPDpredicted percentage dissatisfied (%) ϕ relative humidity (kg moissure/kgdry air ⁻¹)	Jresale	to the initial cost	ир I	initial	
gap GMDHintermediationGMDHgroup method of data handling type neural networkfanfanfrh_ccooler height (m)h_cconvective heat transfer coefficient (W m ⁻² K ⁻¹)iinflation rateO1Iinsulation (m ² K W ⁻¹)I_dinsulation (m ² K W ⁻¹)I_kresale income (\$)Kconductive heat transfer coefficient (W m ⁻¹ K ⁻¹)I_kresale income (\$)Lchannel length (m)Lchannel length (m)L*dimensionless length of the channelLCClife-cycle cost (\$)mthe mass flow rate (kg s ⁻¹)Mmetabolic rate (W m ⁻²)Waworking airMCIECMaisotsenko (M-cycle) indirect evaporative coolerNSGA-IInon-dominated sorted genetic algorithm 2Qvolumetric flow rate of required fresh air (m ³ h ⁻¹)Qvolumetric flow rate of required fresh air (m ³ h ⁻¹)Qvolumetric flow rate of required fresh air (m ³ h ⁻¹)Qvolumetric flow rate of required fresh air (m ³ h ⁻¹)Qvolumetric flow rate of required fresh air (m ³ h ⁻¹)Ppressure (Pa)Ppressure (Pa)Ppressure (Pa)Ppressure (Pa)Ppressure (Pa)Ppredicted percentage dissatisfied (%)PWCpresent worth of the cash flow of C (\$)Wabsolute humidity (kg _{moisture} kg _{dry air} ⁻¹)	aan	the height of dry channel (m)	in	inlet air	
$\begin{array}{llllllllllllllllllllllllllllllllllll$	S ^M P GMDH	group method of data handling type neural network	fan	fan	
$\begin{array}{ccccc} & & & & & & & & & & & & & & & & &$	H	cooler height (m)	fun fr	friction	
n_c contractive incluster boundary (with K^{-1}) O operatingiinflation rateO1operating in the first year l_d insulation ($m^2 K W^{-1}$) out outlet (product) air I_R resale income (\$) PE purchase of equipmentkconductive heat transfer coefficient ($W m^{-1} K^{-1}$) rel relativeLchannel length (m)sasupply airL*dimensionless length of the channelsensiblesensibleLCClife-cycle cost (\$)thermostat thermostatmthe mass flow rate ($kg s^{-1}$) w waterMmetabolic rate ($W m^{-2}$)waworking airMCIECMaiotsenko (M-cycle) indirect evaporative cooler $Wcilling Maiotsenko (M-cycle)$ indirect evaporative coolerNSGA-IInon-dominated sorted genetic algorithm 2Greek symbolsQvolumetric flow rate of required fresh air ($m^3 h^{-1}$) Δ differencePpressure (Pa) ζ minor loss coefficientPawater vapor partial pressure (Pa) η efficiencyPMVpredicted mean vote ν kinematics viscosity ($m^2 s^{-1}$)POFPareto optimal frontier ρ density ($kg m^{-3}$)PPDpredicted percentage dissatisfied (%) ϕ relative humidity ($kg_{moisture} kg_{dry air}^{-1}$)	h	convective heat transfer coefficient ($W m^{-2} K^{-1}$))' O	operating	
$I_{d} = Initial on Tate and the first year of the operating in the first year of t$	i i	inflation rate	01	operating in the first year	
$\begin{array}{cccc} I & \text{instration (in KW)} & \text{out} & \text{outer (product) an} \\ I_R & \text{resale income ($)} & PE & \text{purchase of equipment} \\ k & \text{conductive heat transfer coefficient (Wm^{-1}K^{-1})} & rel & \text{relative} \\ L & \text{channel length (m)} & sa & \text{supply air} \\ L^* & \text{dimensionless length of the channel} & sensible & sensible \\ LCC & \text{life-cycle cost ($)} & thermostat & thermostat \\ \dot{m} & \text{the mass flow rate (kg s^{-1})} & w & water \\ M & \text{metabolic rate (Wm^{-2})} & wa & working air \\ MCIEC & Maisotsenko (M-cycle) indirect evaporative cooler \\ NSGA-II & non-dominated sorted genetic algorithm 2 & Greek symbols \\ Q & volumetric flow rate (m^3 h^{-1}) & \Delta & \text{difference} \\ P & pressure (Pa) & \zeta & \text{minor loss coefficient} \\ P_a & water vapor partial pressure (Pa) & \eta & efficiency \\ PMV & predicted mean vote & v & kinematics viscosity (m^2 s^{-1}) \\ POF & Pareto optimal frontier & \rho & density (kg m^{-3}) \\ PPD & predicted percentage dissatisfied (%) & \phi & relative humidity (%) \\ PW_C & present worth of the cash flow of C ($) & \omega & absolute humidity (kgmoisture kgdry air^{-1}) \end{array}$	ι Τ.	insulation $(m^2 K W^{-1})$	out	outlet (product) air	
I_R result intoine (s) I_L putchase of equipment k conductive heat transfer coefficient (W m ⁻¹ K ⁻¹) rel relative L channel length (m) sa supply air L^* dimensionless length of the channel $sensible$ sensible LCC life-cycle cost (\$)thermostatthermostat m the mass flow rate (kg s ⁻¹) w water M metabolic rate (W m ⁻²) wa working air $MCIEC$ Maisotsenko (M-cycle) indirect evaporative cooler $Greek symbols$ $NSGA-II$ non-dominated sorted genetic algorithm 2 $Greek symbols$ Q volumetric flow rate of required fresh air (m ³ h ⁻¹) Δ difference P pressure (Pa) ζ minor loss coefficient P_a water vapor partial pressure (Pa) η efficiency PMV predicted mean vote ν kinematics viscosity (m ² s ⁻¹) POF Pareto optimal frontier ρ density (kg m ⁻³) PPD predicted percentage dissatisfied (%) ϕ relative humidity (kg _{moisture} -kg _{dry air} ⁻¹)	I _{cl}	resola income (\$)	DE	purchase of equipment	
kconductive near transfer coefficient (will K f)refrefailiveLchannel length (m)sasupply airL*dimensionless length of the channelsensiblesensibleLCClife-cycle cost (\$)thermostatthermostatmthe mass flow rate (kg s ⁻¹)wwaterMmetabolic rate (W m ⁻²)waworking airMCIECMaisotsenko (M-cycle) indirect evaporative coolerGreek symbolsQvolumetric flow rate (m ³ h ⁻¹)Greek symbolsQvolumetric flow rate of required fresh air (m ³ h ⁻¹) Δ differencePpressure (Pa) γ efficiencyPMVpredicted mean vote ν kinematics viscosity (m ² s ⁻¹)POFPareto optimal frontier ρ density (kg m ⁻³)PPDpredicted percentage dissatisfied (%) ϕ relative humidity (%)PWcpresent worth of the cash flow of C (\$) ω absolute humidity (kgmoisture kgdry air ⁻¹)	IR Ir	conductive heat transfer coefficient $(Mm^{-1}K^{-1})$	rol	relative	
LStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStdStd	к т	conductive field transfer coefficient (will K)	50		
Lcontraction between the chainersensibleLCClife-cycle cost (\$)the remostat \dot{m} the mass flow rate (kg s ⁻¹) w Mmetabolic rate (W m ⁻²) wa MCIECMaisotsenko (M-cycle) indirect evaporative coolerNSGA-IInon-dominated sorted genetic algorithm 2Greek symbolsQvolumetric flow rate (m ³ h ⁻¹) Δ Qavolumetric flow rate of required fresh air (m ³ h ⁻¹) Δ Ppressure (Pa) ζ Pawater vapor partial pressure (Pa)PMVpredicted mean vote v POFPareto optimal frontier ρ PDDpredicted percentage dissatisfied (%) ϕ PWCpresent worth of the cash flow of C (\$) ω		dimensionless length of the channel	sansibla	songible	
Inter-cycle cost (a)Intermostat mermostat mermostat \dot{m} the mass flow rate (kg s ⁻¹) w water M metabolic rate (W m ⁻²) wa working air $MCIEC$ Maisotsenko (M-cycle) indirect evaporative cooler wa working air $NSGA-II$ non-dominated sorted genetic algorithm 2 $Greek symbols$ Q volumetric flow rate (m ³ h ⁻¹) Δ difference Q_a volumetric flow rate of required fresh air (m ³ h ⁻¹) Δ difference P pressure (Pa) ζ minor loss coefficient P_a water vapor partial pressure (Pa) η efficiency PMV predicted mean vote ν kinematics viscosity (m ² s ⁻¹) POF Pareto optimal frontier ρ density (kg m ⁻³) PPD predicted percentage dissatisfied (%) ϕ relative humidity (%) PW_C present worth of the cash flow of C (\$) ω absolute humidity (kg _{moisture} ·kg _{dry air} ⁻¹)		life cycle cost (\$)	thermosta	thermostat	
mthe mass now rate (kg s -)wwaterMmetabolic rate (W m ⁻²)waworking airMCIECMaisotsenko (M-cycle) indirect evaporative coolerwaworking airNSGA-IInon-dominated sorted genetic algorithm 2Greek symbolsQvolumetric flow rate (m ³ h ⁻¹) Δ difference Q_a volumetric flow rate of required fresh air (m ³ h ⁻¹) Δ difference P pressure (Pa) ζ minor loss coefficient P_a water vapor partial pressure (Pa) η efficiencyPMVpredicted mean vote ν kinematics viscosity (m ² s ⁻¹)POFPareto optimal frontier ρ density (kg m ⁻³)PPDpredicted percentage dissatisfied (%) ϕ relative humidity (%)PW _C present worth of the cash flow of C (\$) ω absolute humidity (kg _{moisture} ·kg _{dry air} ⁻¹)	LCC m	the mass flow rate (lag e^{-1})	w	water	
MInterabolic face (W III -)WaWorking anMCIECMaisotsenko (M-cycle) indirect evaporative coolerWaWorking anNSGA-IInon-dominated sorted genetic algorithm 2Greek symbolsQvolumetric flow rate ($m^3 h^{-1}$) Δ differenceQ_avolumetric flow rate of required fresh air ($m^3 h^{-1}$) Δ differencePpressure (Pa) ζ minor loss coefficientP_awater vapor partial pressure (Pa) η efficiencyPMVpredicted mean vote ν kinematics viscosity ($m^2 s^{-1}$)POFPareto optimal frontier ρ density (kg m^{-3})PPDpredicted percentage dissatisfied (%) ϕ relative humidity (%)PW_Cpresent worth of the cash flow of C (\$) ω absolute humidity (kg _{moisture} ·kg _{dry air} ^{-1})	m M	metabolic rate (Mm^{-2})	w	wale	
<i>NSGA-II</i> non-dominated sorted genetic algorithm 2 <i>Greek symbols</i> Q volumetric flow rate $(m^3 h^{-1})$ Δ difference Q_a volumetric flow rate of required fresh air $(m^3 h^{-1})$ Δ difference P pressure (Pa) ζ minor loss coefficient P_a water vapor partial pressure (Pa) η efficiency <i>PMV</i> predicted mean vote ν kinematics viscosity $(m^2 s^{-1})$ <i>POF</i> Pareto optimal frontier ρ density (kg m^{-3}) <i>PPD</i> predicted percentage dissatisfied (%) ϕ relative humidity (%) <i>PW_C</i> present worth of the cash flow of C (\$) ω absolute humidity (kg _{moisture} ·kg _{dry air} ^{-1})		Meiseteenke (Marale) indirect evenerative cooler	wa	working an	
NSCA-IInon-dominated sorted genetic algorithm 2Greek symbols Q volumetric flow rate $(m^3 h^{-1})$ Δ difference Q_a volumetric flow rate of required fresh air $(m^3 h^{-1})$ Δ difference P pressure (Pa) ζ minor loss coefficient P_a water vapor partial pressure (Pa) η efficiencyPMVpredicted mean vote ν kinematics viscosity $(m^2 s^{-1})$ POFPareto optimal frontier ρ density (kg m^{-3})PPDpredicted percentage dissatisfied (%) ϕ relative humidity (%) PW_C present worth of the cash flow of C (\$) ω absolute humidity (kg _{moisture} ·kg _{dry air} ^{-1})	MCIEC	maisotseliko (M-cycle) indirect evaporative cooler	Creak am	abolo	
Qvolumetric flow rate (m n -) Δ differenceQ_avolumetric flow rate of required fresh air (m ³ h ⁻¹) Δ differencePpressure (Pa) ζ minor loss coefficientP_awater vapor partial pressure (Pa) η efficiencyPMVpredicted mean vote ν kinematics viscosity (m ² s ⁻¹)POFPareto optimal frontier ρ density (kg m ⁻³)PPDpredicted percentage dissatisfied (%) ϕ relative humidity (%)PW_Cpresent worth of the cash flow of C (\$) ω absolute humidity (kg _{moisture} ·kg _{dry air} ⁻¹)	NSGA-II	Non-dominated solved genetic algorithm 2 $(m^3 h^{-1})$		Greek symbols	
Q_a volumetric flow rate of required fresh air (m n f) Δ difference P pressure (Pa) ζ minor loss coefficient P_a water vapor partial pressure (Pa) η efficiency PMV predicted mean vote ν kinematics viscosity (m ² s ⁻¹) POF Pareto optimal frontier ρ density (kg m ⁻³) PPD predicted percentage dissatisfied (%) ϕ relative humidity (%) PW_C present worth of the cash flow of C (\$) ω absolute humidity (kg _{moisture} ·kg _{dry air} ⁻¹)	Q	volumetric flow rate (m h) $(1 - 1)^{-1}$	•	difference	
Ppressure (Pa) ς minor loss confidentP_awater vapor partial pressure (Pa) η efficiencyPMVpredicted mean vote v kinematics viscosity (m ² s ⁻¹)POFPareto optimal frontier ρ density (kg m ⁻³)PPDpredicted percentage dissatisfied (%) ϕ relative humidity (%)PW_Cpresent worth of the cash flow of C (\$) ω absolute humidity (kg _{moisture} ·kg _{dry air} ⁻¹)	Q_a	volumetric flow rate of required fresh air (m n)		difference	
P_a water vapor partial pressure (Pa) η efficiency PMV predicted mean vote ν kinematics viscosity (m² s ⁻¹) POF Pareto optimal frontier ρ density (kg m ⁻³) PPD predicted percentage dissatisfied (%) ϕ relative humidity (%) PW_C present worth of the cash flow of C (\$) ω absolute humidity (kg _{moisture} ·kg _{dry air} ⁻¹)	P	pressure (Pa)	ς		
PMVpredicted mean vote ψ kinematics viscosity (m ⁻ s ⁻¹)POFPareto optimal frontier ρ density (kg m ⁻³)PPDpredicted percentage dissatisfied (%) ϕ relative humidity (%) PW_C present worth of the cash flow of C (\$) ω absolute humidity (kg _{moisture} ·kg _{dry air} ⁻¹)	P_a	water vapor partial pressure (Pa)	η	Ellipsing the state $(m^2 - 1)$	
POPPareto optimal frontier ρ density (kg m °)PPDpredicted percentage dissatisfied (%) ϕ relative humidity (%)PW_Cpresent worth of the cash flow of C (\$) ω absolute humidity (kg _{moisture} ·kg _{dry air} ⁻¹)	PMV	predicted mean vote	V	kinematics viscosity (iii s) density (i.e. m^{-3})	
PPDpredicted percentage dissatisfied (%) ϕ relative humidity (%) PW_C present worth of the cash flow of C (\$) ω absolute humidity ($kg_{moisture}$: $kg_{dry air}^{-1}$)	POF	Pareto optimal frontier	ρ	density (kg m [°])	
PW_C present worth of the cash flow of C (\$) ω absolute humidity ($kg_{moisture}kg_{dry air}^{-1}$)	PPD	predicted percentage dissatisfied (%)	φ	relative numidity (%)	
	PW_C	present worth of the cash flow of C (\$)	ω	absolute humidity ($kg_{moisture} kg_{dry air}$)	

velocity conditions experimentally. Although experimental measurements provide accurate results, they suffer from the cost of experiments. Developing a model is an alternative approach; however, a developed model must be validated with experimental data. If numerical or analytical models are validated using experimental data, they can be employed in the cases in which there is a lack of experimental data. The models have been obtained either by numerical methods or soft computing and statistical techniques (SCSTs). In the numerical modeling [15–19], different analytical methods such as the effectiveness-NTU method (ε -NTU) [16,18], the Eulerian-Lagrangian computational fluid dynamics (CFD) [15] and the finite difference method (FDM) [17,19] have been applied and the obtained numerical results have been validated against existing experimental data. Moreover, in the statistical modeling [5,7,20,21], the effective parameters have been determined and after extraction of enough data from experiments or numerical models, the modeling process has been conducted to transfer the data into analytical models [22]. Artificial neural networks (ANN) [20], group method of data handling (GMDH) [5,7,20], genetic programming (GP) [20], response surface methodology (RSM) [21], multiple linear regression (MLR) [20] and stepwise regression method (SRM) [6,20] are the statistical techniques by which MCIECs have been modeled so far. In Fig. 2, a graphical summary of the mentioned classification was presented.

From the point of view of the subject, the conducted studies about MCIECs were categorized into some groups. The largest group of studies is those research that the performances of the system are investigated under a variety of effective parameters such as inlet air conditions, the air flow velocity, the dimensions of the air flow passages, and working Download English Version:

https://daneshyari.com/en/article/7159201

Download Persian Version:

https://daneshyari.com/article/7159201

Daneshyari.com