SELECTION OF THE MELTING TEMPERATURE OF PHASE CHANGE MATERIALS CONSIDERING LOCAL CLIMATE

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ABSTRACT

The selection of melting temperature of phase change materials (PCMs) is crucial part of PCM applications in building sector in order to achieve better thermal performance. This study examines various temperatures in Adelaide local climate such as conditioned indoor air temperature and outdoor dry/web bulb air temperature in order to find suitable melting temperature of PCM for passive and active application. According to the conditioned indoor temperature from ten houses in Adelaide, indoor air temperature is maintained between 15°C and 32°C with 22–23°C as an average. Average outdoor dry and web bulb air temperature is less than 18°C and 15°C, respectively. The temperature analysis demonstrates that the PCM with melting temperature around 22°C is assumed to be suitable for passive and free cooling system of residential buildings in Adelaide. On the other hand, the PCM for passive and free heating system is assumed not to work well during most of the day in winter because the outdoor air temperature during the winter lies under the thermal comfort range. Furthermore, the PCM thermal storage unit coupled with evaporative cooling system (EVAP-CS) is expected to increase energy efficiency of building by using outdoor cooled air during the summer night comparing to conventional vapour compression air conditioning system.

Keywords: phase change material, phase change temperature, local climate, indoor thermal comfort.

1 INTRODUCTION

The use of phase change material (PCM) has been paid considerable attention for more than three decades in order to increase the thermal performance of buildings by moderating indoor air temperature (IAT) fluctuation and shifting peak load during extremely hot and cold seasons [1]–[5]. As the energy used for indoor heating and cooling (H/C) has significantly increased and peak demand especially during the summer and winter has long been concerned in Australia [6], the thermal storage system (TSS) using PCM has been considered as one of the promising methods to resolve this energy usage trend [7, 8]. A PCM, practically refers to a material which has a high heat of fusion as latent heat (LH) at its melting and solidifying temperature [9], has been used as building application in multiple ways to take advantage of their high thermal storage capacity. The PCM applications in building can be divided into mainly two types; namely, passive system and active system. In passive system of PCMs, additional mechanical energy is not required after installation of PCMs by using natural circulation of air as heat medium. On the other hand, active system needs additional energy while working such as using fans or integrating into A/Cs and heat pump in order to increase the performance of PCMs application [10]. In order to maximise the energy efficiency of the PCM application, there are various requirements PCM should meet; namely, thermos-physical, kinetic and chemical properties [11]. Traditionally, the melting temperature (or phase change temperature, PCT) range of PCMs with high enthalpy have been regarded as crucial thermal properties of the material for a potential PCM [3], [12]. In order to select suitable PCT in application of PCMs as passive and active system, various types of temperatures should be considered such as indoor thermal comfort temperature range, average and desired indoor air temperature (IAT), outdoor air temperature (OAT) variation (e.g., maximum, minimum, average), air temperature from additional heat sources

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such as A/Cs or heat pump, etc. [13]–[15]. Especially, the consideration of local climate is crucial in passive application of PCMs and 'free heating/cooling (H/C) system' which is one types of active application of PCM using only fan for air circulation and depends on OAT in order to charge and discharge PCMs like passive system [15], [16]. In addition, numerous researches have tried to integrate PCM thermal storage into conventional vapour compression A/Cs, and identified peak load shaving and reduction of A/C's capacity. However, PCM thermal storage integrated into other types of A/Cs needs to be further investigated because EVAP-CS could lead to better energy efficiency by using outdoor cool air during the summer night in hot and dry Adelaide climate. Therefore, this study reviews previous researches on the important properties of PCMs including selection of PCMs' PCT considering local climate and provide suitable PCT of PCMs for passive and active application in Adelaide by analysis of its local temperature. Furthermore, this study proposes the feasibility of the PCM TSS coupled with EVAP-CS which can lead to better energy efficiency as building application than that with R/C A/Cs based on the analysis of the wet bulb air temperature (WBAT) of Adelaide.

2 CLASSIFICATION OF PCM

A material absorbs and releases sensible heat (SH) and latent heat (LH) when it obtains and lose thermal energy, and when it changes phases (i.e., from solid to liquid, from liquid to gas, solid to gas and vice versa) [17]. SH means stored thermal energy when the temperature of a solid or liquid material rises. Storage using SH is one of the commonly used methods for thermal storage [9]. For instance, hot water storage system using SH has been widely used for domestic hot water or heating. The quantity of SH a material can store depends on mass, the specific heat of the material, and temperature changes. On the other hand, LH can be stored by using a phase change of a material [17]. When a material absorbs heat and reaches its PCT, the material starts to change its phase from solid to liquid by absorbing thermal energy at a constant temperature. During phase change period, the material stores heat (LH) which is equal to the increased enthalpy of the material [9]. TSS using LH possess much higher storage capacity with a narrower temperature range while storing and releasing heat than those using SH [18], [19]. Even though there are several phase changes among solid, liquid and gas, the most commonly studied and practically applied phase change is solid-liquid. Therefore, a PCM practically refers to a material which has a high heat of fusion as LH at its melting and solidifying temperature [9].

PCMs are classified various ways depending on temperature range, mode of phase transition, material, etc. Based on temperature range, PCMs are divided into three group; i.e., low temperature PCMs (PCT lower than 15°C), mid temperature PCMs (PCT ranges between 15–90°C), high temperature PCMs (PCT over 90°C) [18].

Based on phase transition mode, PCMs are also divided into four systems; i.e., gas–liquid, solid–gas, solid–liquid and solid–solid systems. However, other systems except solid–liquid are limited to practical application due to various reasons such as high-volume change (gas–liquid, solid–gas) and low LH (solid–solid) [9]. Therefore, various types of thermal storage applications employ solid–liquid PCMs such as water, salt hydrates, paraffin, eutectics, metal alloys, etc.

The solid–liquid PCMs are also categorised into mainly three types based on material; namely, organic PCMs, inorganic PCMs and eutectics. Organic PCMs include a wide range of materials such as paraffin, fatty acids and their eutectic mixtures, esters and other organic compounds. Organic PCMs are further divided into paraffin and non-paraffin materials. Paraffin wax is composed of a mixture of straight chain n alkanes CH3–(CH2)–CH3 which can store high LH storage capacity. The non-paraffin organic (e.g., fatty acid) are the most abundant PCMs with considerably varied properties. Organic PCMs have various merits such as high LH storage capacities over a narrow temperature, chemically stable, non-reactive, resistance to sub-cooling, non-toxic and ecologically harmless. However, relatively low thermal conductivity, lower thermal stability, low fire resistance (flammable) and high costs have severely restricted the application of Organic PCMs in building field [11], [20].

Inorganic PCMs typically means salt-based material such as salt hydrates (general formula AB·nH2O) with wide temperature range, and also include Metallic alloys used for high-temperature PCMs [11]. However, metallic are not suitable for building application because they are out of desired temperature range and severe weight penalties [21]. Inorganic material have a variety of properties suitable as a PCM such as larger phase transition LH and wider range of PCT than organic material, economically competitive, and typically non-flammable. On the other hand, researches have indicated various disadvantages of inorganic PCMs such as phase separation, sedimentation, sub-cooling and in a certain case high-volume change in phase transition [3], [9], [17].

Alternatively, eutectics, mixtures of only organics, only inorganics, or a mixtures of the organics and inorganics, are also considered as potential PCMs with LT storage capabilities slightly above organics and sharp melting points. However, their physical and thermal properties are needed to be investigated further [17].

3 CONSIDERATION OF PROPERTIES IN PCM SELECTION

In order to store and release higher thermal energy with consideration of economical aspect, selection of a proper PCM is essential. There are a number of properties required for PCM; namely, thermos-physical, kinetic and chemical properties [11], which will be reviewed in this section.

As required *thermal properties*, it is essential to match the PCT of the material with desired operating range in particular application. A high LH per unit volume during phase change is also crucial for a PCM because the quantity of the material required to absorb a given amount of thermal energy decreases. A high specific heat of the material is also important because it allows the material to store additional SH. High thermal conductivity in both phases is desired to enable high heat transfer rate into and out of the storage system, and high heat transfer rate can reduce heat transfer area [9], [12]. The required *physical properties* of a potential PCM include small volume change during phase change, low vapour pressure during the operating, favourable phase stability, congruent melting without phase separation and high density [9], [11], [17]. Using the PCMs with small volume change and low vapour pressure can reduce the requirements for PCM containers such as mechanical stability and tightness. Favourable phase equilibrium during phase change would ease heat storage setting, and high density are able to reduce the size of PCM containers. ‘Congruent’ means without change of composition, enthalpy, PCT during repeated phase change cycles between solidification and melting [9]. Congruent melting affects the storage capacity of a PCM during subsequent solidification processes. As most hydrated salts melt incongruently, various modifications are required to avoid phase separation [12], [22]. *Kinetic properties* required for PCMs are no sub-cooling, high nucleation rate and adequate rate of crystallization [9], [11], [17]. Sub-cooling (also called super-cooling) refers to the phenomenon when a material does not solidify immediately upon cooling below its PCT and starts crystallisation when temperature goes significantly below the PCT. A PCM will thus release SH instead of LH during sub-cooling because sub-cooling interferes with proper heat extraction from the PCM [23]. Therefore, little (5–10°C) or no sub-cooling is required for a PCM in order to prevent the interference [12], [22]. Sub-cooling has been a critical issue in PCM particularly for salt hydrates) development and various effective nucleating agents have been tested to supress sub-cooling effect by increasing nucleation and crystallization rate [9], [24]. PCMs also need adequate *chemical properties* such as long-term chemical stability, compatibility with the construction materials, non-toxic, non-flammable, and non-explosive to ensure safety [3], [11], [17]. During the expected life time of a PCM, oxidation, thermal decomposition, hydrolysis or other chemical reaction prevent or decrease the proper operation of the PCM. In addition, a PCM must not corrode construction materials because the use of a corrosive PCM requires expensive and high quality compatible construction materials [3], [12]. *Economic requirement* is one of the most important properties as a PCM. PCMs or its row material should be readily available and abundant at low price. Good recyclability not only increase the economical effectiveness of PCMs but also decrease environmental burden [3], [12]. As shown above, relevant combinations of thermal, physical, chemical, kinetic and economic properties should be considered in order to select an appropriate PCM. Among the properties required for candidate PCM, the most important properties are considered to be PCT, heat of fusion, thermal conductivity and density [25].

4 LOCAL WEATHER DATA COLLECTION

The conditioned indoor air temperature data was collected from 10 low energy residential buildings (LERBs) in Lochiel Park (LP) Green Village in order to obtain the thermal comfort temperature range in Adelaide local climate. LP Green Village was established in Campbell town, 8km north-east of the Adelaide CBD, in 2009 with 106 low-energy. The houses in Lochiel Park green village have 7.5 star house energy rating and the monitoring system already installed in the houses in LP green village was used. The energy consumption of the106 dwellings has been comprehensively monitored and displayed by programmable logic controller (PLC), intelligent meter and in-home display [26]. Data will be monitored in Eco Vision and sent to Lochiel park server by Ethernet and fibre optical cable. The stored CVS data can be retrieved by UniSA by remote desktop connection. Among the 106 houses in LP green village, 10 houses are also monitored in detail including indoor air temperature/relative humidity, individual appliance electricity usage, etc. In this study, 10 houses were selected in order to increase the reliability of collected data by removing the effect of missing data. The conditioned IAT data was generated by the data from existing monitoring system using excel spread sheet.

The daily outdoor dry bulb air temperature (DBAT) data (2005–2015) and hourly web bulb air temperature (WBAT) data (1988~2003) of Adelaide were obtained from the Bureau of Meteorology (BOM) and Typical Meteorological Year (TMY), respectively. In this study, the outdoor air temperature (OAT) means outdoor dry bulb air temperature (DBAT) unless otherwise noted. The collected data are processed and analysed by using excel spread sheet and Minitab (ver. 16.1.0).

5 CONSIDERED TEMPERATURE IN SELECTION OF PCM PHASE CHANGE TEMPERATURE

Numerous researched intensively investigated the performance of PCM as passive and active system application in various geographical areas. Even though there is slight difference in the range of the PCT, most of them indicate that the PCT should cover the recommended temperature range (19°C to 28°C) for indoor thermal comfort which is defined in ‘ANSI/ASHRAE Standard 55-2010’[27], but the high and low boundary can be extended 2–4°C depending on the local climate and use of additional H/C appliances such as A/C system or solar collector[7], [12]–[15]. According to ‘ANSI/ASHRAE Standard 55-2010’,

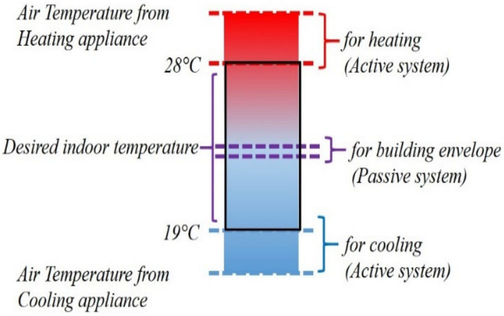


Figure 1: Temperature range of PCMs for passive and active system.

thermal comfort is defined as ‘*a condition of mind which expresses satisfaction with the thermal environment*’. The standard also indicates that ‘*the recommended temperature range to optimise indoor thermal comfort for most people is 19°C to 28°C even though it is difficult to satisfy everyone within the same thermal environment due to large variations from person to person’* [27], [28].

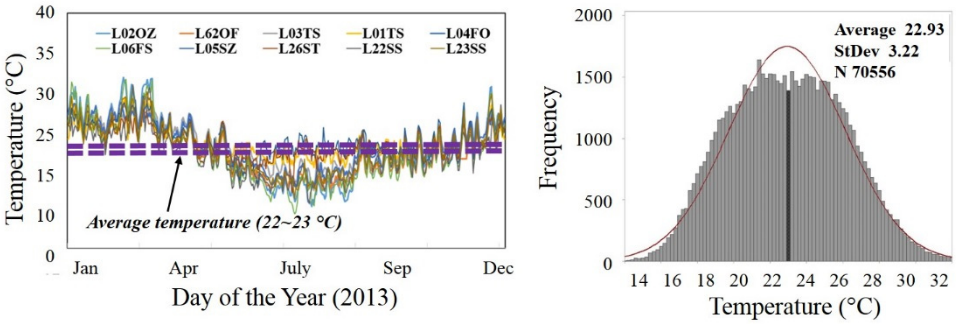
For example, the PCT of a PCM is recommended to lie between 20 and 32°C for PCM application as passive and active system in buildings [13]. In the researches which applied PCMs as a new layer of building such as plasterboard, sandwich panel and clay board, the PCT ranges mostly 18~33°C and showed the considerable reduction of indoor heat flux, temperature swing, H/C load and the shift of peak load [7]. More specifically, researches also recommended the PCT to be close desired mean IAT in application of PCM for passive system (i.e, wall/ceiling board, plasterboard, concrete blocks and wall/floor tiles containing micro-encapsulated PCM, etc.) and free H/C system which uses only fan for air circulation [15], [16]. In addition, in application of PCM TSS used in conjunction with A/C system (e.g., R/C AC), it is recommended that the PCT of a PCM for heating should be higher than indoor thermal comfort temperature and less than the maximum warm air temperature obtained from A/C or average maximum OAT. For cooling purpose, the PCT of PCM should be less than indoor comfort temperature and higher than the minimum cool air temperature obtained from A/C or average minimum OAT[12]. For examples, the research which applied PCM TSS integrated into R/C A/C system used the PCMs with PCT around 28°C for heating and 18°C for cooling, and the result showed 76% and 55% heating and cooling load shift [12]. Other research which applied the PCT of PCM with 17–20°C in similar configuration also showed reduced cooling load and peak load shift [29], [30]. Therefore, three different temperature ranges should be considered as shown in Fig. 1 in order to decide suitable PCT of PCM TSS for integration into the building envelope as a passive system, and for integration into domestic and commercial H/C appliances as an active system.

6 ANALYSIS OF LOCAL TEMPERATURE

6.1 Desired indoor air temperature

For PCM application as passive system (e.g., encapsulated PCM claddings) and free H/C system, the PCT range of a PCM should be close to desired or average IAT as mentioned in previous researches [15], [16]. However, it is unsure to define desired IAT because the word ‘desired’ is quite ambiguous and subjective. Therefore, the conditioned indoor air temperature of residential buildings of Adelaide area is analysed in order to find the desired IAT, because it is reasonable to consider the conditioned IAT as desired IAT.

In order to obtain conditioned IAT, detailed monitored IAT data from 10 houses in Lochiel Park Green Village were collected and analysed. As shown in Fig. 2(a), even though there is slight variation among 10 houses, the daily average IAT lies between 15~32°C during the monitored year, and annual average IAT lies between 22–23°C. Hourly IAT of the houses in Fig. 2(b) indicated that 82% of the hourly IAT is maintained between 19~28°C which is same thermal comfort range as defined in ‘ANSI/ASHRAE Standard 55-2010’ and average IAT is 22.9°C. The IATs of spring and autumn show similar to that of the whole year, as shown in Table 1, whereas the IATs in summer and winter are maintained in different temperature range (25.9°C and 19.8°C, respectively) which is also similar to the thermostat cooling (25°C) and heating (20°C) set points of Adelaide defined in Australian Building Codes board (2006). The average IAT obtained in this analysis is not representative the whole Adelaide residential buildings, but this temperature range has been tested and recommended for suitable PCT for PCM application in other researches as well [31].



(a) Daily Indoor Temperature (b) Hourly Indoor Temperature

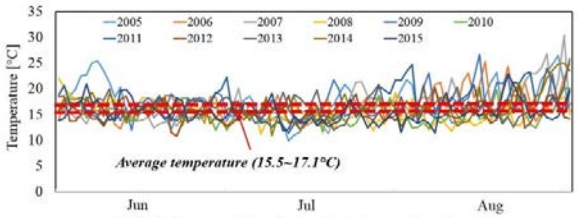
Figure 2: (a) Daily; and (b) Hourly indoor air temperature of 10 residential buildings in Lochiel Park Village.

Table 1: Seasonal average indoor air temperature of 10 houses in LP Green Village.

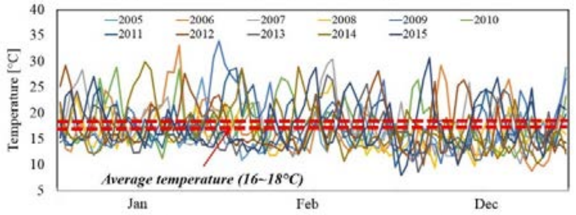
House ID	Spring (°C)	Summer (°C)	Autumn (°C)	Winter (°C)	Year (°C)
L02OZ	22.1	27.0	24.5	17.8	22.8
L62OF	21.0	25.8	23.4	18.7	22.2
L03TS	23.1	26.2	24.9	20.2	23.6
L01TS	23.0	25.5	24.3	21.7	23.6
L04FO	22.6	26.5	24.6	19.6	23.2
L06FS	21.1	26.3	23.3	17.9	22.1
L05SZ	22.9	25.7	24.0	22.7	23.8
L26ST	22.7	25.0	23.6	21.7	23.1
L22SS	21.9	24.9	22.9	18.7	22.1
L23SS	22.3	26.0	23.6	19.1	22.7
Average	22.3	25.9	23.9	19.8	22.9

6.2 Dry bulb air temperature (DBAT)

In selection of PCT, the maximum and minimum DBAT should be carefully examined because large temperature swing between day and night would provide PCM TSS with better performance [32]. For instance, the paraffin based PCM with PCT of 23–26°C did not work in summer in Greece because the lowest temperature was higher than the PCT of PCM [33]. The daily OAT data of Adelaide obtained from the BOM were analysed in order to examine whether the OAT swings between average IAT which is candidate PCT of a PCM for passive and active system in building application. The daily DBAT data is composed of maximum and minimum temperature for 4017 days which is 11 years data from Jan. 2005 to Dec. 2015. For heating purpose, it is assumed that the maximum outdoor DBAT during the day time in winter should be higher than PCT in order to charge PCM. Likewise, for cooling purpose, the minimum OAT during the night time in summer should be lower than solidification temperature.



(a) Maximum outdoor dry bulb air temperature in winter



(b) Minimum outdoor dry bulb air temperature in summer

Figure 3: Maximum (a) and minimum (b) outdoor dry bulb air temperature (2005–2015).

Table 2: Maximum and minimum dry bulb air temperature.

Temperature (T, °C)	Maximum						Minimum					
	Summer		Winter		Spring& Autumn		Summer		Winter		Spring& Autumn	
	No. of days	(%)	No. of days	(%)	No. of days	(%)	No. of days	(%)	No. of days	(%)	No. of days	(%)
28 ≤ T	552	55.8	1	0.1	417	20.7	22	2.2	0	0.0	1	0.0
24 ≤ T < 28	228	23.0	15	1.5	372	18.5	54	5.5	0	0.0	22	1.1
23 ≤ T < 24	73	7.4	9	0.9	110	5.5	28	2.8	0	0.0	14	0.7
22 ≤ T < 23	54	5.5	14	1.4	144	7.2	26	2.6	0	0.0	25	1.2
20 ≤ T < 22	66	6.7	45	4.4	313	15.5	97	9.8	0	0.0	59	2.9
18 ≤ T < 20	15	1.5	118	11.7	300	14.9	136	13.7	0	0.0	92	4.6
16 ≤ T < 18	2	0.2	282	27.9	255	12.7	159	16.1	2	0.2	158	7.8
T < 16	0	0.0	528	52.2	102	5.1	468	47.3	1010	99.8	1642	81.6

As shown in Fig. 3(a), the average maximum DBAT ranges from 15.5°C to 17.1°C during the winter when heating is required. With consideration of PCM application as passive system and free H/C system in residential buildings where the desired PCT of PCM is 22–23°C, the effect of PCM is assumed to be limited because the PCM might not be melted or charged by the DBAT which is lower than the PCT of the applied PCM. During the winter in 2005–2015 as shown in Fig. 3(a), the days when maximum DBAT is higher than 22°C are only 39 days out of 1012 days (3.9%) as indicated in Table 2, which means PCM with 22–23°C as PCT would works only 2~3 days per year in Adelaide climate. During the spring and autumn, more than 50% of the days have maximum OAT higher than 22°C. This data indicates that PCMs with 22°C PCT is not suitable for passive application and additional heat source as an active system is required to meet indoor thermal comfort temperature. On the other hand, the average minimum DBAT ranges 16–18°C during the summer as shown in Fig. 3(b) when cooling is required and 87% of the days are lower than 22°C. It means that PCM with PCT with 22°C can provide considerable cooling effect on indoor thermal comfort during the summer as passive system and active system without additional cooling source (e.g., A/Cs). During the summer in 2005–2015, the days when minimum DBAT is less than 22°C are 861 days out of 991 days (86.9%) in Table 2. According to the DBAT during the summer, cooling air less than 22°C can be provided for solidification of PCMs without additional cooling sources.

6.3 Web bulb air temperature (WBAR)

Especially, the WBAR is also considered as an important parameter for the performance of an EVAP-CS. The WBAR is measured by a temperature sensor covered with a water moistened wick and approximately same as the adiabatic saturation temperature which is normally lower than DBAT in hot and dry climate [34]. EVAP-CS uses water and a fan to blow cool humidified air into indoor and takes advantage of cooled air by the evaporation of water in hot and dry climate. [14]. Therefore, EVAP-CS requires relatively low operating energy demand and small capacity comparing with vapour compression systems [35].

Considering PCMs TSS integrated into EVAP-CS, WBAT of target local climate area should be examined instead of DBAT in selection of PCT because WBAT is lower than DBAT, especially in hot and dry climate region. According to the analysis of hourly WBAT

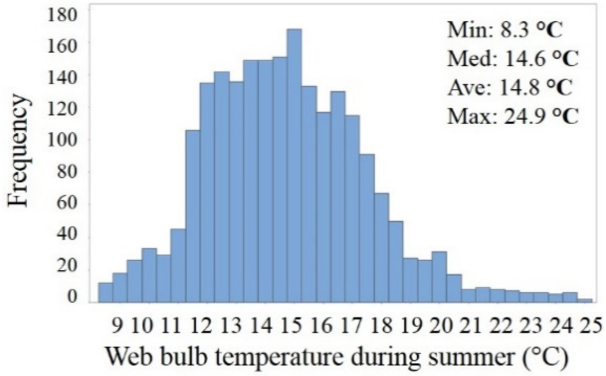


Figure 4: Hourly Wet Bulb Air Temperature of summer in Adelaide (1984–2004).

Table 3: Hourly Wet bulb air temperature of summer in Adelaide (1984–2004).

Temperature (T, °C)	Summer	
	Frequency	(%)
28 ≤ T	0	0.0
22 ≤ T < 28	36	1.7
20 ≤ T < 22	52	2.4
18 ≤ T < 20	153	7.1
	422	19.5
T < 16	1497	69.3

in Adelaide during the summer (Fig. 4 and Table 3), WBAT lies between 8.3°C–24.9°C with average 14.8°C, and 88% of whole hours are less than 18°C and 69.3% are less than 16°C.

This analysis indicates that cooled air less than 18°C can be obtained by wetted air from EVAP-CS without using high energy consuming R/C A/C in Adelaide climate, and the PCT of PCM used for cooling purpose might be lower than 18°C. Therefore, it is assumed that PCMs TSS integrated into EVAP-CS can enhance the cooling effect on indoor thermal comfort during the summer in Adelaide by increasing energy efficiency of building.

7 DISCUSSION

In selection of PCT of PCM for building applications, various parameters are required to be considered such as the designs of heat exchangers, geometry of PCM containers etc. However, this study examined only conditioned IAT and DBAT/WBAT in order to find the thermal comfort temperature range and suitable PCT of PCM for passive and active application. Based on the conditioned IAT from 10 housed in LP Green Village in Adelaide, desired IAT was estimated to find out thermal comfort range. According to the analysis of the conditioned IAT which are within thermal comfort ranges defined in 'ANSI/ASHRAE Standard 55-2010'[27],the desired PCT of PCM should be lie between 22–23°C. Ideally, the OAT should swing between the PCTs of PCM during each day in order to take advantage of PCM as TSS in building (as passive system). Considering the OAT in Adelaide where the desired IAT is 22–23°C, 87% of the days of maximum OAT are lower than 22°C and 92% of the days of minimum OAT are higher than 22°C during the summer. It indicates that the PCM with PCT 22°Cis suitable during the summer except for only 130 days in 11 years (12 days in summer per year). However, only 3.9% of the days of maximum OAT are higher than 22°C and all days of minimum OAT are lower than 22°C during the winter. It means the PCM with PCT 22°C is not working most of the days in winter. Even the lower PCT of a PCM will not change the result much. For example, PCMs with PCT 20°C and 18°C would work only 8 and 18 days in winter per year, respectively. Furthermore, PCMs with PCT lower than 18°C is not suitable for building application as passive or free H/C system because the PCT is out of thermal comfort range. Therefore, in selection of PCT of a PCM for building application as passive and free H/C system in Adelaide climate, it is reasonable to choose around 22°C as the PCT of a PCM by considering only cooling during the summer because the OAT temperature is not warm enough to enable PCMs' melting and solidification cycle during the winter. For cooling purpose such as PCM TSS integrated into A/C system, the PCT should be lower than desired IAT and higher than the minimum OAT or temperature obtained from A/C system. According to the minimum DBAT in Table 2, 87% and 77% of the days are lower than 22°C and 20°C, respectively. Therefore, it is assumed that enough cooled air can be obtained from outdoor air in Adelaide climate. Considering the minimum air temperature is generally obtained during the night time, free cooling system coupled with

PCM TSS is assumed to provide enough cooled air during the daytime and contribute to shift cooling demand. Furthermore, the WBAT is considered to be lower than the DBAT in hot and dry climate. As shown in Table 3, 96% and 89% of the hourly WBAT lower than 20°C and 18°C.Therefore, the EVAP-CS coupled with PCM TSS is assumed to be more energy efficient than R/C A/C system in in Adelaide climate. However, EVAP-CS with PCM TSS has not been tested and need more researches in dry and hot climate area such as Adelaide. In this application, the PCT of PCM can be lower than 18°C as many other researched conducted with R/C A/C system.

8 CONCLUSION

Finding suitable PCT of a PCM is considered the starting point of developing PCM application in building sector. This study investigated various temperatures in order to estimate the suitable PCT of a PCM for building application in Adelaide local climate. Especially for PCM application as passive system (e.g., building envelope) and free H/C system, the OAT of local area and thermal comfort temperature are crucial factors for decision of PCT of a PCM. In Adelaide local climate, the PCM is assumed to perform well during only the summer but not winter because outdoor air during summer night is cool enough and swings around thermal comfort temperature while outdoor air not warm enough and lower than thermal comfort temperature during the day time in winter. Therefore, PCT around 22°C is assumed to be suitable for a PCM application as passive which can provide enough thermal performance during the summer considering Adelaide local climate and indoor thermal comfort range. Free cooling system integrated with PCM TSS with PCT around 20–22°C is also assumed to provided sufficient cooled air during the day time in summer. For active application as TSS integrated into H/C appliances, EVAP-CS will perform better than R/C A/C system in hot and dry Adelaide climate. As other researches tried with R/C A/C system, PTC around 18°C is assumed to provide enough cooled air during summer. On the other hand, outdoor air cannot provide enough warm temperature, additional heating sources are necessary for indoor thermal comfort during the night. In this study, the PCT of PCMs as passive and active system is estimated throughout various temperatures analysis in Adelaide local climate, which will be the foundation for the later study on development of PCM heat exchanger designs and simulation model.

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