Water Flow Window Effect on Energy Efficiency in Terms of Energy Consumption Comparison

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Abstract

In this study, commercial air-filled window system, WFW system with domestic water input and WFW system with water tank includes PCM is compared with the comparison of energy consumption in summer climatic conditions. There is a closed water cycle between the WFW and the tank includes PCM. The temperature of the water inside the tank increases over time. This increase causes the temperature rise and phase change of PCM. After this rise, water inside the tank can be used as domestic hot water. There is an open water circulation from the domestic water source to WFW in the second cabinet. The water left window can be used in daily life. Another cabinet has an air-filled commercial window in front. In day time There is a cooling consumption ratios around 0.4 for WFW with domestic water and 0.9 for WFW with PCM tank (without any load or unload of domestic hot water). The consumptions during nighttime of the systems are considered. In summer conditions, the comparison of cabinets can be neglected compared to the daytime consumption.

Keywords: Water Flow Window, Solar Energy, Energy Efficiency, Energy Storage, Phase Change Material

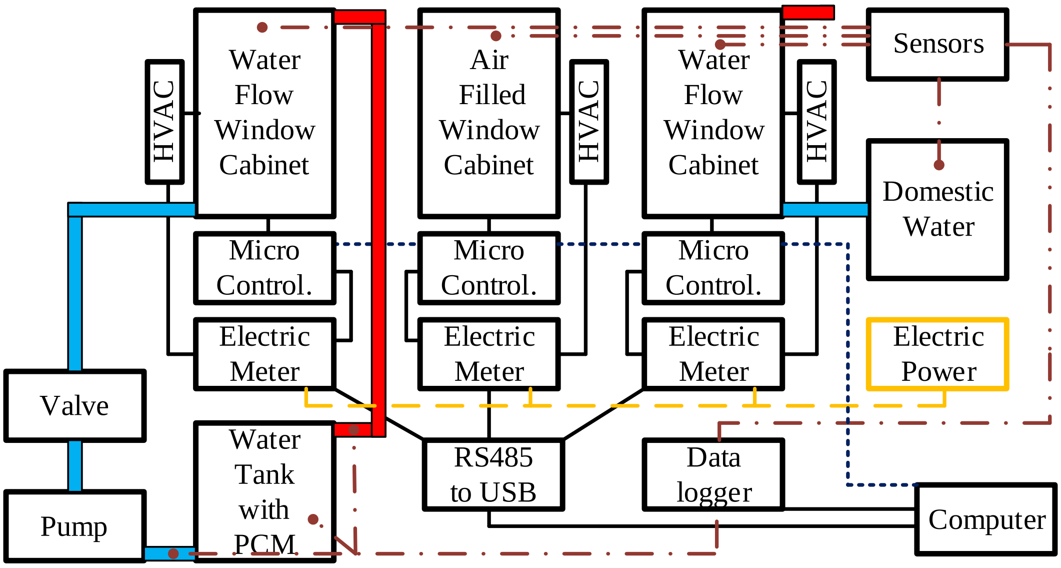
1. Introduction

The energy consumption of the buildings is more than 40% of total energy consumption (Berardi, 2015). 30% of the building energy consumption is used for heating, ventilating and air conditioning (HVAC) (X. Li & Wen, 2014). Windows has a huge effect on energy efficiency construction. The proper construction of windows will substantially reduce the energy usage of buildings (Tian et al., 2010). Liu (Liu, 2012) works on the evolution of new window systems for low-carbon buildings. Under various experimental thermal conditions, the electrical output of a thermoelectric generator device coupled with a vacuum tube is studied. The systems named Water Flow Window (WFW) or Water Flow Glazing (WFG) are studied to decrease energy loss from a window. There are numerical and experimental studies on WFW. Pfanner et al. (Pfanner et al., 2018) work on an enveloped new building to increase daylight and efficiency of energy with WFG. The glazing captures infrared solar energy. The transmittance of natural light is found the same with common glazing. WFG reduces the transmission of heat to interior space. Adu (Adu, 2015) works on the characterization of a double glazing unit filled with water. The high convective coefficient and the high thermal mass of the water can be used to its benefit as it is allowed to circulate at peak temperatures while retaining smaller temperature fluctuations indoors. Li et al.(C. Li et al., 2019) research on WFW thermal performance as curtain wall of hospital numerically. Preheated water should be used in the shower rooms and can help to save electricity. Water-flow windows have tremendous scope for large-scale installation in related structures. Chow et al. (Chow et al., 2011) make a prediction on the performance of WFG with reflective coating numerically. The validated model was used to research the efficiency of the window while mounted in the gymnasium of a major sports center. The findings show an attractive water heat production benefit and a decrease in the use of energy in the air-conditioning system. Lyu et al. (Lyu & Chow, 2015) evaluate the header design influence on characteristics of water flow in the cavity of the window numerically. The adjustment in opening size or interval is observed to influence the local temperature distribution and flow velocity across the headers. But their impact on the overall efficiency of the system is negligible. Li and Chow (C. Li & Chow, 2011) study the performance of the water-filled double reflective window and its year-round performance. The findings demonstrate that the indoor room heat gain can be greatly decreased by using this new glazing device. Also, the absorbed heat from the water flow in the cavity may be used as a pre-heated water supply to serve the hot water system. There is also tremendous scope for energy conservation in its use in big buildings. Claros-Marfil et al. (Claros-Marfil et al., 2016) make an application to WFG in terms of solar research with data acquisition and open source control. The proposed data collection and control scheme, the code sequence steps, the model algorithm and the relation between the data obtained by the system and the commercial data loggers are discussed. The drawbacks of utilizing an open-source board for the planned control system are analyzed, and the benefits of using a microcontroller-based control system are addressed. Gonzalo and Ramos (Gonzalo & Ramos, 2016) test WFG in geothermal systems. The flowing water through the chamber both absorbs infrared radiation and decreases the temperature of the inner glass pane. Besides, it gives thermal inertia to the window and a strong propensity for absorbing and transporting energy. Goia et. al. (Goia, Perino, et al., 2014) work on a prototype of full-scale PCM glazing energy performance experimentally. The obtained results suggest the promising performance of PCM glazing, while careful alignment of the PCM glazing portion with the indoor temperature control techniques is important. Goia et. al. (Goia et al., 2012) make a PCM glazing systems' optical properties characterization. The various thicknesses of the PCM layer are used to determine the reliance of the optical properties on the PCM layer thickness. An angular dependence is also investigated for beam angles of up to 45 deg. Goia et al. (Goia, Bianco, et al., 2014) investigate the prototype of PCM integrated dynamic glazing and thermotropic layers experimentally. In contrast to the reference technology, versions are capable of minimizing the direct transferred solar energy to a significant degree, as well as smoothing the peak indoor surface temperature of the glazing. There are several studies on Phase Change Material (PCM) applications with glazing to increase energy efficiency in buildings. In this study, commercial air-filled window system, WFW system with domestic water input and WFW system with water tank includes PCM is compared with the comparison with energy consumption in summer climatic conditions.

2. Methods

There is a closed water cycle between the WFW and the tank includes PCM. The temperature of the water inside the tank increases over time. This increase causes the temperature rise and phase change of PCM. After this rise, water inside the tank can be used as domestic hot water. There is an open water circulation from the domestic water source to WFW in the second cabinet. The water left window can be used in daily life. Another cabinet has an air-filled commercial window in front. The water flow rate is the same in both WFW and approximately 1l/min. Windows' gap volume is approximately 3l. There is a schematic diagram of the experimental system in Fig. 1.

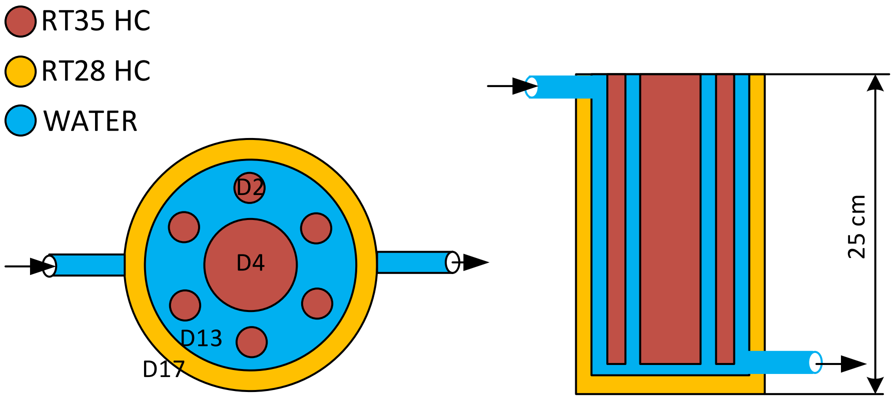
Figure 1: Schematic diagram of experimental system



The test system includes water cycles, measurement devices connected to the data logger, HVAC systems for cooling of cabinets, control devices includes relay to control the HVAC system, electric meters. The yellow colored line represents electrical power used to provide energy to HVAC system. There are relays controlled from microcontroller board. Electric meters start count when relay are open. The dark blue dashed line shows the connection to computer and the microcontroller board. The burgundy dashed line represents the connection of sensor to data logger for measurement. In the right side of the Fig.1, it can be seen that the inlet water of the window is supplied by domestic water.

In the left side of the Fig.1, the blue colored line represents the water left the tank. The water is pumped to gap between glazing. The water inlet of the window is at the bottom and outlet is at the top. The red colored line shows the water left the window and go back to the tank. The schematic of tank can be seen in Fig.2.

Figure 2: The schematic view of water tank includes PCM



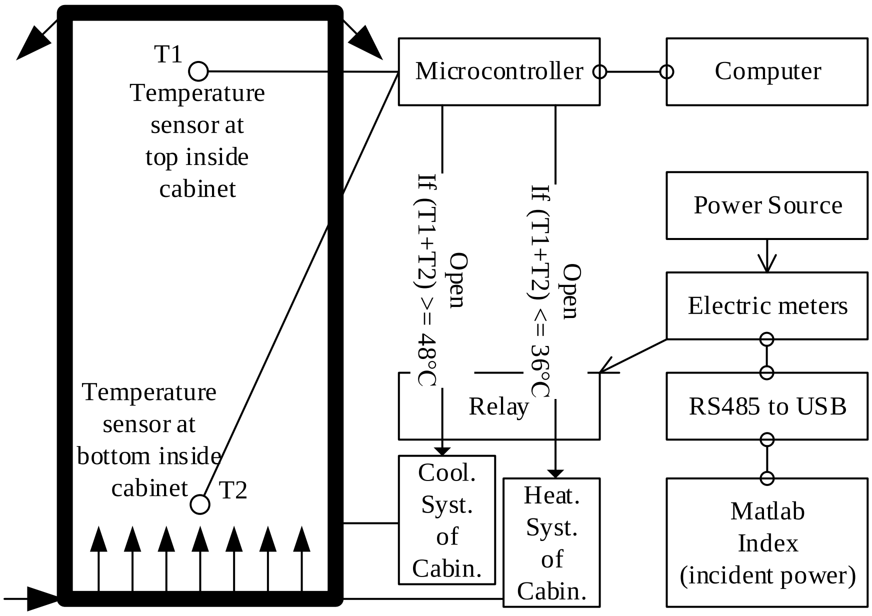
The RT28HC surrounds the water reservoir. The RT35HC is inside the tubes which are placed into water reservoir. The dimensions of tank and tubes can be seen from Fig.2. the inlet of the tank is at the top, outlet of the tank is at the bottom. Thermal specifications of these commercial wax based PCM are shown in Table 1.

Table 1: Thermal Specifications of PCM (*Rubitherm*, 2021)

Property	**RT28HC**	**RT35HC**
Melting area [°C]	27-29	34-36
Congealing area [°C]	29-27	36-34
Heat Storage Capacity [kJ/kg]	250	240
Specific Heat Capacity[kJ/kg.K]	2	2
Heat Conductivity [W/m.K]	0.2	0.2

The PCMs are chosen because of their heat storage capacity as wax between the temperatures, which water circulation rises. The volume of tank is approximately 5.5l. Half of this tank is filled with RT28HC, one tenth of the tank is filled with RT35HC and forthy percent of tank is circulation water. The connections of microcontroller board, how code of microcontroller works, relay-electric meters-cooling system connections are shown in Fig. 3.

Figure 3: The schematic view HVAC system



The microcontroller is used for open and close the gates of relay board. Equation for the condition to engage the cooling system is :

$$(T1 + T2) \geq 48\ °C \tag{1}$$

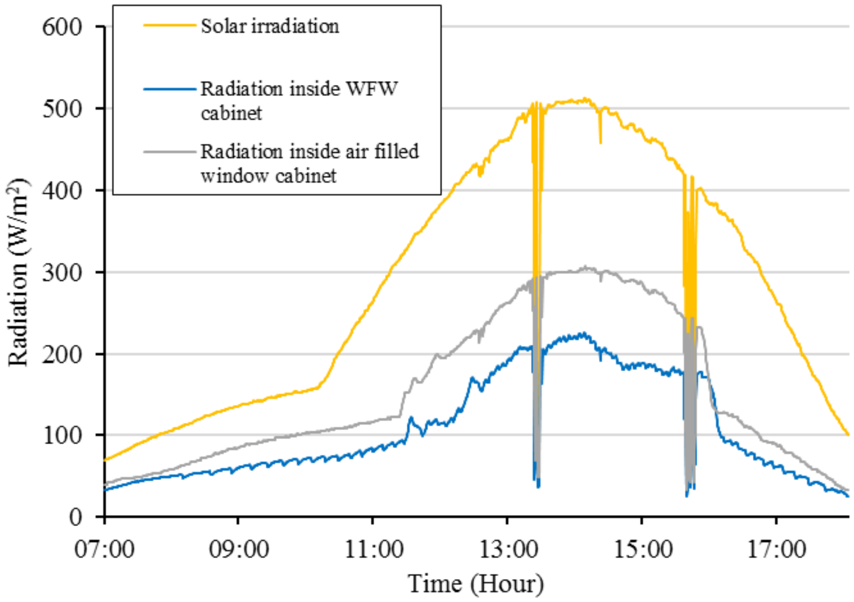
$$(T1 + T2) \leq 36\ °C \tag{2}$$

With these equations used in HVAC control, the cabinets' temperatures stays between 20-26° can be considered as thermal comfort temperatures. Entes RS32-LS electric meters are used with RS485 to USB converter. MATLAB code is used to obtained simultaneous electrical consumption of heating and cooling systems.

3. Results and Discussion

The experimental study is made under environmental conditions. The most important environmental condition effect on WFW system is solar irradiation. In addition The radiation inside cabinets is measured to estimate the effect of water between the gaps of glazing on reduction of radiation. Pyranometers are used to measure radiation inside and outside of the test cabinets. The pyranometers are placed perpendicular to ground, parallel to window surface area. The results as radiation vs. day time can be seen in Fig. 4.

Figure 4: Radiation vs. time chart

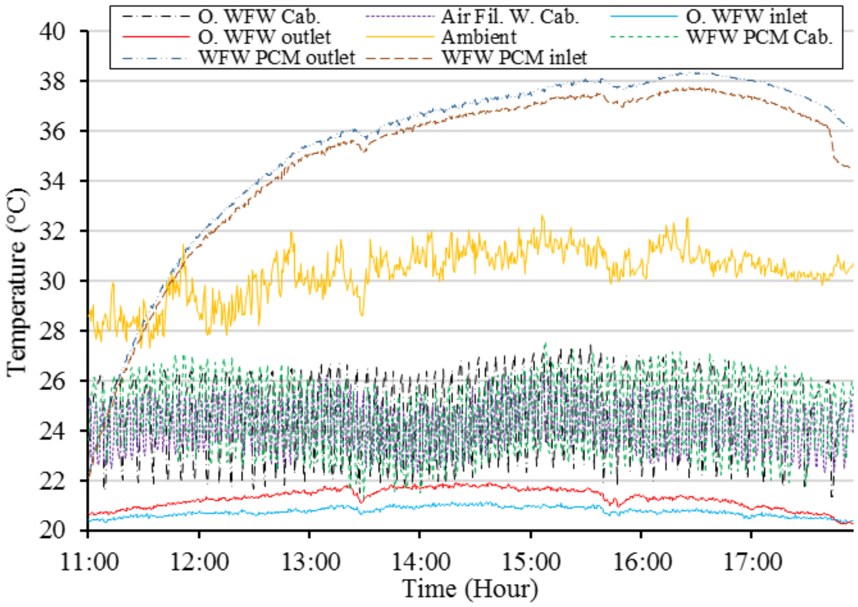


The downstream peaks are obtained in when the weather is cloudy. Measurement intervals are kept frequent enough to display even this change. As can be seen in Fig.5. The maximum solar irradiation is 500W/m2, The maximum radition inside WFW cabinet is approximately 200W/m2 and the maximum radiation inside cabinet which have air filled window front is 200W/m2. This situation is the evidence of less cooling electricity load.
The comparison of energy consumption and the thermal situation of test environment must be grouped as daylight and night hours. The results of the day and night performances are examined under separate headings.

3.1 Daylight Hours Results

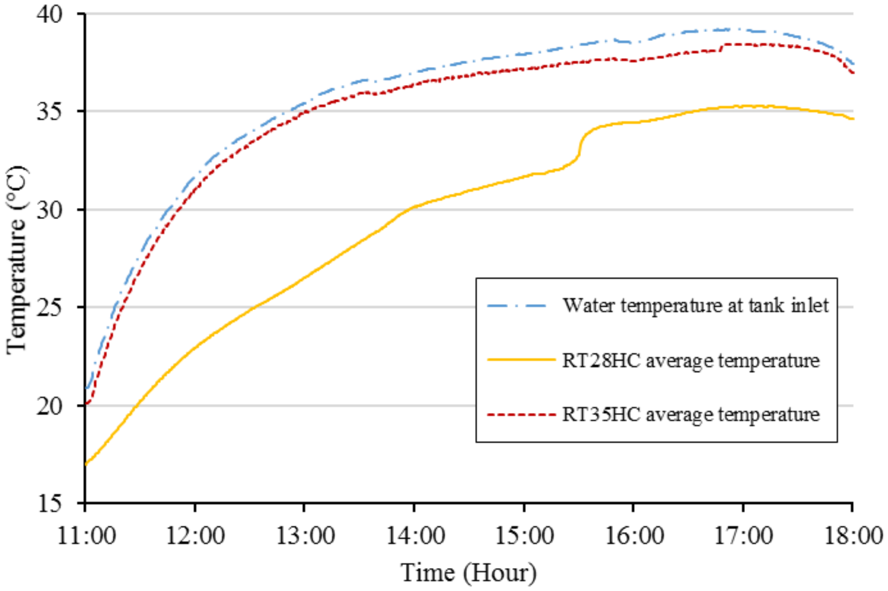
First off all the results as temperatures of the cabinets' inside temperature, environmental temperature, inlet and outlet temperatures of WFW are obtained.

Figure 5: Temperatures of experimental system in daylight hours



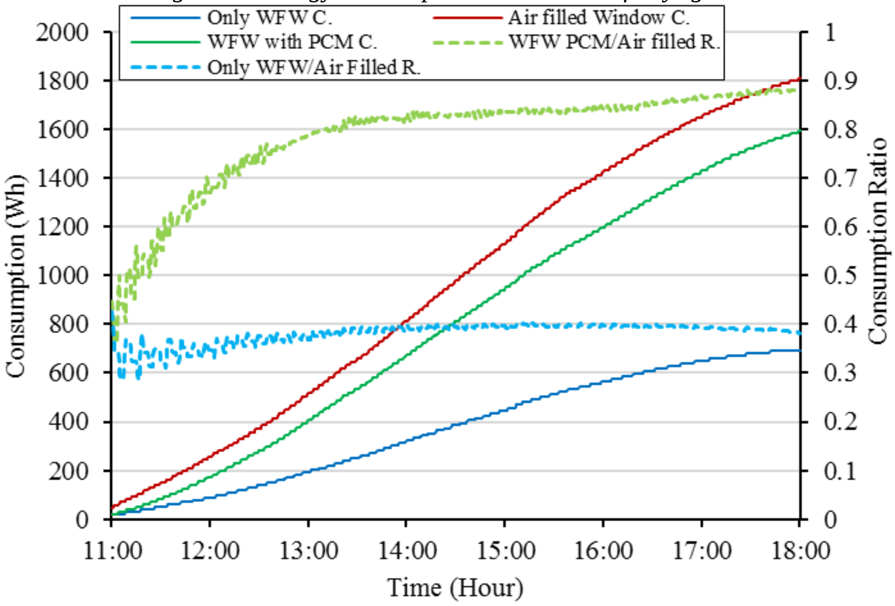
In Fig. 5. 'O. WFW Cab.' term is the abbreviation of Only WFW cabinet, 'Air Fil. W. Cab.' means air filled window cabinet, 'WFW PCM Cab.' represents the WFW system used with PCM tank. Minimum and maximum ambient temperatures are 28°C and 32°C as a typical summer day. All of the cabinets inside temperature varies between 22-26°C as planned. These are thermal comfort temperatures. The water inlet temperature of only WFW cabinet is approximately 21 °C. Outlet temperature is higher than inlet and varies under 22°C. The inlet and outlet temperature of the WFW system with PCM tank start from around 22°C, There is a high slope rise up to environmental temperature after this point the rise have lower slope than before. The decrease in solar irradiation causes the decrease temperature decrease in WFW inlet and outlet in system used PCM tank. The temperatures in gap of window can't be considered without the temperatures inside PCM-water tank. Fig. 6. shows the temperatures of PCM-water tank materials and inlet water temperature.

Figure 6: Temperatures of PCM-water tank during daylight hours



There are sensors inside PCM in tank at various places, the average of the measurement of these sensors are used to obtain the chart in Fig.6. There is a continuous rise in PCM temperatures due to increased water temperature. RT35HC temperature rises similar with inlet water of tank because tubes of this material is surrounded by water. There is heat transfer water to RT35HC from all faces. RT28HC is located around water tank, one face of material have heat transfer but the other side is isolation. This explains the slow temperature rise of the PCM. The main aim of the study is to find the WFW effect on energy consumption of climated cabinets. In Fig. 7, the electric consumptions of cooling system-their ratios vs. time chart is shown.

Figure 7: Energy consumptions and ratios of daylight



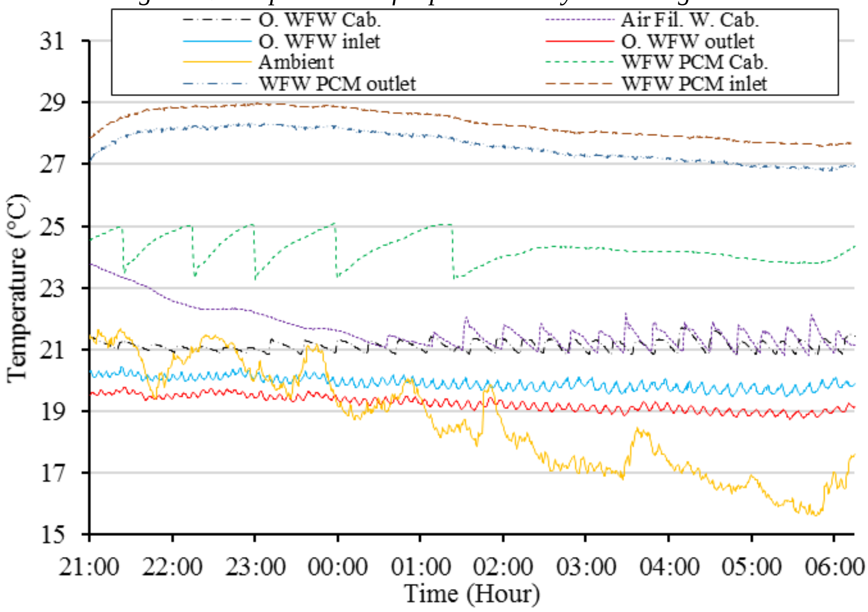
hours

The electric consumption of air filled cabinet rises 1800Wh at the end of daytime. WFW cabinet with PCM tank consumption is around 1600Wh. Only WFW cabinet consumption is around 700Wh at the end of the day. The difference of WFW systems are coming from the inlet temperature of water between gap of glazing. The consumption ratio of WFW system have inlet water source as domestic water air filled window don't change a lot during day because of constant water inlet temperature. There is a rise in ratio of consumptions of air filled window and WFW with PCM tank cabinet until the end of the daylight. That can be explained with inlet temperature rise time by time.

3.2 Night Hours Results

Except from general view of the WFW studies, in this study WFW system's night performance is tested. The most effective parameter is environmental temperature instead of solar energy in nighttime. In Fig.8, there are the results of the same measurements are shown in Fig. 5 but during nighttime. In Fig. 8, maximum and minimum ambient temperatures are 21°C and 16°C as a typical summer night. The cabinets' inside temperature varies in various range. The temperature of WFW system with PCM tank cabinet have a highest temperature values because of the effect of inlet water temperature in the gap of glazing.

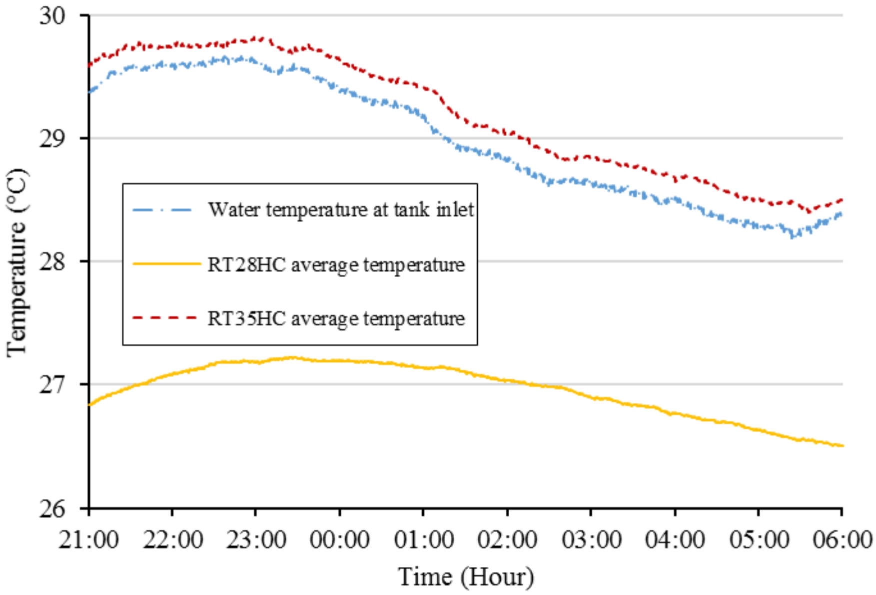
Figure 8: Temperatures of experimental system in night hours



The WFW system supported by domestic water have the lowest temperature until the start of the night measurements. The inlet water temperature has cooling effect on this cabinet. The air filled window cabinet temperature decreases slowly. After 00:30 this cabinet's temperature shows similar behavior with the last explained one. The water inlet temperature of only WFW cabinet is approximately 20 °C. Outlet temperature is lower than inlet and varies over 19°C. The inlet and outlet temperature of the WFW system with PCM tank start from around 27°C, The situation becomes after getting water inside tank as a domestic heat

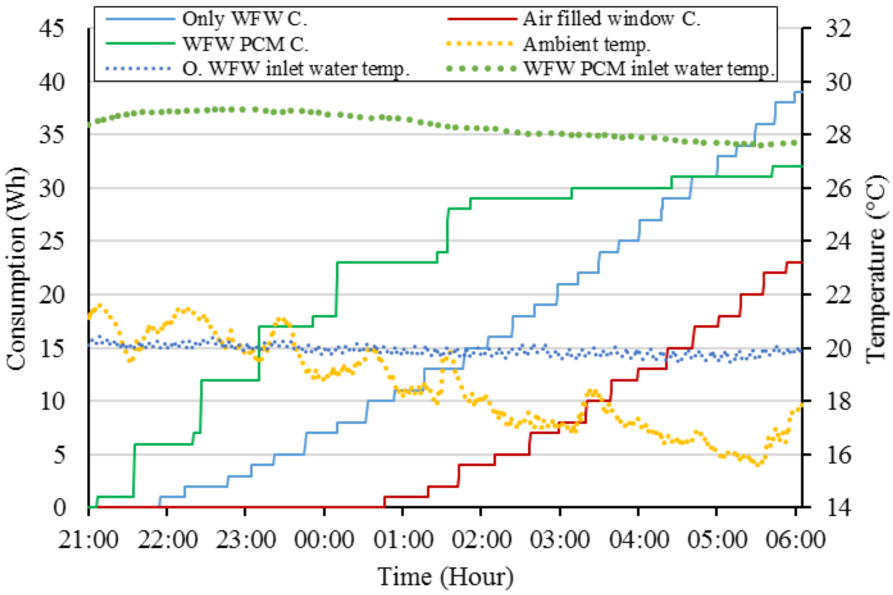
water supply. Then the water tank is filled again, but the PCM causes increase up to this point. The decrease in environmental temperature is the reason of the decrease in temperature of WFW inlet and outlet in system used PCM tank PCM-water tank. Temperatures are obtained results and shown in Fig. 9.

Figure 9: Temperatures of PCM-water tank during night hours



There is a rise in temperature of RT28HC up to 00:00. The heat transfer from RT35HC to RT28HC causes this increase. After this time the water inlet temperature has effect on RT35HC by means of decrease. The decrease in RT28HC temperature can be explained with environmental effects. Absolutely there is an isolation, but isolation means low thermal conductivity, not non-zero heat transfer. It must be specified that this decrease is about 1°C. The temperature distribution of materials inside tank are similar and the maximum difference between them is around 2°C. The WFW effect on energy consumption of test cabinets is shown In Fig. 10, the electric consumptions of heating system-water inlet temperatures of WFW vs. time chart is shown.

Figure 10: Energy consumptions and inlet water temperatures of night hours



The electric consumption of air filled cabinet rises 25Wh at the end of nighttime. WFW cabinet with PCM tank consumption is around 33Wh. Only WFW cabinet consumption is around 40Wh at the end of the night. The difference of WFW systems are coming from the inlet temperature of water between gap of glazing as it mentioned for the day results before. The dashed curves are temperatures of inlet waters of WFW and environmental temperatures. The consumptions curves are seemed like ladder. The vertical lines are obtained from the times which the HVAC devices works and the horizontal lines represent zero consumption means the HVAC devices don't work. If The Fig. 8 and Fig. 10 are considered together Air filled window cabinets' heating system starts working around 01:00. The cabinet of WFW system supported by domestic water needs heating before 22:00. These two cabinets don't use cooling system night The cabinet of WFW system with PCM tank cause the consumption of cooling system until 02:00. The air filled cabinet needs the less power to have thermal comfort around 21-24°C.

4. Conclusion

- Water inlet temperature of WFW system has huge effect on energy consumption of climated cabinets.
- The cooling consumption of WFW system used domestic water as inlet is two fifths of commercial air filled window.

- The cooling consumption of WFW system with PCM tank is nine tenth of air-filled window. But this value must be accepted as the highest ratio. This ratio will decrease if the water tank is emptied and filled again with relatively cold water.
- In summer night PCM can't be used as heat source for cabinet. But it seemed promising for colder seasons than summer. And also discharging of PCM is seemed like a problem. Discharging must be done with environmental affects (maybe with removal of insulation at night) instead of water circulation for cooling.

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