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Thermal Null Offset of Open and Closed Water Tank in Dynamic Environment

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Abstract: This paper studies the thermal null offset of half-filled water tank left in ambient environment. The study was performed by analyzing multi-days reading from various sensors employed on the system. Repeated reading pattern produced by each sensor indicated that dynamics of ambient temperature affects the thermal null offset of the open and closed water tank. However, the sequential quasi steady state is different for open and closed tank. For the open tank, daily thermal equilibrium condition was achieved with significant temperature difference between the sensors located below the water surface. Yet, insignificant temperature difference was found in closed tank. Hence, it indicates that the lid-closing accelerates the thermal equilibrium inside the tank. The thermal null offset of water tank will be used as a basis for developing new model of heat transfer from hot fluid inside the tank to ambient air which commonly found in various industries.

Keywords: thermal null offset; dynamic environment; water tank

1. Introduction

Analysis of the phenomena that occur in the nature is often neglected or considered insignificant, especially when it seems steady, passive, or inactive on daily basis. However, the analysis of the system is mostly carried out in a steady state to obtain a representative picture of the stable condition of each parameter[1]). All systems basically want to maintain their equilibrium position, according to Newton's 1st law of inertia[2]). The intervention given to a system from its initial stable state will change the state of the system until it reaches a new state which over time tends to be stable as well so that a new stable state is created. The process of transition from an initial state to a new state is indirectly represented by the difference between the two steady states, so steady-state analysis is generally used to represent the entire phenomenon in the system [3)4)].

The initial stable state is better known as null offset in electronics field. The term itself is not without meaning, because the absolute condition of zero (null absolute) is an ideal condition that is difficult to obtain even with sophisticated engineering revolution[5]). This makes the measuring instruments, both electronic and mechanical, have a virtual zero value called a null offset[6)7)]. The virtual zero value is based on the natural state of the measuring instrument before starting to measure anything. As is in the pressure gauge, the pressure gauge needle shows the number 0 when measuring atmospheric pressure in the range of 1 atm. In this case, the selection of atmospheric pressure as the virtual zero benchmark is not simple, because its value varies with altitude. The existing variations cause measurement uncertainties or errors[8]), so the terms accuracy and precision appear on the measuring instrument. By studying the initial stable state of the measuring instrument, reading errors or measurement errors can be minimized so the accuracy can be more accounted for.

Based on this phenomenon, this paper aims to analyse the natural state of a system, namely a tank that contains water almost half of its volume prior to heat intervention. Mostly, tanks are used as thermal energy storage in both the industrial and domestic sectors[9)10)], such as the solar water heating system[11)12)13)] and plant cooling system [14)]. The function of the tank as thermal energy storage makes the fluid stored inside the tank sensitive to temperature changes, especially changes in dynamic environmental conditions[15)16)]. The analysis of the natural state of the system will be used as the basis for obtaining a new calculation model of heat transfer from the hot water tank to the outside air that hopefully will be more accurate.

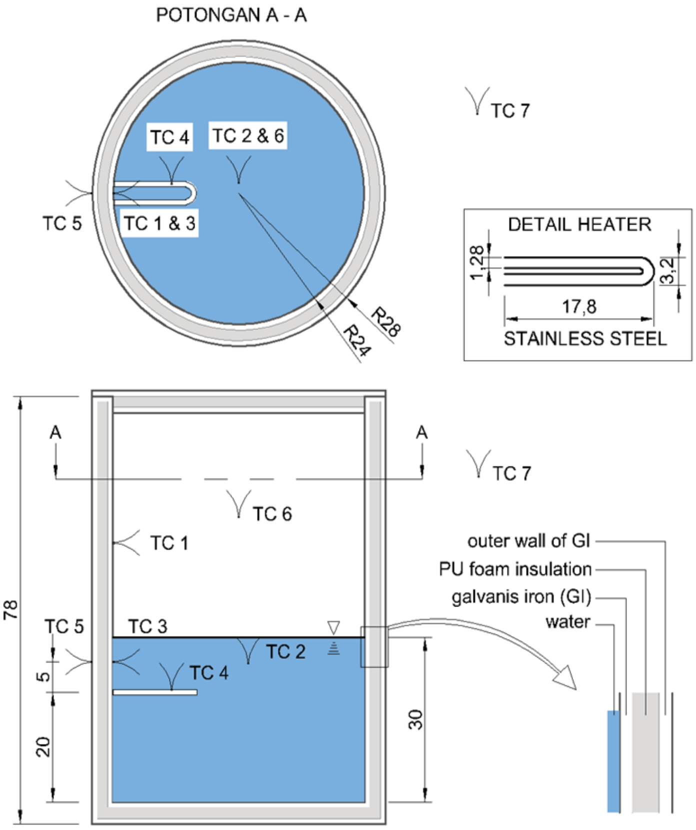

Fig. 1: Illustration of the tank.

2. Methodology

The water tank used is made of galvanized iron and has an inner diameter of 48 cm and a height of 78 cm. The overall thickness of the tank wall is 4 cm, consisting of 3 cm polyurethane foam insulation flanked by two galvanized iron, 0.5 cm thick, as the inner and outer walls. The inside of the tank is filled with water to a height of 30 cm from the inner bottom and was left in direct contact with ambient air. There is a 2000Watt submerged heater made of stainless steel which is not turned-on during data collection. The height of the heater is 20 cm from the bottom of the tank. The open water tank used is placed on an iron frame so that it does not come into direct contact with the floor. The experimental set-up is located indoors without air conditioning inside the MRC Building Depok, Indonesia.

Seven types of MAX6675 and K-type thermocouple sensors17)18) that have been filtered and calibrated 19)20) were used to map the thermal null-offset condition of the system. The placement of the sensor can be seen in Fig. 1 and Table 1.

Natural data retrieval is carried out after all sensors are installed and the water in the tank is filled according to the desired volume. The data retrieval process is carried out in real-time using Arduino Mega as a microprocessor template21)22)23). Seven temperature readings acquired by the sensor and Arduino every minute are then stored as text on the SD Card24)25).

The null offset process is carried out in an open tank first. The working fluid is drained and then refilled before taking closed tank data. Closing the tank does not change the configuration and placement of the sensors used. The tank lid is made of galvanized iron which is insulated on the inner surface.

Table 1. Sensor placement.

Sensor no	Location
1	Upper inner wall
2	Water temperature
3	Lower inner wall (under the water)
4	Surface heater
5	Lower outer wall
6	Bulk air inside the tank
7	Ambient air

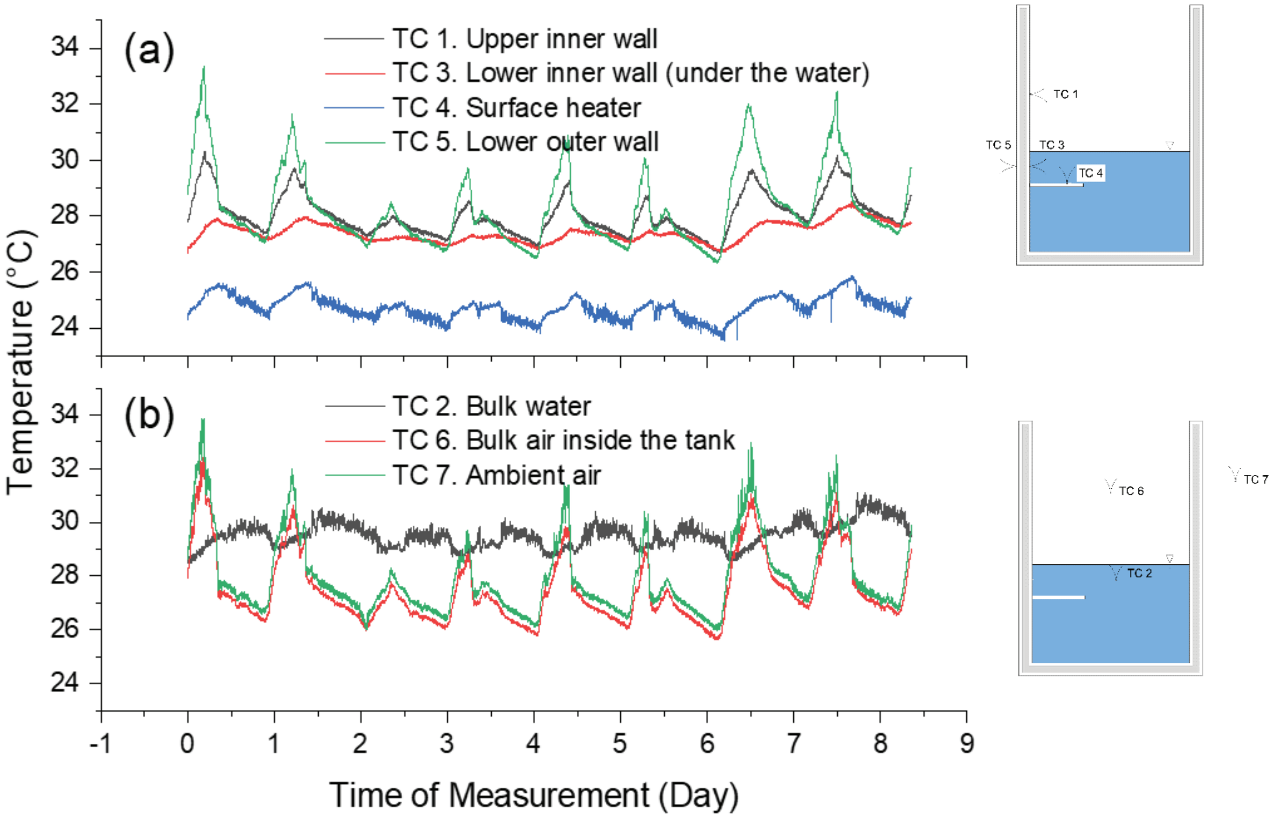

Fig. 2: Typical sensors reading for (a) surface (b) fluids.

3. Results and Discussion

3.1 Thermal Null Offset of The Open Tank

The performance of the seven sensors in reading the natural initial conditions or null offset of an open water tank system for 8 x 24 consecutive hours is shown in Fig. 2. Eight days of measurement are depicted by eight peaks of ambient temperature that occur around 12 noon. The peak temperature value is not the same every day because it is greatly affected by weather conditions.

Figure 2 is divided into two parts, namely Fig. 2(a) which shows the readings of the surface temperature and Fig. 2(b) which shows the readings of the fluid temperature. Figure 2(a) has two different reading patterns, where TC 1 and TC 5 are more volatile than TC 3 and TC 4 which were submerged in the water. The same thing is shown in Fig. 2(b), where the sensor in contact with air has a higher fluctuation than water. The diffusivity of the fluid medium that surrounds the location of the sensor greatly affects the sensor readings.

During the eight days of data collection, the reading pattern of each sensor under natural environmental conditions was relatively consistent every day. The difference in TC 3 and TC 4 readings is also consistent with a significant gap even though both are underwater. This occurs because of the evaporation process on the surface of the water, where the phase change of water into steam requires large amounts of energy supplied from all parts of the water including the heater surface (TC 4). Due to the nature of the material that can conduct heat well, the surface temperature of the heater is always of a lower value than other surfaces.

In general, the natural balance of an open water tank system occurs with a temperature difference that is quite significant for the sensors measuring the temperature below the water surface.

3.2 Reading Analysis for 24-hour Measurement of Open Tank Null Offset

Figure 3 shows the readings of all sensors during 1 x 24 hours of system natural data collection. A 24-hour reading starting at 9am makes it easy to analyze the phenomena that all sensors experience daily. At the beginning of the measurement in the morning, water acts as a heat donor for all reading measurement points because the temperature is the highest. However, towards noon, when the sun begins to rise and is at its peak, the role of heat donor is taken over by ambient air. The increase in ambient temperature is followed by all sensors at different rates. Sensors in contact with air have a rise response that is almost the same as ambient. While the sensors that are under water have increased with a slightly slow response.

The ambient temperature is higher than the water temperature for 4 hours out of 24 hours of measurement. However, the heat transferred by the ambient air in this time interval is so large that it can raise the temperature of 54 kg of water. Ambient air can provide a very large amount of heat over a short span of time because of its infinite mass. As a result of the large enough heat capacity of water, the heat received by the water is not immediately responded to by an increase in temperature. Most of the energy is stored in the very strong polar bonds of the water molecule. The remaining energy that is able to vibrate water molecules is responsible for the increase in temperature. However, because the distance between the molecules is not too tight and the hydrogen bonds are strong in water, the vibrations of one molecule do not easily vibrate other nearby molecules, so the temperature rise is slow. The large amount of heat stored in the water and the slow rate of thermal diffusivity make the water temperature relatively higher than the ambient air for the entire measurement time, including the initial measurement. The small value of thermal diffusivity makes the water still experience an increase in temperature even though the ambient air temperature has dropped drastically.

The decrease in ambient air temperature causes all readable temperatures to decrease as well. Sensors in contact with air respond to temperature changes quickly. Sensors that are in the water also experience a decrease but with a rather long-time lag. The massive effect caused by changes in ambient temperature, either when it rises or falls, makes ambient air act as a controller for all temperatures that are read in the measurement of natural environmental conditions.

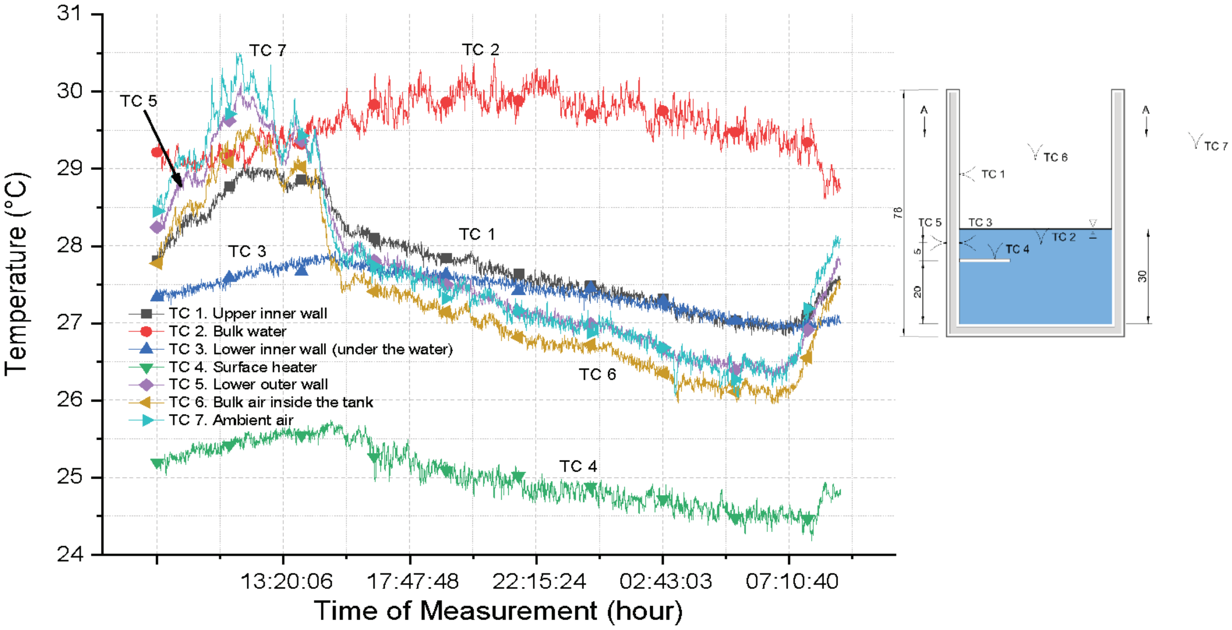

Fig. 3: Zoom view of 24-hour readings for open tank null offset.

3.3 Thermal Null Offset of The Closed Tank

The performance of the seven sensors in reading the null-offset of a closed water tank system for approximately 6 consecutive days is shown in Fig. 4. The six peaks of ambient air temperature are not equal in value because they are affected by weather conditions that are in the rainy season when data collection takes place.

Figure 4 is divided into two parts, namely Fig. 4(a) which shows the readings of the surface temperature measuring sensor and Fig. 4(b) which shows the readings of the fluid temperature measuring sensor. In a closed tank, the surface temperature sensor in the tank has almost the same temperature reading value, even though the working fluid adjacent to the sensor is different. Even the surface temperature of the heater has a relatively small difference with the walls in the tank, different when the tank is left open.

The sensor for measuring the temperature of the fluid in the tank also has a reading that is relatively the same when the tank is closed. Closing the tank causes the evaporation process from the water to the surrounding air to be limited, so that over time there is a process of condensation on the walls in the tank above the water which homogenizes all temperatures in the tank.

Indirectly closing the tank accelerates the heat balance process that occurs in the air in the tank and water as well as in the water and the underwater walls

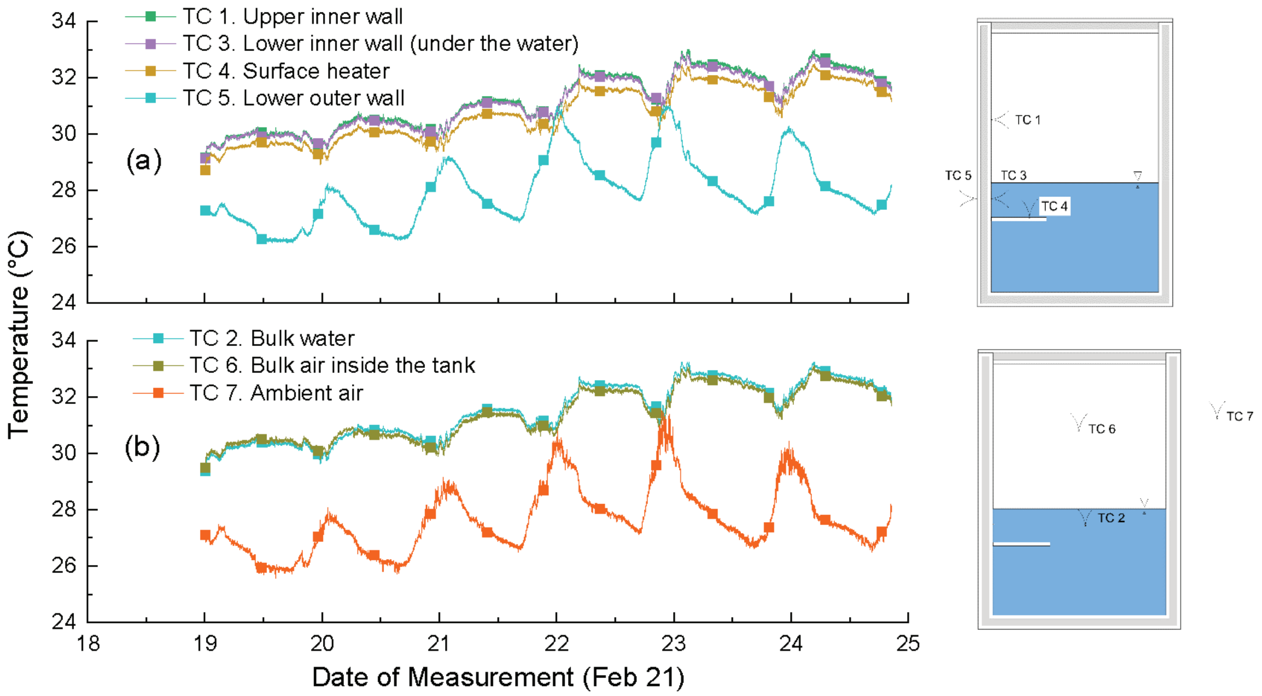

Fig. 4: Typical readings of sensors in closed tank: (a) surface (b) fluids.

3.4 Reading Analysis for 24-hour Measurement of Closed Tank Null Offset

Figure 5 shows the readings of all sensors for 1 x 24 hours of natural data collection starting at midnight. At the beginning of the measurement, the temperature of the fluid and the surface inside the tank is higher than the outside. So that there is a transfer of heat from the inside of the tank to the outside by conduction through the surrounding walls and convection through the gaps in the cover. The higher inner wall temperature transfers heat by conduction through the perimeter of the insulated wall, so the outer wall temperature is slightly higher than the ambient air.

The water temperature is slightly higher than the air temperature because the heat capacity of 54 kg water is quite large compared to the air in the tank. The air in the tank has a higher temperature than the surface of the walls in the tank under water because of its relatively small mass and limited circulation so that heat accumulates at the top of the tank. Inner air provides heat by convection around the upper wall of the water, so that the temperature of the upper wall tends to be higher than the lower wall.

The surface temperature of the heater remains the lowest temperature in the tank because the heat on the surface of the heater is used for the evaporation of water which takes place at any time, even though the tank is closed.

After the sun begins to rise, the ambient air temperature and the outer walls of the tank also increase. However, the temperature of the outer wall of the tank remains higher than the ambient because it is affected by conduction from the inner wall. The increase in temperature values on the sensors outside the tank is not followed by the sensors inside the tank. When the sensor outside the tank increases, the sensor in the tank tends to decrease, and vice versa when the sensor outside the tank decreases. In a closed tank, it is rather difficult to see the effect of ambient air as a heat controller, especially when data collection is carried out during rainy weather conditions, so that the ambient temperature value is much lower than all parts of the tank.

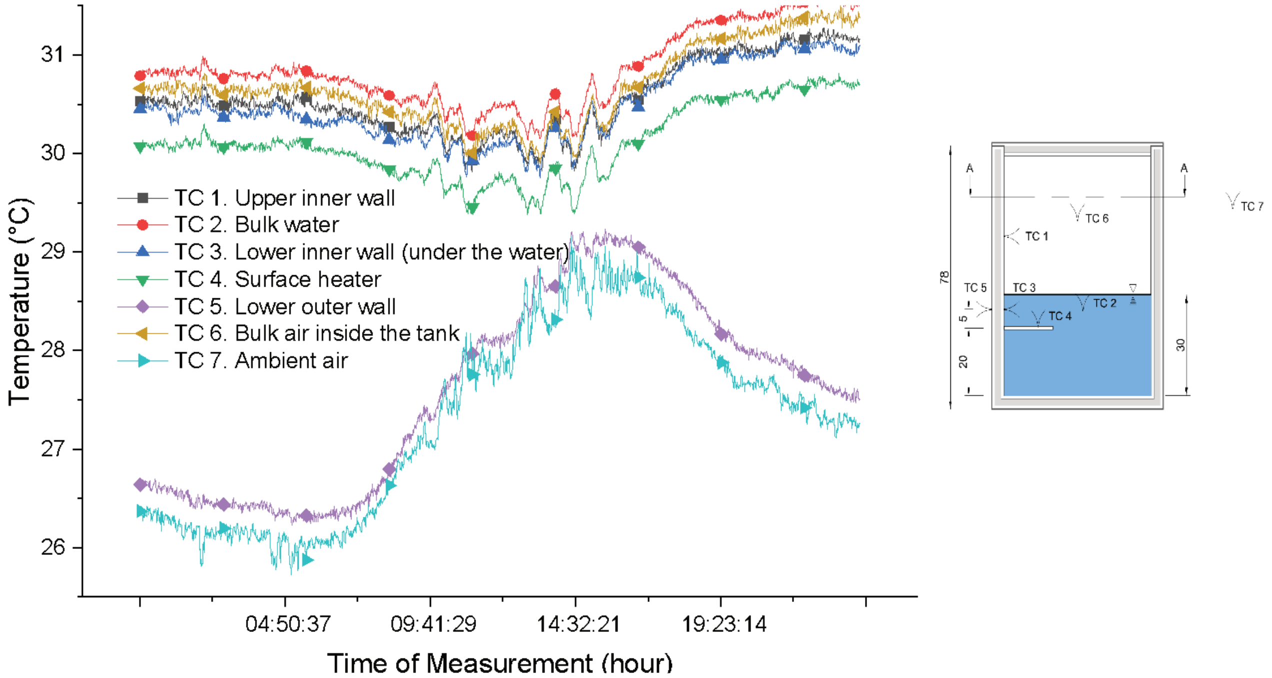

Fig. 5: Zoom view of 24-hour readings for closed tank null offset

4. Conclusion

The difference in the readings of the natural state of the water tank system when it is open and closed indicates the importance of doing a null-offset analysis before modeling the heat transfer process in the system. Null-offset occurs in all systems, whether the test environment is conditioned or not, as a result of natural phenomena experienced by fluids and materials due to their thermophysical properties. These properties are very helpful in analyzing the thermal null-offset in water tanks, because the readings of each sensor are a balance of various energy pools that are affected by fluid and material properties.

Based on the null-offset analysis that has been carried out, it is known that the thermal balance in the open tank is achieved every day with a significant temperature difference for the sensors that are below the water surface due to the evaporation process. The results are different in a closed tank, where the evaporation process is limited and a condensation process occurs which causes all sensor readings in the tank to be relatively close to each other even though they are surrounded by different fluids. The results of the null-offset thermal analysis on the water tank are expected to be a reference for the development of a new model of heat transfer from the hot water tank to the outside air.

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