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EXPERIMENTAL ANALYSIS OF A WALL-MOUNTED THERMOSYPHON RADIATOR

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Abstract. *Energy efficiency is a fundamental factor on ensuring sustainable use of resources and minimizing environmental impacts. In this context, heating systems represent a significant portion of energy consumption in buildings. Wall-mounted radiators are used for indoor heaters due to their ease of installation and maintenance. Therefore, conducting tests on prototypes of wall-mounted radiators is important to evaluate their performance. This study aims to evaluate the thermal and energy performance of a wall-mounted thermosyphon radiator under different operating conditions and its filling ratio (from 30 to 50%). Experimental tests were carried out on a test rig with a controlled environment, containing two wall-mounted radiators, one using the conventional working principals with oil as the working and the other using the principle of the thermosyphons with distilled water. The prototypes were both made of stainless steel with the same geometry, having an internal volume of 4.45L. The system used type K thermocouples, enabling the measurement of internal and surface temperatures for each individual prototype. In addition, for the energy analysis, a power measurement system was implemented. In the context of thermal performance analysis, the wall-mounted thermosyphon radiator with a 40% filling rate stands out prominently. This configuration exhibited the lowest energy consumption required to achieve the operational temperature of 100°C within the 60 minutes data collection interval. The findings indicate the thermosyphon mechanism's distinctive advantages, allowing rapid temperature attainment with reduced energy usage. This energy-efficient characteristic aligns well with the growing demand for sustainable heating solutions, reinforcing the thermosyphon concept's prominence as an efficient choice for wall-mounted radiators.*

Keywords: *thermosyphon, phase change, test rig, heat exchanger, energy efficiency.*

1. INTRODUCTION

The wall-mounted radiators for internal heat are devices that increase its surrounding temperature by transforming electric energy into thermal energy. They use different approaches to generate heat, like electric resistance (using the Joule effect), burning fuel, or heat exchange using a fluid. Through conduction, convection, and radiation, the generated heat is then transferred to the surroundings, attempting to reach and keep a certain temperature (Moran et al., 2018).

These devices are widely used for thermal comfort in homestays, offices, commercial establishments, industries, and other indoor spaces to ensure a comfortable environment during cold weather periods or in regions with low temperatures (Frota and Schiffer, 2016).

Ristinen et al. (2016) state, that thermal efficiency improvement reduces energy consumption, thus reducing operational costs as well. In addition, maximizing the provided energy usage minimizes the environmental impact caused by its production and use. Therefore, studies of thermal efficiency improvement are appealing due to the economic and environmental benefits attached to this field.

An alternative option are the thermosyphons, also known as heat pipes assisted by gravitational forces. Mantelli (2021), describes thermosyphons as passive heat transfer devices that use the latent heat of the working fluid facilitating energy transfer in a two-phase cycle.

Machado et al. (2023), present the device divided into three separate regions as shown in Figure 1.

(i) *Evaporator*: absorbs heat from a heat source and transfers it to the working fluid;

(ii) *Condenser*: dissipates heat from the fluid to a cold source;

(iii) *Adiabatic Section*: connects the other sections, not having any heat transfer; this region can be excluded from certain applications.

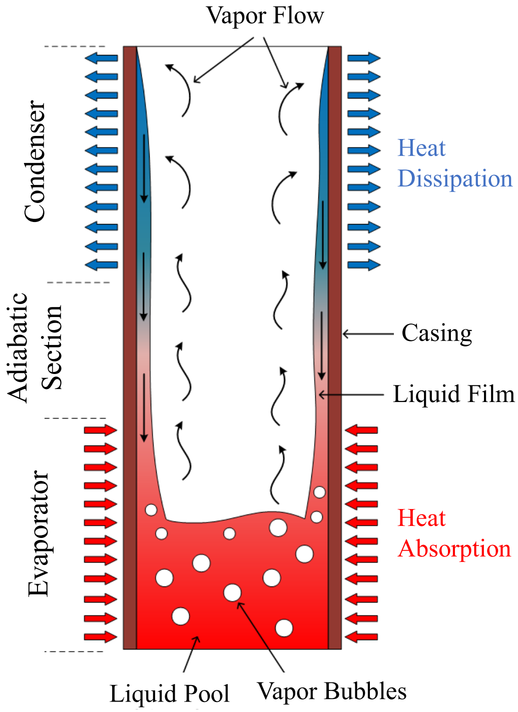

Figure 1. Thermosyphon's work principle (Biglia et al., 2022)

The main components of these devices are the casing and the working fluid. The casing serves to isolate the working fluid from external forces. On the other hand, the working fluid is responsible to assist on the heat transfer, therefore is necessary to known the thermodynamics properties of the fluid, such as, the operational temperature range, vapor pressure, toxicity, thermal conductivity, and wettability between working fluid and casting (Zohuri, 2016).

In this context, the present study has the goal of evaluating the thermal and energy performance of a wall-mounted thermosyphon radiator under different operating conditions and filling ratio, from 30 to 50% of the total prototype volume.

2. EXPERIMENTAL APPARATUS

The experimental trials were carried out on a test rig with a controlled environment, containing two wall-mounted radiators, as shown on Figures 2 and 3. One uses the conventional working principles and the other uses the principle of the thermosyphons. The prototypes were both made of stainless steel with the same geometry. The conventional wall-mounted radiator used oil as the working fluid while the wall-mounted thermosyphon radiator used distilled water.

The geometric characteristics of the system have a design comprising two vertical tubes, each with a diameter of 0.0315m and a length of 1.45m, interconnected by 28 central tubes. Each of these central tubes has a diameter of 0.019m and a length of 0.41m. The combination of these elements yields a total internal volume of 4.45L and an equivalent length of 14.38m. In wall-mounted thermosyphon radiator prototype different fill ratios were tested, namely 0.30, 0.40, and 0.50, resulting in the addition of three distinct volumes, represented as 1.335L, 1.780L, and 2.225L, respectively.

The experimental apparatus used on the investigation of this study was done in such a way that it was used a Keysight® DAQ970A data acquisition system with a 20 channels multiplexer, an EOS Value® 10 CFM vacuum pump, a Dell® computer, and a NHS® uninterruptible power supply. The prototypes were heated applying electric resistance with a power dissipation of 1200W, using Joule effect, being controlled by a Temperature Controller Novus® N1040T, configured in a PID control. The system to evaluate the surface temperature used type K thermocouples of Omega Engineering®, on both prototypes. Figure 3 illustrates the strategic locations where the thermocouples were attached for further analysis.

It is noteworthy that the evaporator, with a length of 6.37m, is positioned in the lower-region, where heat is supplied to the device. The adiabatic section is nonexistent in this application, as thermal exchange takes place with the environment across the entire prototype (Da Cunha, 2008). Finally, the condenser, measuring 8.01m in length, is located in the middle and upper regions, where heat is dissipated.

Figure 2. Test rig

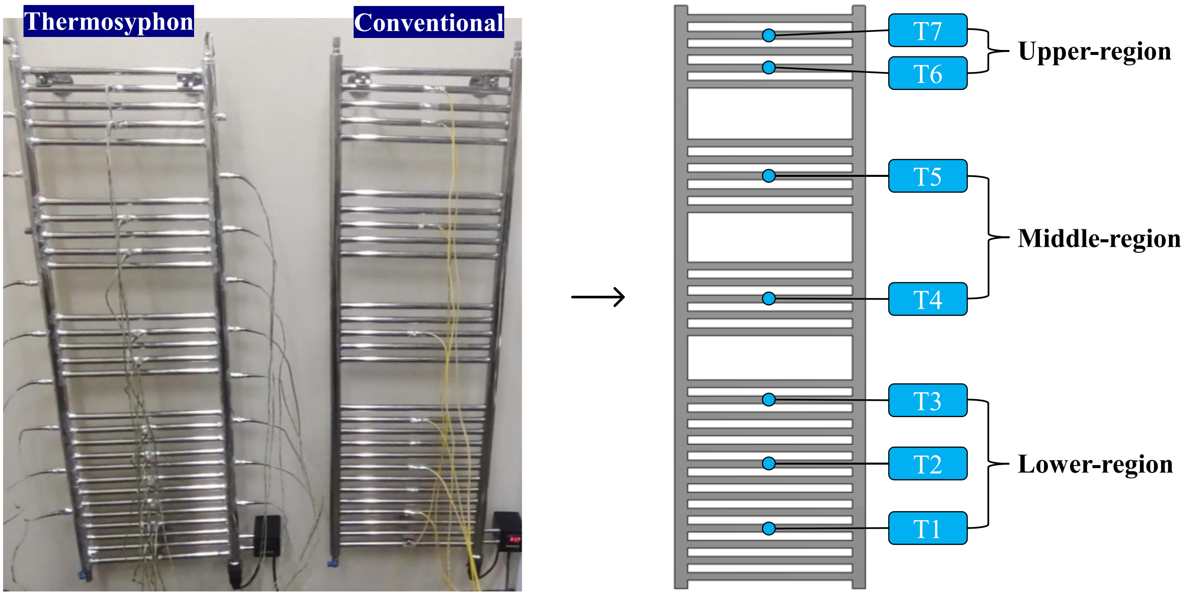

Figure 3. Temperature measurement points

For the power analysis, an Arduino® UNO system was implemented to measure the values of current, voltage, and power consumed by each apparatus, as well as the measurement of environmental parameters, such as environmental temperature and relative humidity of the air, this is shown on Figure 4.

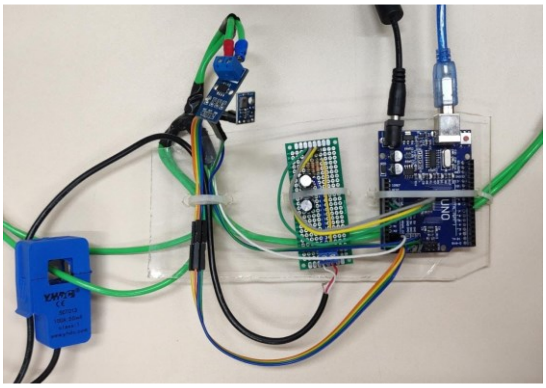

Figure 4. Power measurement system

2.1 Experimental methodology

The procedure adopted in the present work is divided on the following steps (where Steps #5 and #6 apply only to the wall-mounted thermosyphon radiator):

#1 - Isolate the test site (laboratory);
#2 - Prepare and check the measurement systems;
#3 - Make sure the environmental parameters are at the steady-state regime;
#4 - Turn on the controller and data acquisition systems;
#5 - Turn on the vacuum pump;
#6 - Fill the prototype with the working fluid (distilled water);
#7 - Turn on the electric resistance, setting the temperature control thermostat to 100ºC;
#8 - Acquire data in an interval of 10 seconds during a total of 60 minutes;
#9 - Save the data for further analysis.

The vacuum procedure was meticulously conducted through a carefully controlled process, using a vacuum pump. This procedure ensured the elimination of any undesired air or gases, thereby establishing a controlled and stable vacuum within the prototype. Subsequently, the prototype was filled with the working fluid. This was achieved using a graduated burette, which allowed for a controlled injection process, in which the fluid was introduced into the prototype, displacing the previous vacuum. Throughout the filling process, precautions were taken to prevent the formation of air bubbles or other types of impurities. Finally, the prototype underwent a purging process to remove any residual air.

Settings the thermostat at 100°C was based on the necessity to comprehend the system's response under controlled thermal conditions, aiming to provide a test environment representative of situations where elevated temperatures are pertinent. This setup seeks to capture heating patterns, stabilization, and potential fluctuations occurring within a controlled environment, offering a comprehensive insight into the thermal characteristics of the system during an extended analysis.

The experimental uncertainties related to the measurement instruments used are presented in Table 1.

Table 1. Experimental uncertainties

Parameter	Measuring Instrument	Uncertainty	Unit
Current	STC013 current sensor	± 0.10	A
Power	Power measurement system	± 16.97	W
Temperature	Type K thermocouple	± 0.50	ºC
Voltage	ZMPT101B voltage sensor	± 2.50	V

3. RESULTS

Figures 5, 6, and 7, show the temperature distribution versus time in each wall-mounted thermosyphon radiator prototype, for each one of the filling ratios, 30, 40, and 50%, respectively.

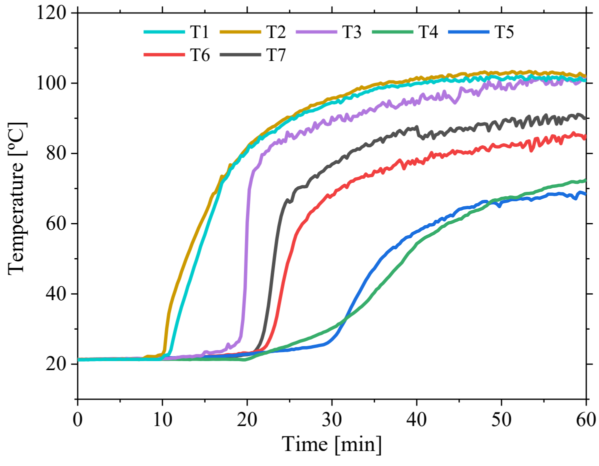

Figure 5. Temperature distribution versus time at experimental test - filling ratio of 30%

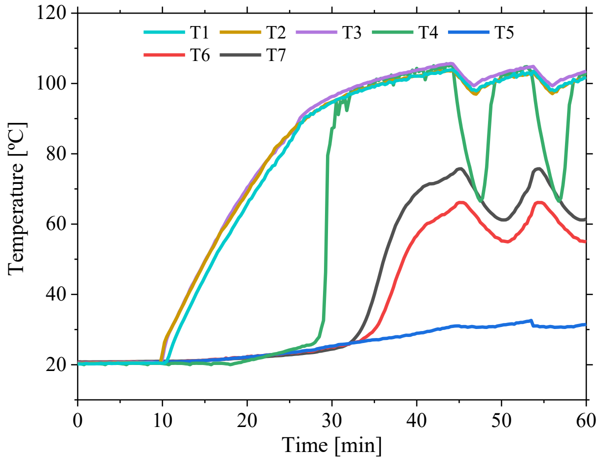

Figure 6. Temperature distribution versus time at experimental test - filling ratio of 40%

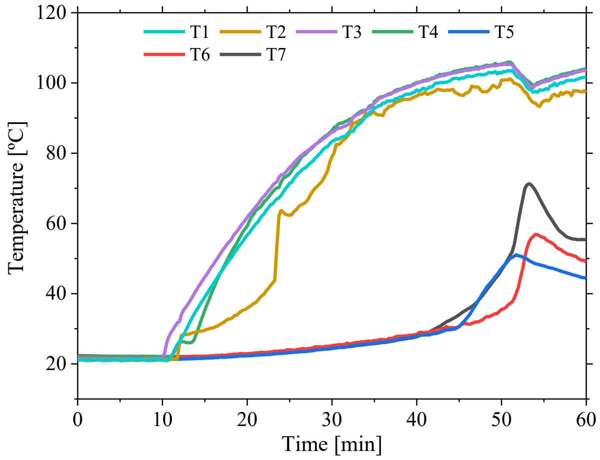

Figure 7. Temperature distribution versus time at experimental test - filling ratio of 50%

The higher temperatures are located on the evaporator section where the heat dissipation happens, while the lowest temperatures are located on the condenser section where the fluid is cooled by natural convection. These observed results are consonant with the working principles of a thermosyphon (Krambeck, 2018).

Figures 8, 9, and 10, show the power dissipation (obtained from power system measurements) versus time in each wall-mounted thermosyphon radiator prototype, for each one of the filling ratios, 30, 40, and 50%, respectively. Where $T_{av\text{-}1}$, $T_{av\text{-}2}$, and $T_{av\text{-}3}$ are the average temperatures of the lower, middle, and upper regions.

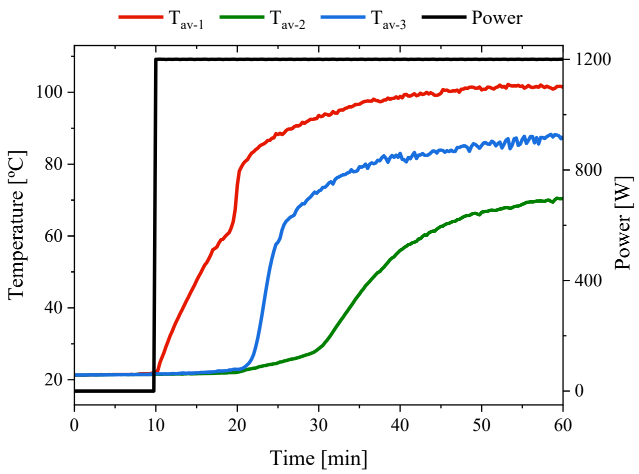

Figure 8. Power dissipation versus time at experimental test - filling ratio of 30%

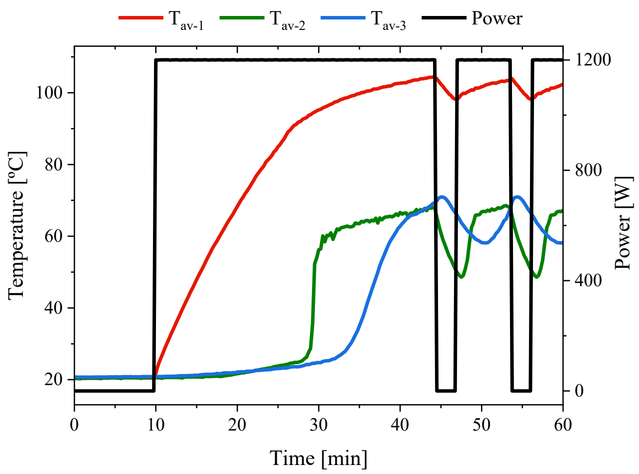

Figure 9. Power dissipation versus time at experimental test - filling ratio of 40%

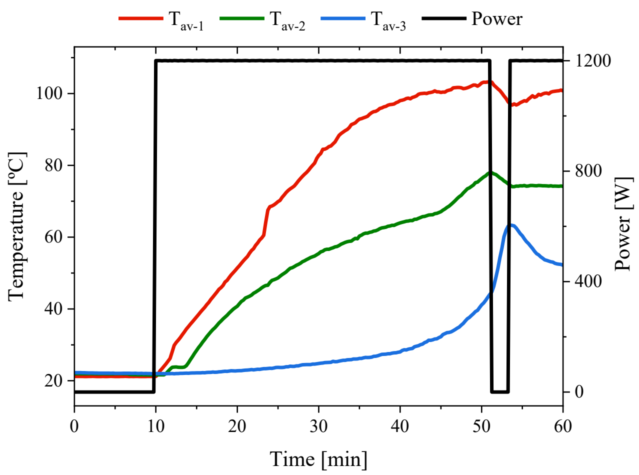

Figure 10. Power dissipation versus time at experimental test - filling ratio of 50%

It is observed that power dissipation is directly related to the increase in device temperature (Çengel and Ghajar, 2020). In each cycle, the device gradually heats up as power dissipation increases, reaching a peak, and then cools down as the dissipated power is suspended, as seen in Figures 9 and 10.

Figures 11 and 12, show the temperature and power distribution versus time in each wall-mounted radiator prototype (oil), respectively.

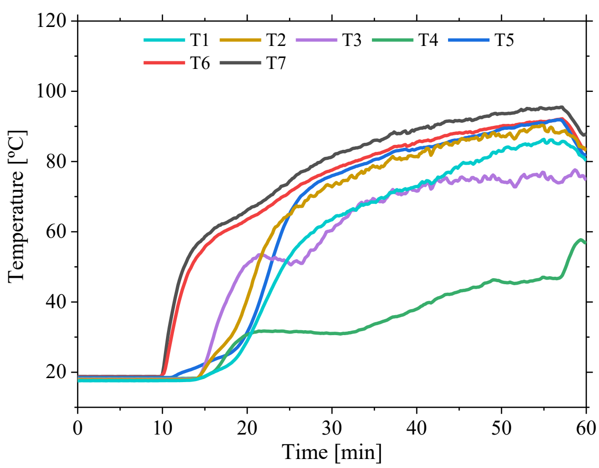

Figure 11. Temperature distribution versus time at experimental test - oil

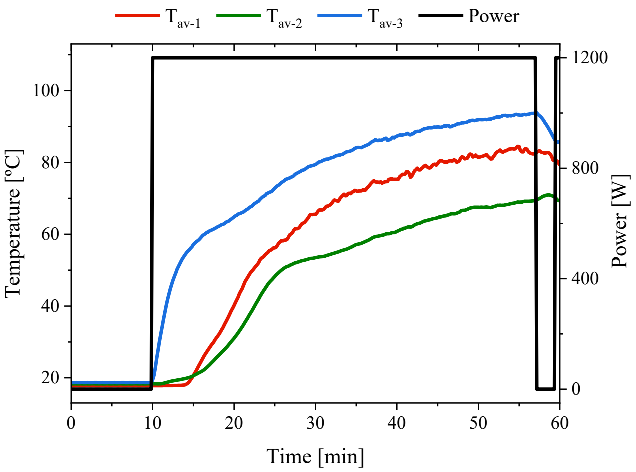

Figure 12. Power dissipation versus time at experimental test - oil

The temperature distribution comparison shows the different behavior between the two prototypes, this is a result of the different characteristics of the internal fluid circulation phenomenon, described by Lahoubi et al. (2008). The higher temperatures are located on the upper-region of the conventional wall-mounted radiator, while the opposite happens for the wall-mounted thermosyphon radiator, where the higher temperatures are located on the lower-region (evaporator).

The investigation of heat dissipation in the systems reveals interesting aspects, especially in the middle and upper regions. The condensation process, characteristic of the thermosyphon, plays a pivotal role in dissipating heat more effectively in these regions. This phenomenon is linked in the phase change from vapor to liquid, which releases latent heat, further helping to moderate the temperature. The conventional heater, which lacks such a phase change mechanism, exhibits comparatively lower rates of heat dissipation in these regions (Machado et al., 2023).

A key parameter that can be evaluated is the necessary time for the electric resistance to break in accordance with the temperature control thermostat; these can be observed on Table 2 and Figure 13.

Table 2. Necessary time for the electric resistance to break

Wall-mounted radiator prototype	Time [min]
Conventional - oil	57
Thermosyphon - filling ratio of 30%	> 60
Thermosyphon - filling ratio of 40%	44
Thermosyphon - filling ratio of 50%	51

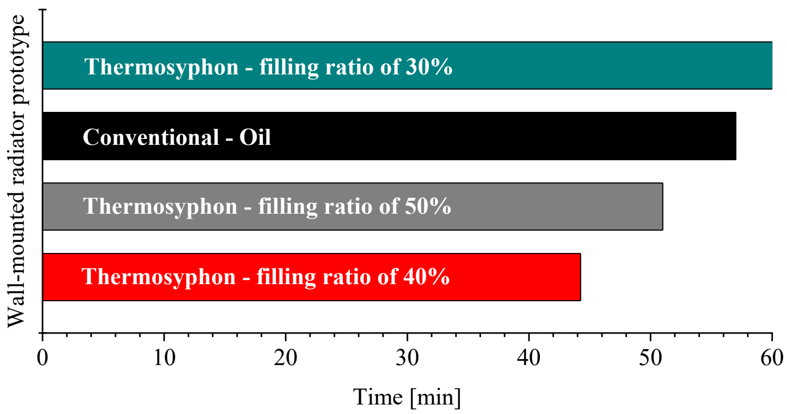

Figure 13. Time for the electric resistance to break

Notably, the trends presented in Figure 13 elucidate the direct correlation between energy consumption and the time required to achieve the target temperature. The importance of this assessment lies in its capacity to provide clarifications regarding the system's responsiveness to the set operational temperature.

Considering the 60 minutes data collection interval, the experiment demonstrating the lowest energy consumption to attain the operational temperature (100°C) is the wall-mounted thermosyphon radiator with a 40% filling ratio. This observation highlights the distinct advantages offered by the thermosyphon mechanism, whose characteristics are aligned with the current demand for sustainable heating solutions, further emphasizing the prominence of the thermosyphon concept as a viable choice for wall-mounted radiators.

4. CONCLUSION

In conclusion, this study provides relevant information about the performance and efficiency of the specific wall-mounted thermosyphon radiator. Through a detailed analysis of the collected data, we examined temperature distribution for each filling ratio, comparing both prototypes to explore thermal performance and heat transfer characteristics of wall-mounted radiators. Significantly, the results indicate that implementing the thermosyphon concept in these radiators, particularly with a 40% filling ratio, holds promise as a sustainable strategy to enhance thermal efficiency. Moreover, the wall-mounted thermosyphon radiator, according to the analysis parameters and experimental characteristics, exhibits remarkable advantages over the conventional prototype. Across all investigated filling ratios, the attainment and even surpassing of the configured operational temperature were observed, a scenario that did not occur in the conventional prototype.

5. ACKNOWLEDGEMENTS

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