Preliminary Experimental Analysis of R32 Refrigerant Thermal Response in a Residential Air Conditioner

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Abstract. Air conditioning systems are widely used in residential buildings, increasing the need for accurate and representative performance evaluation methods. However, conventional testing approaches are often limited in capturing the dynamic thermal behavior of residential air conditioning systems under varying indoor conditions. This study presents the development of a 2 × 2 × 2.5 m experimental chamber for controlled performance evaluation of a residential air conditioning system with a 0.5 PK compressor. The chamber enables real-time monitoring of indoor air temperature, supply air temperature, and refrigerant thermal characteristics. Experiments were conducted at room temperature setpoints of 20°C, 25°C, and variable conditions of 26°C–24°C–22°C–26°C. The results show that the system successfully achieved all setpoints, although lower temperatures required longer stabilization times due to higher cooling loads. Significant transient behavior was observed during startup, including rapid supply air cooling and increased compressor outlet temperature. In addition, the coefficient of performance (COP) increased during stable operating conditions, indicating improved cooling efficiency. The developed chamber provides a reliable platform for controlled residential air conditioning performance evaluation and future HVAC thermal monitoring studies.

1 Introduction

Air conditioning systems are widely used to provide thermal comfort in residential and commercial buildings, particularly in tropical regions where cooling demand remains high throughout the year. The increasing global use of residential air conditioners has led to significant growth in electricity consumption, making energy efficiency and operational performance important concerns in HVAC research [1–11, 14, 15]. Consequently, accurate performance evaluation methods are required to ensure reliable system operation, improve cooling efficiency, and support the development of more energy-efficient air conditioning technologies.

Performance evaluation of air conditioning systems is commonly conducted under controlled laboratory conditions using standardized testing procedures. However, conventional psychrometric and steady-state testing methods are often limited in representing the dynamic operating characteristics and real-world performance of modern residential air conditioners [1, 5–7, 12]. Variations in room thermal load, indoor temperature, compressor operating conditions, ambient environmental conditions, psychrometric air properties, and outdoor weather conditions can significantly influence system behavior and cooling performance during operation [3, 4, 10, 12, 13]. Recent studies have demonstrated that load-based testing methods are capable of providing more representative operational performance evaluation compared to conventional steady-state testing approaches [1, 5–7, 12, 13]. These approaches enable testing systems to emulate dynamic thermal loads, building interactions, and integrated equipment control behavior under realistic operating conditions [6, 7, 12, 13]. In addition, accurate thermodynamic and refrigerant parameter measurements under dynamic operating conditions remain challenging for modern residential air conditioning systems [9]. As a result, there is a growing need for experimental facilities capable of reproducing controlled environmental conditions and monitoring system performance under varying operating scenarios.

Experimental chambers play an important role in HVAC research because they provide a controlled environment for analyzing air conditioning system behavior. Through controlled room conditions, parameters such as temperature, humidity, refrigerant thermal response, and cooling performance can be observed systematically [8, 9, 12, 13]. In addition, experimental chambers enable investigation of transient operating conditions, including start-up behavior, temperature stabilization, and compressor response during cooling processes. Such facilities are also useful for supporting studies related to system optimization, energy efficiency improvement, refrigerant performance analysis, and control strategy development [2–10, 12, 13].

Several experimental facilities for air conditioning performance testing have been developed in previous

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studies. Recent studies have introduced emulator-type and load-based testing approaches capable of reproducing dynamic thermal interactions and environmental conditions more realistically [1, 5–7, 12, 13]. Other experimental investigations have evaluated the influence of ambient conditions, psychrometric properties, weather variations, thermal enhancement techniques, and condenser cooling methods on air conditioning system performance, particularly on cooling efficiency, condenser heat transfer, cooling capacity, and energy-saving control strategies [2–4, 8, 10]. Nevertheless, most existing experimental facilities primarily focus on system-level performance evaluation and load emulation, while detailed real-time monitoring of refrigerant thermal characteristics remains limited. In particular, experimental platforms for residential-scale air conditioning systems capable of monitoring refrigerant thermal response under varying indoor thermal conditions are still rarely reported. Therefore, the development of a flexible experimental chamber with integrated thermodynamic monitoring is necessary for more comprehensive evaluation of air conditioning system behavior.

In this study, an experimental chamber with dimensions of 2 × 2 × 2.5 m was developed to evaluate the operational performance of a residential air conditioning system. The developed chamber is equipped with multiple temperature measurement points to monitor refrigerant thermal characteristics during operation. The experimental setup enables real-time acquisition of thermodynamic parameters under different room temperature conditions, allowing further analysis of cooling system behavior and thermal response during operation.

This study contributes to the development of a residential-scale experimental chamber for air conditioning performance evaluation under controlled indoor thermal conditions. The developed system enables real-time monitoring of refrigerant thermal characteristics at multiple measurement points. The proposed setup provides a flexible platform for investigating thermal response behavior and operational performance of residential air conditioning systems under varying room temperature conditions. Furthermore, the developed experimental platform may support future studies related to HVAC monitoring systems, thermal control strategies, and intelligent performance evaluation methods for residential cooling applications.

The development of this experimental chamber is expected to provide a flexible platform for residential HVAC performance testing and future thermal system studies. In addition to supporting experimental analysis of refrigerant thermal response, the facility may also contribute to the development of more energy-efficient air conditioning systems and serve as an educational platform for studying HVAC system behavior through controlled experimental conditions.

2 Method

2.1 Experimental setup

The experiments were conducted inside a test chamber constructed using a light steel-framed sandwich wall system with double-sided Glass Fiber Reinforced Cement (GRC) panels. The test chamber was designed as an enclosed space with internal dimensions of 2 m × 2 m × 2.5 m. The lightsteel frame provided structural integrity, while the GRC panels installed on both sides of the frame formed an enclosure, creating a stable boundary for the experimental environment. A split-type inverter air conditioner with a 1/2 PK compressor was also installed inside the test chamber, as shown in Figure 1 and Figure 2. The air conditioner consists of standard vapor compression components, including a compressor, condenser, expansion valve, and evaporator. Figure 1 and Figure 2 present the 3D design model of the experimental chamber from the front and rear perspectives, respectively. Meanwhile, Figure 3 shows the actual fabricated experimental chamber used during the testing process.

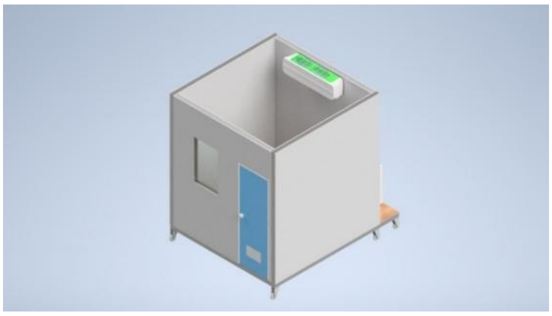

Fig. 1. Front view of test chamber 3d model

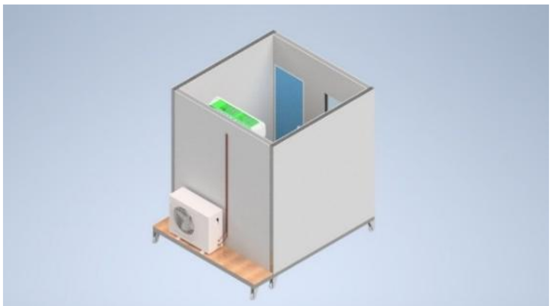

Fig. 2. Rear view of test chamber 3d model

Fig. 3. Experimental Chamber

2.2 Instrumentation and Data Acquisition

Temperature measurements were performed using K-type thermocouples installed at several locations on the refrigerant piping, including, supply air, compressor inlet, and compressor outlet as shown in Figure 4. It should be noted that the temperature sensors were mounted using cable ties without the use of thermal paste. Therefore, thermal contact between the sensor and the measured surface may not be optimal, which may lead to slight measurement inaccuracies.

An ESP32 microcontroller-based data acquisition system was used to record temperature data at fixed 1-second intervals. Additional parameters such as indoor and outdoor temperatures were also recorded during the experiment. Meanwhile, Figure 5 shows the actual data logger developed for this study. The system was built using an ESP32 microcontroller integrated with MAX31855 thermocouple interface modules for temperature data acquisition from multiple K-type thermocouples.

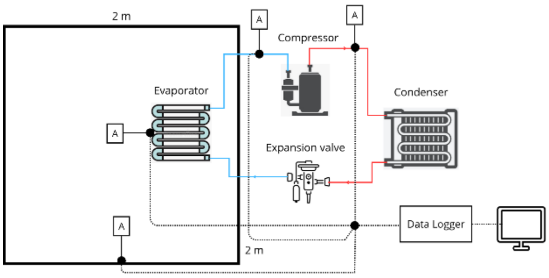

Fig. 4. Test chamber refrigeration system schematic

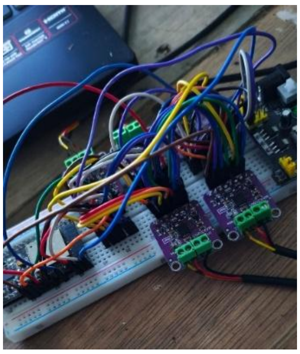

Fig. 5. Data logger

2.3 Experimental Procedure

The experiment was conducted under three different operating conditions :

- Constant setpoint of 20°C
- Constant setpoint of 25°C
- Variable setpoint (26°C–24°C–22°C–24°C–26°C)

For each condition, the system was operated until steady-state conditions were reached. Steady-state conditions were defined as the stabilization of the room temperature within a narrow range around a setpoint. Due to the dynamic operation of the system, fluctuations were observed during the 10-minute steady-state period. Temperature data from the room and refrigerant lines were continuously recorded to observe the system's thermal response.

2.4 Data Analysis

The recorded data was analyzed to evaluate the relationship between room temperature variations and refrigerant temperature behavior. The analysis included visualization of temperature trends and performance evaluation based on system response characteristics. The results were presented as a temperature-time graph to illustrate the dynamic behavior of the air conditioning system.

In addition, the system performance was evaluated by calculating the coefficient of performance (COP) based on several simplifying assumptions. COP was calculated as the ratio between the estimated cooling capacity and the corresponding power input as shown in Equation 1 .

$$COP = Q/W_{in} \tag{1}$$

As shown in Equation 2, cooling capacity was estimated using the air-side method, where the air mass flow rate ($\dot{m}$) was derived from the manufacturer's specified airflow rate of the air conditioning unit (338, 328, 266, 208, and 191 CFM). In this study, the lowest airflow rate (191 CFM) was selected, as the air conditioner was operated at the lowest fan speed setting. The calculation of cooling capacity was based on the temperature difference between the indoor air (T_{indoor}) and the supply air (T_{supply}), representing the heat removed from the conditioned space. The specific heat capacity of air (c_p) was assumed to be constant, considering that its variation is relatively small within the temperature range of 20–30°C. Furthermore, the power input of the system was approximated using the rated power range provided in the AC specifications (310 W, with a range of 180 to 580 W). In this study, the input power was not assumed constant but was varied within this range to better represent the actual operating behavior of the air conditioning system. During periods of higher cooling demand, such as when the setpoint was lowered, the power input was assumed to increase toward the upper limit of the range. Conversely, when the cooling load decreased, such as when the setpoint was raised, the power input was assumed to decrease toward the lower limit.

$$Q = \dot{m} \cdot c_p \cdot (T_{indoor} - T_{supply}) \quad (2)$$

The calculated COP values were then plotted as a function of time to illustrate the variation of system efficiency during the cooling process. This analysis complements the temperature-time graphs by providing additional insight into the relationship between thermal behavior and energy performance of the air conditioning system.

3 Results and Discussion

3.1 Room Cooling Performance

The experimental results show that the air conditioning system successfully reduced the room temperature from an initial condition of approximately 27-29°C to the desired setpoints.

3.2 Refrigerant Temperature Dynamics

3.2.1 Setpoint of 20℃

Figure 6 shows that the outdoor temperature varied between 28 and 31°C. The indoor temperature gradually decreased until it reached the set point of 20°C, after which it stabilized. The system took approximately 57 minutes to reach the set point. At the beginning of operation, the supply air temperature decreased significantly, indicating that the evaporator had begun removing heat from the indoor air. Conversely, the compressor inlet temperature also decreased early in the experiment. This behavior may be due to the system's transition from shutdown to operation or to an initially suboptimal heat absorption process. The compressor inlet temperature tended to follow the decrease in indoor temperature due to heat absorption from the room, indicating that the evaporator was functioning effectively. At the beginning of the experiment, the compressor outlet temperature rose sharply, reaching approximately 49°C before gradually decreasing. This phenomenon was caused by the high cooling load at the beginning of the test, which required the compressor to operate at higher capacity to reduce the indoor temperature. The graph shows that the system performed well in achieving the set point temperature. However, it took a relatively long time to reach the set point.

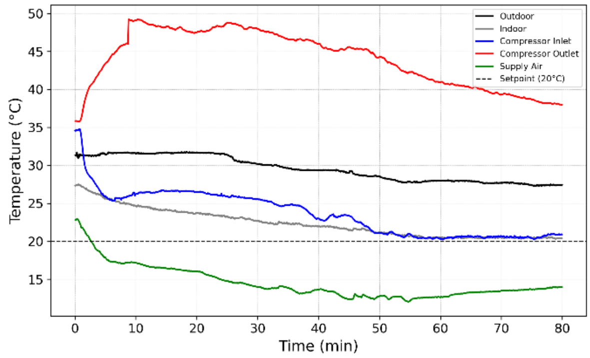

Fig. 6. Temperature profiles of test chamber under 20℃ setpoint

3.2.2 Setpoint of 25℃

Based on Figure 7, the outdoor temperature remained relatively constant in the range of 31–32°C. The indoor temperature gradually decreased until it stabilized at the setpoint temperature. The system took approximately 23 minutes to reach the setpoint, which was faster than the 20°C setpoint due to the lower cooling load. The supply air temperature decreased at the start of operation due to the high initial cooling load. After some time, the temperature gradually increased as the cooling load decreased. Meanwhile, the compressor inlet temperature decreased from its initial value and remained relatively constant after the indoor temperature reached the setpoint. The compressor outlet temperature increased sharply at the start of the test before decreasing and stabilizing at approximately 38°C. This indicates that the compressor was operating in accordance with the cooling load, which was highest at the beginning of the experiment.

Based on these observations, it can be concluded that the system was operating effectively and reached the setpoint temperature more quickly than at lower setpoints. The observed temperature remained relatively constant after the indoor temperature reached the setpoint, indicating that the compressor was responding appropriately to the cooling load.

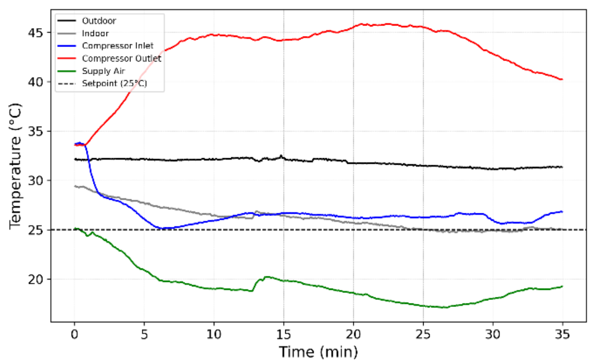

Fig. 7. Temperature profiles of test chamber under 25℃ setpoint

3.2.3 Variable setpoints

The experiment was conducted with temperatures set at 26°C, 24°C, and 22°C. At the start of operation as show in Figure 8, the setpoint was set at 26°C. Once the temperature was reached, the setpoint was adjusted to 24°C, then 22°C. After reaching the lowest setpoint, the temperature was gradually raised back to 26°C. The graph shows a variable trend in the outdoor temperature. During the first three hours of operation, the outdoor temperature increased, followed by a decrease over the next four hours. This variation corresponds to ambient conditions, as the system operated from morning to afternoon. The indoor temperature successfully reached each setpoint and remained relatively stable. The supply air temperature decreased at the start of operation due to the high initial cooling load, and then gradually decreased as cooling demand decreased. Conversely, the compressor inlet temperature tended to follow the indoor air temperature. The compressor outlet temperature exhibited several spikes, which occurred during setpoint changes as the compressor adjusted to the increased cooling demand.

Based on these results, it can be concluded that the system is operating effectively, as the room temperature is able to reach each setpoint. The observed temperature remains relatively constant after reaching the setpoint, indicating that the compressor is operating according to the cooling load.

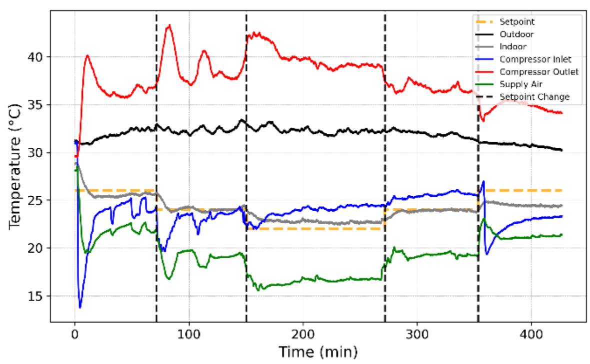

Fig. 8. Temperature profiles of test chamber under varying setpoint

3.3 Thermal Behaviour and System Performance Analysis

3.3.1 Setpoint of 20℃

Figure 9 shows the variation of the coefficient of performance (COP) over time under a setpoint of 20°C, in relation to the temperature profiles at different locations of the air conditioning system. At the beginning of operation, the COP started at a relatively low value of approximately 0.8 and gradually increased as the system operated. This initial low COP corresponds to the high cooling load observed in the temperature graph, where the indoor temperature was still far above the setpoint and the compressor outlet temperature rapidly increased to around 49°C. During the early stage of operation, supply air temperature decreased significantly, indicating an intensive heat absorption process. However, the compressor was operating at high capacity, resulting in high power consumption and consequently a lower COP. As the indoor temperature gradually decreased toward the setpoint, the compressor inlet temperature also followed this trend, showing effective heat removal from the indoor air. As the system approached steady-state conditions, the compressor outlet temperature began to decrease and stabilize, indicating a reduction in compressor workload. This behavior is reflected in the COP curve, which shows a continuous increase over time. After approximately 57 minutes, when the indoor temperature reached and stabilized around the setpoint of 20°C, the COP reached higher values in the range of 3.0–3.6. Minor fluctuations in the COP curve were still observed, which are consistent with the dynamic operation of the inverter compressor in maintaining the setpoint temperature.

Overall, the graphs indicate that the system operated less efficiently during the initial transient phase due to high cooling demand, but became more efficient as it approached steady-state conditions. This confirms that the system performance is strongly influenced by the thermal load and operational characteristics of the compressor.

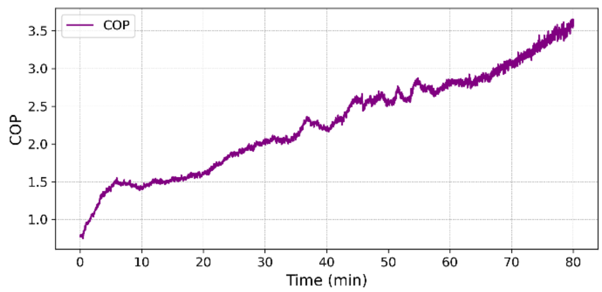

Fig. 9. COP of AC under 20℃ setpoint

3.3.2 Setpoint of 25℃

Based on Figure 10, at the beginning of operation, the COP started at a relatively low value of around 0.7–0.8 and gradually increased over time. This behavior corresponds to the initial operating condition where the compressor outlet temperature rose sharply to approximately 45–46°C, indicating that the compressor was working at high capacity to handle the high initial cooling load. Simultaneously, the supply air temperature decreased significantly, showing that the evaporator was actively absorbing heat from the indoor air. As the indoor temperature approached the setpoint, the compressor inlet temperature decreased from its initial value and then remained relatively stable. In contrast, the compressor outlet temperature began to decrease gradually, reflecting a reduction in compressor workload. This transition is clearly reflected in the COP curve, where the COP increased steadily as the system moved toward steady-state conditions. After the indoor temperature reached the setpoint, the COP continued to rise and fluctuated slightly in the range of approximately 2.5–3.3. These fluctuations are attributed to the dynamic operation of the inverter compressor in maintaining the setpoint temperature. The increase in COP indicates that the reduction in power consumption was more significant than the decrease in cooling capacity, resulting in improved system efficiency.

Based on these observations, it can be concluded that the system operated effectively and achieved the setpoint temperature more quickly compared to lower setpoints. The relatively stable temperature profiles after reaching the setpoint indicate that the compressor responded appropriately to the cooling load, while the increasing COP demonstrates improved efficiency as the system approached steady-state conditions.

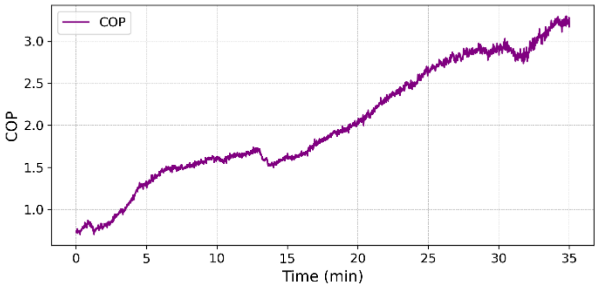

Fig. 10. COP of AC under 25°C setpoint

3.3.3 Variable setpoints

Based on the COP profile shown in Figure 11, the system exhibited a transient behavior at the beginning of operation. The COP rapidly increased to its peak value during the initial minutes, which corresponds to the high temperature difference between indoor air and supply air temperature. At this stage, the cooling load was at its maximum, resulting in a high heat transfer rate relative to the compressor power input. As the system approached steady-state operation at the first setpoint (26°C), the COP gradually decreased and fluctuated within a moderate range. This behavior is consistent with the temperature graph, where the indoor temperature stabilized and the temperature difference across the evaporator decreased, reducing the cooling capacity. When the setpoint was lowered to 24°C and subsequently to 22°C, noticeable changes in the COP trend were observed. During each setpoint transition, the COP temporarily increased or fluctuated due to a sudden rise in cooling demand. This is supported by the temperature data, where the supply air temperature dropped significantly and the compressor outlet temperature showed spikes, indicating increased compressor activity. However, after reaching each new setpoint, the COP tended to decrease again. This reduction can be attributed to the lower temperature difference between the indoor air and the supply air, as well as the increased compressor workload required to maintain lower temperatures. Additionally, fluctuations in COP during steady operation are influenced by variations in outdoor temperature, which affect the condenser performance. Toward the later stage of the experiment, when the setpoint was increased again, the COP showed a declining trend with smaller fluctuations. This is consistent with the reduced cooling load and smaller temperature gradients observed in the temperature graph. The system required less cooling capacity, but the compressor continued to operate, resulting in a lower COP.

Based on these results, it can be concluded that the COP is strongly influenced by the cooling load and temperature differences within the system. Higher COP values occur during periods of high cooling demand, particularly at startup and during setpoint transitions. Conversely, lower COP values are observed during steady-state conditions and at lower cooling loads. Overall, the system demonstrates expected thermodynamic behavior, where performance varies dynamically in response to operating conditions and setpoint changes.

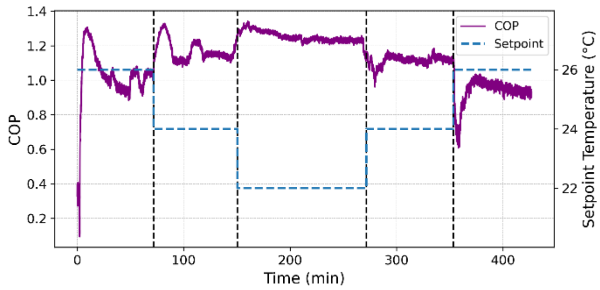

Fig. 11. COP of AC under varying setpoint

4 Conclusion

This study investigated the performance of a residential air conditioning system using a controlled experimental chamber under various room temperature setpoints. The results confirmed that the developed chamber was capable of achieving stable operating conditions and effectively evaluating system performance under different cooling loads. The analysis showed that lower temperature setpoints required longer stabilization times due to higher cooling demands. Significant transient behavior was observed during startup, characterized by rapid supply air cooling and increased compressor outlet temperature. As the system approached steady-state conditions, the temperature profiles became more stable and the coefficient of performance (COP) gradually increased, indicating improved operating efficiency. COP fluctuations were also observed during dynamic setpoint transitions due to inverter compressor operation. Overall, the results demonstrate that room temperature variations significantly influence refrigerant thermal behavior and system performance. The developed experimental chamber provides a reliable platform for residential HVAC performance evaluation and may support future studies related to thermal monitoring, control strategies, and energy efficiency improvement.

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