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Performance of a drying machine utilizing an air dehumidification process for marungga leaves and identification of marungga flour

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Abstract: Marungga leaves have the potential to be a source of antioxidants, minerals, and carbohydrates. These leaves can be processed into flour for further processing into various products. Marungga leaves must be dried before they can be processed into flour. They are heat-sensitive, so some of their nutritional content will be degraded if dried at high temperatures. A dehumidification system dryer was designed and built to produce low temperature and humidity to overcome the problem of high-temperature drying. The purpose of this study was to evaluate the performance of the dehumidification dryer and to assess the quality of dried Marungga flour. Drying was carried out under normal working conditions for 8 hours, with air temperature and humidity monitored at 20-minute intervals. The dried Marungga leaves were milled into flour and analyzed for physicochemical properties. The test results yielded the following data: air flow rate 0.109 kg/s, drying temperature 33.5°C, relative humidity 54.7%, drying rate 0.732 kg H2O/hour, specific humidity drop 0.01703 kg H2O/kgda, Carnot COP 6.8, actual COP 4.2, efficiency 61.8 %, SMER 0.055 kg/kWh. The Marungga flour produced had a moisture content 6.4%, protein 36.86%, antioxidants 58.765%, vitamin C 50.338%, and green color (a = -12.75) meets SNI 9228: 2023.

Keywords: air dehumidifying; flour marungga, physicochemical properties

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1. Introduction

The Marungga plant (Moringa oleifera) is clinically known to contain protein, flavonoid compounds, polyphenols, terpenoids, alkaloids, saponins, vitamins and minerals such as: selenium, zinc, copper, manganese and magnesium which function as immunomodulators in helping to improve the body's immune system and are widely used as alternative foods to overcome malnutrition. WHO even nicknamed marungga as "The Miracle Tree" [1] and [2]. Marungga leaves are easily damaged after harvesting, to reduce the risk of damage, a drying process is carried out [3]. Dried marungga leaves are then ground into flour so that they can be utilized as a fortificant to meet the nutritional needs of nutritional supplements [4-9].

Drying in addition to providing benefits can also cause changes in food properties such as changes in active compound content, color, microbial contamination and secondary metabolites such as essentials, phenolics, flavanoids and chlorophyll, aroma, texture and physical form [10]. The use of high drying temperatures can reduce drying time but results in poor product quality and higher energy consumption, while drying using low temperatures can improve product quality but longer drying periods [11].

Drying marungga leaves using sunlight resulted in the highest antioxidant capacity and activity and mineral content compared to cabinet dryers at 50 oC and shade dryers, but the drying time is very long 2-3 days depending on the weather and may be contaminated with impurities [12] and [13]. Most tray-type artificial dryers still use temperatures 55-65 oC above the sun drying temperature, drying can take place faster but can reduce the quality of the dried marungga leaves produced.

Based on this background, a dehumidifier dryer has been designed and constructed [14]. Dehumidifier is a component that can reduce the water content contained in the air so that the air humidity level becomes low through a process called dehumidification. The dehumidifier dryer is a combination of work between a dehumidifier and a dryer, where the dehumidifier utilizes the refrigeration cycle through several components, namely the evaporator, compressor, condenser, expansion valve, and refrigerant liquid [15].

The application of dehumidifier drying has been widely documented by previous researchers in the drying of seaweed [16], mushrooms [17], ginger [18], and red chili [19]. The operational principle of a dehumidifier dryer is as follows: air from the surrounding environment is drawn into the evaporator, which is maintained at a low temperature. The heat or thermal energy present in the air is absorbed by the refrigerant within the evaporator, resulting in a reduction in temperature until it reaches the dew point. This process causes water vapor to condense, thereby reducing the moisture content of the air. The air exiting the evaporator is characterized by a low temperature and humidity. In the evaporator, the refrigerant absorbs heat from the air and then passes through the compressor. During this process, the refrigerant vapor undergoes compression, resulting in an increase in its temperature and pressure. The high-temperature refrigerant is subjected to pre-cooling on the pre-cooling coil (PC) prior to its entry into the condenser. During this process, the refrigerant absorbs heat from the air just exiting the evaporator, resulting in an increase in air temperature to nearly that of the ambient environment. The incorporation of the PC coil facilitates the transfer of heat from the refrigerant to the drying air, thereby enhancing the efficiency of the cooling process within the condenser. Subsequently, the liquid refrigerant passes through the expansion valve, resulting in a pressure drop. It then continues into the evaporator at a low temperature, thereby prepared to absorb the heat from the air that has been passed to the evaporator. This refrigerant cycle is repeated for the purpose of dehumidification in the evaporator. The air, having passed through the PC coil, has a temperature close to that of the ambient air, with a low humidity. It is expected that the low temperature and humidity will facilitate the drying process without damaging the nutritional value of marungga leaves. This study aims to test the performance of a rack-type dehumidifier dryer and identify the quality of marungga flour produced from drying using a dehumidifier dryer.

2. Materials and Methods

The Materials and Methods should be described with sufficient details to allow others to replicate and build on the published results. Please note that the publication of your manuscript implicates that you must make all materials, data, computer code, and protocols associated with the publication available to readers. Please disclose at the submission stage any restrictions on the availability of materials or information. New methods and protocols should be described in detail while well-established methods can be briefly described and appropriately cited.

The research activities were conducted at the Agricultural Equipment and Machinery Laboratory and the Bioscience Laboratory of Jember State Polytechnic. The principal material utilized was freshly harvested marungga leaves. The following tools were employed: dehumidifier dryer, anemometer, thermometer, Arduino DHT22 data logger, wet ball, dry ball, fan, stopwatch, digital scale, oven, analytical balance, and opaque paper. The temperature and humidity were measured with a type K thermocouple and recorded on an Arduino DHT22 data logger. The drying temperature utilized in this study is the ambient temperature processed in the dehumidifier dryer without the addition of heat other than that generated by the PC coil prior to the refrigerant entering the condenser. The temperature and RH were monitored at 20-minute intervals throughout the drying process. The drying process is conducted with the blower in the fully open position until the moisture content of the marungga leaves reaches a level below 10%. The configuration and components of the dehumidifier dryer are illustrated in figures 1 and 2.

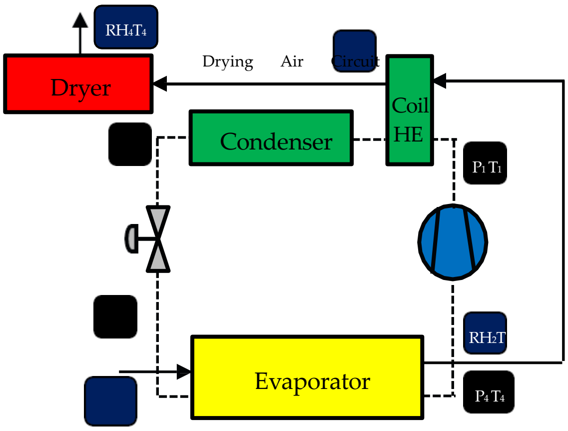

Figure 1. Schematic of the dryer and data collection

Figure 2. Drying machine parts

Description figure 2 :
1. Compressor, 2. Evaporator, 3. Condenser, 4. Expansion valve, 5. PC coil, 6. Blower, 7. Rack-type drying

The principal components of a dehumidifier are the environmental air inlet, evaporator, PC coil, condenser, fan, blower, and drying rack. The air inlet is situated in front of the evaporator and serves the function of an air inlet from the surrounding environment. The evaporator reduces the ambient air temperature to a point below the dew point temperature, thus enabling the condensation of water vapor in the air as water. The condensation water then flows to the lower portion of the apparatus and is discharged into the reservoir designated for the collection of condensate water. Air with low temperature and humidity is directed to the PC coil, where it absorbs heat from the refrigerant, thereby increasing the air temperature to a level approaching that of the ambient environment. Subsequently, the air is conveyed through the blower and directed to the drying rack, which contains the desiccated marungga leaves. The drying chamber is equipped with four trays for the material to be subjected to the drying process. A total of 500 grams of marungga leaves were subjected to drying, with each tray containing 125 grams. The process of drying is driven by the difference in air-water vapor pressure, which is lower than the water vapor pressure of the Marungga leaves. This results in the water within the material evaporating as steam, which is then carried away by the drying air [20].

The performance of a dehumidifier dryer can be gauged based on a number of parameters, including the fluctuations in air temperature and humidity throughout the drying process, the reduction in air specific humidity, the alterations in refrigerant temperature and pressure during the refrigeration cycle, the Coefficient of Performance (COP), the drying rate, and the Specific Moisture Extraction Rate (SMER) value [21]. The physicochemical properties of marungga flour were analyzed, including color, moisture content, total protein content, vitamin C content, and antioxidant content [22].

2.1. Changes in temperature and relative humidity

Data on the air temperature and relative humidity of the air used in the drying process are measured with a wet bulb and dry bulb thermometer and stored on an Arduino DHT22 data logger. The air temperature measurement points are placed before entering the evaporator, after the evaporator, after the pre-cooling coil, after the blower and after the material with an interval of 20 minutes for 8 hours.

2.2. Air specific humidity reduction

Collecting air specific humidity data involves quantifying the amount of water vapor in units of kgH2O/kgdry air. Absolute humidity data can be obtained from temperature and relative humidity data using a psychrometric calculator.

2.3. Dehumidifier coefficient of performance (cop)

The Coefficient of Performance (COP) is the ratio between the heat absorbed from the environment by the evaporator (evaporation process) and the work done by the compressor (compression process) [23]. The work done by the compressor or compression process can be calculated using equation 1.

$$Wc = h_{2\,refrigeran} - h_{1\,refrigeran} \qquad (1)$$

where: Wc = work done by compressor (kJ/kg), h1 refrigerant = compressor inlet enthalpy (kJ/kg), h2 refrigerant = compressor outlet enthalpy (kJ/kg), the enthalpy value obtained using the P-H Mollier diagram of R22 refrigerant with reference to the evaporator inlet temperature and coil pre-cooling refrigerant.

To calculate the evaporation process, the refrigerant changes phase from the mixed phase (liquid-vapor) to the saturated vapor phase. The heat absorbed in the evaporator can be calculated using equation 2.

$$Qe = h_{1\,refrigeran} - h_{4\,refrigeran} \qquad (2)$$

where: Qe = evaporator absorbed heat (kJ/kg), h1 refrigerant = evaporator outlet enthalpy (kJ/kg), h4 refrigerant = evaporator inlet enthalpy (kJ/kg), the enthalpy value obtained using the R22 refrigerant P-H Mollier diagram with reference to the evaporator inlet temperature and refrigerant pre-cooling coil.

Based on the above calculations, the coefficient of performance (COP) is calculated by comparing the cooling effect with the work of compression. The actual COP can be calculated using equation 3.

$$COP\ aktual = \frac{\mathrm{Qe}}{Wc} \qquad (3)$$

The Carnot COP calculation is a comparison between the evaporating temperature and the difference between the condensing and evaporating temperatures. This formula uses Kelvin temperature units.

$$COP\ carnot = \frac{T\ Evaporation}{T\ Condensation - TEvaporation} \qquad (4)$$

where: T Evaporation = evaporation temperature (oK), TCondensation = condensation temperature (oK)

The efficiency of the vapor compression heat pump system in the dryer is the ratio between the actual COP and the Carnot COP [23].

$$Efficiency = \frac{actual\ COP}{Carnot\ COP} x100 \tag{5}$$

2.4. Drying rate

The drying rate of the material can be determined by calculating the initial moisture content minus the final moisture content divided by the drying time. Equation 6 and 7 were used to calculate the drying rate.

$$w_{air} = \frac{(KA_1 - KA_2)}{100 - KA_2} \times wd \tag{6}$$

where: w_{air}= water vapor load (kg), wd : = initial material mass (kg), KA_1 = initial moisture content (%), KA_2= final moisture content (%)

$$W_1 = \frac{w_{air}}{t} \tag{7}$$

where: W1= drying rate (kg/hour), t = drying time (hour)

2.5. Spesific moisture extraction rate (SMER)

SMER can be known by the amount of water mass evaporated with the energy used, the SMER formula can be calculated by equation 8.

$$SMER_{total} = \frac{w_{air}}{E_{total}} \tag{8}$$

Description: SMERtotal = specific moisture extraction rate (kg/kWh), w_{air} = total mass of water evaporated (kg), E_{total} = total energy consumed

3. Results and Discussion

3.1. Air temperature and relative humidity

A study of the performance of a rack type dehumidification dryer using only the heat released by the refrigerant in the PC coil without additional heating was conducted to dry marungga leaves. The drying chamber consists of 4 trays, each filled with 125 g of marungga leaves for a total of 500 g per drying process with an average air discharge of 0.109 kg/s. The measured results of changes in temperature and relative humidity, starting from the ambient temperature entering the evaporator to leaving the drying room during the drying process, are shown in figures 3 and 4. The drying temperature is strongly influenced by the temperature of the incoming ambient air because the drying process uses only the heat released by the refrigerant on its way to the condenser precisely in the PC coil, without any additional heat from other sources. The lowest average drying temperature of 29 oC was reached in the morning when the ambient temperature was 25 oC, the drying temperature increased as the drying time increased toward noon, and the highest average drying temperature of 35 oC was reached when the ambient temperature was 31 oC. This temperature value is inversely proportional to the relative humidity value; when the air temperature increases, the relative humidity decreases [24].

The lowest average relative humidity of drying air was 48.5% in the afternoon when the average relative humidity of ambient air was 74.3%, and the highest average relative humidity of drying air was 69.5% in the morning when the average relative humidity of ambient air was 92.9%. Based on these conditions, the average drying temperature of 33.5

oC with an average relative humidity of 54.7% was able to dry the marungga leaves to a moisture content of 6.4% for 8 hours.

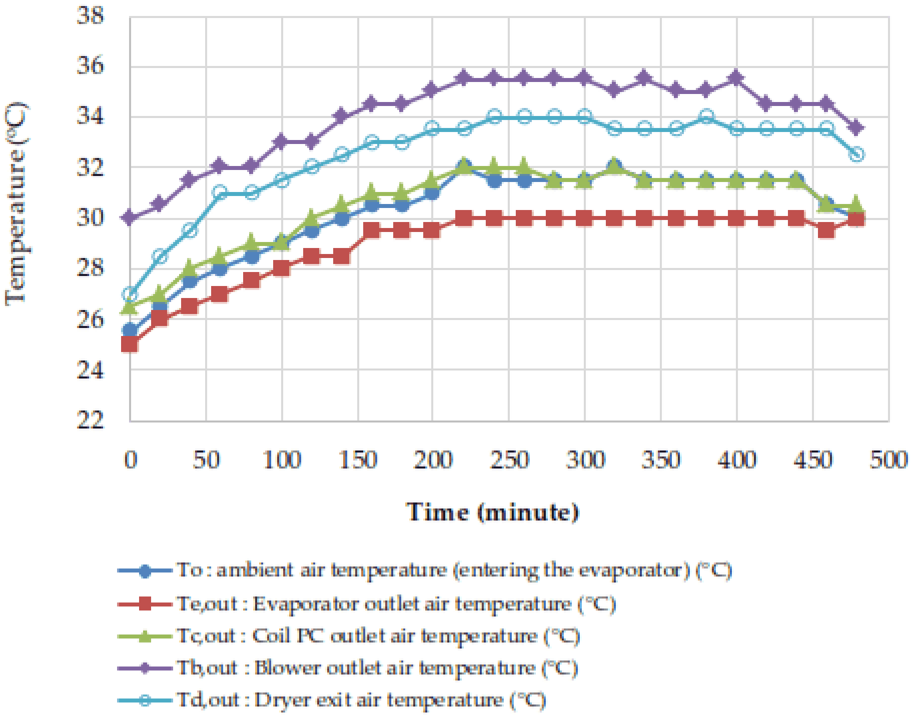

Figure 3. Graph of the relationship between air temperature and drying time

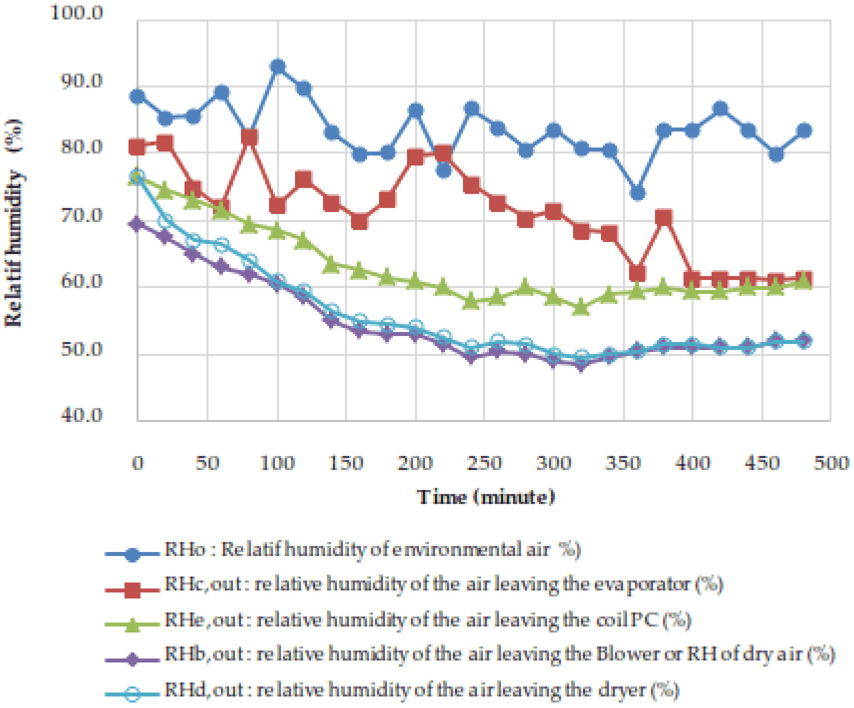

Figure 4. Graph of the relationship between air humidity and drying time

3.2. Specific humidity decrease

The measurement of the specific humidity of the air entering and leaving the evaporator is used to determine how much the water vapor in the air is reduced by the dehumidification process. The specific humidity is obtained from the measurement of Tdb and Twb, by calculating the partial vapor pressure of the air conditions, the specific humidity value of the air can be calculated using Excel. Based on the test results, the decrease of absolute humidity during drying fluctuates according to the ambient air conditions. The decrease of specific humidity of air is between 0.0020812 - 0.0092122 kg H2O/kg dry air. The average specific humidity of drying air was 0.01703 kg H2O/kg dry air. The lower the specific humidity value of the air, the higher the drying rate, so the drying process increases even though the temperature is low.

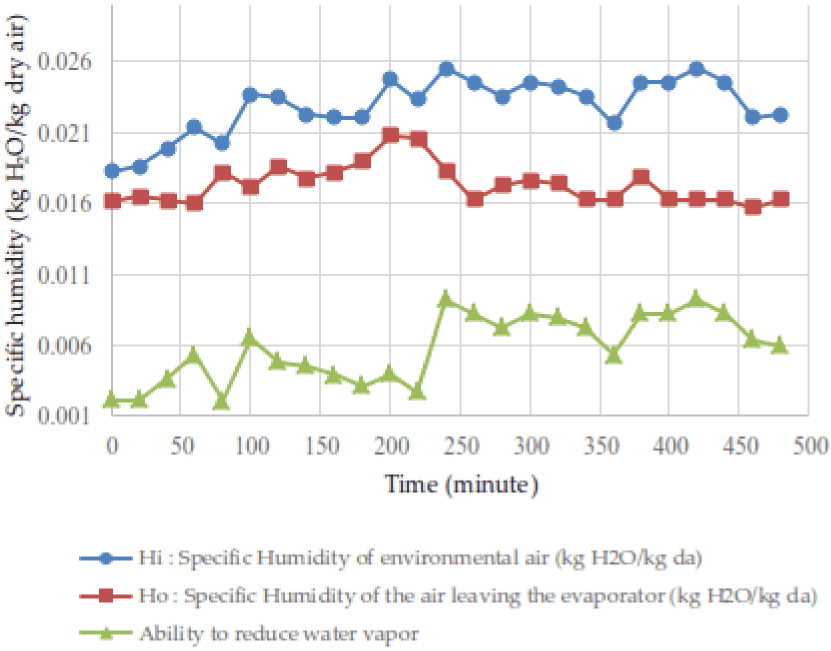

Figure 5. Graph of specific humidity decrease in the evaporator

3.3. Coefficient of performance (cop) of dehumidifier dryer

The results of the refrigerant temperature and pressure measurements at each component were used to calculate the actual COP and Carnot COP and the efficiency of the dehumidification system. Using equations 1, 2, 3, 4 and equation 5 with the help of the Mollier diagram and the R22 refrigerant characteristics table (see figure 6), the average actual COP was 4.2 and the average Carnot COP was 6.8 with an average efficiency of 61.8%. The increase in ambient air temperature results in an increase in compressor input power, which is influenced by the refrigerant mass flow rate, which also increases. The increase in compression power results in a decrease in the resulting COP value [24].

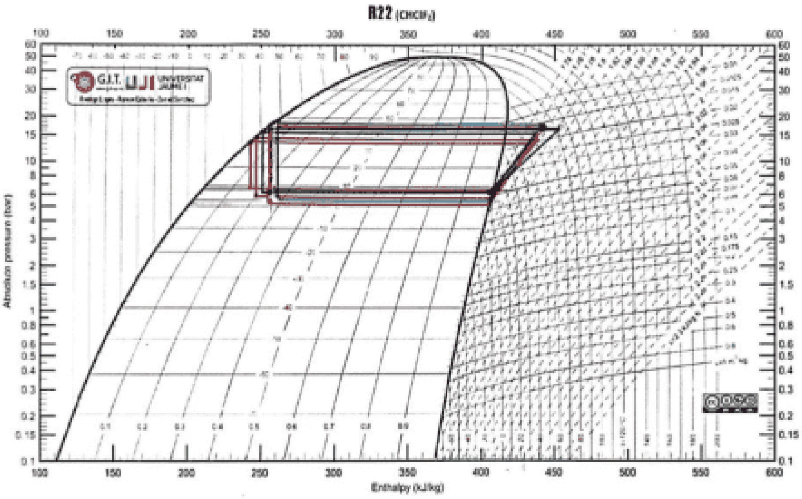

Figure 6. Mollier diagram of the R22 refrigerant cooling cycle

3.4. Drying rate

The drying rate can be obtained from the mass of water evaporated divided by the drying time. The average initial moisture content of Marungga leaves 72.2% wet basis was dried for 8 hours, resulting in an average final moisture content of 6.4% wet basis, the initial mass of material was 500 g, then using equations 6 and 7 the drying rate was 0.732 kgH2O/hour.

3.5. Spesific mouisture extraction rate (SMER)

The Specific Moisture Extraction Rate (SMER) value is used to determine the energy efficiency value, optimize the drying process, and evaluate the performance of the dehumidification dryer system. Using equations 6 and 8, an average SMER of 0.055 kg/kWh was obtained.

3.6. Physicochemical properties of marungga leaf flour

The results of marungga leaves that have been dried and floured have a moisture content of 6.4%, total protein content of 36.862%, antioxidant content of 58.765%, vitamin C 50.338%, and green color with a value of -12.75. Based on SNI 9228: 2023 [23], the quality of dried marungga leaves requires a maximum moisture content of 8%, protein content greater than 28% and green color so that the quality of flour from drying using a demuhudifier dryer can be declared to have met the standard.

4. Conclusions

This section is not mandatory but can be added to the manuscript if the discussion is unusually long or complex.

4.1. Conclusion

The drying of Marungga leaves was performed using a dehumidifier dryer equipped with a PC coil. During the drying process, the average airflow rate was measured at 0.109 kg/s, with a total drying time of 8 hours. The average drying temperature was 33.5°C, and the average relative humidity was recorded at 54.7%. The average drying rate was determined to be 0.732 kg H2O/hour. Performance tests of the dehumidifier dryer revealed an average specific humidity reduction of 0.01703 kg H2O/kg of dry air (kgda), an average actual coefficient of performance (COP) value of 4.2, and a Carnot COP of 6.8, resulting in an efficiency of 62.8%. The specific moisture extraction rate (SMER) was calculated to be 0.055 kg/kWh. Quality analysis of the Marungga leaf flour indicated a moisture content of 6.4%, a total protein content of 36.862%, an antioxidant content of 58.765%, and a vitamin

C content of 50.338%. The flour exhibited a green color value of -12.75, confirming compliance with the SNI 9228: 2023 standard.

4.2. Suggestion

The performance of the dehumidifier-dryer must be improved by adding an additional heater equipped with an automation system so that the temperature of the dryer used can be controlled even if it is used in fluctuating ambient temperature.

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