VARIABILITY ANALYSIS OF TEMPERATURE AND HUMIDITY FOR CONTROL OPTIMIZATION OF A HYBRID DEHUMIDIFIER WITH A HEATING MODULE FOR GREENHOUSES

Young-Woo Seo[1], Won-Jae Lee[1], Yong-Joo Kim[1], Sun-Ok Cung[1*], Seung-Ho Jang[2], Im-Sung Bae[3]

[1]Dept. of Biosystems Machinery Engineering, Chungnam National University, Daejeon, 34134, Republic of Korea
[2]Shinan Green-Tech Co., Ltd, Suncheon, Cheonnam, 58027, Republic of Korea
[3]Green Control System Co., Ltd, Gwangju, 61027, Republic of Korea

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Abstract. *Protected horticulture using greenhouses and also recently plant factories is becoming more popular, especially for high-value crops such as paprika, tomato, strawberry, due to year-round production of high yield and better quality crops under controlled environment. Temperature and humidity are most important ambient environmental factors for not only optimum crop growth but also disease control. This study was conducted to analyze vertical and spatial variability of temperature and humidity in test greenhouses for control optimization of a hybrid dehumidifier with a heating module. In the study, a 600-W dehumidifier with a 3.5-kW heating module, developed for 200 m^2 area for Korean plastic greenhouses The unit was developed to prevent crops from freezing or abnormal growth at temperatures of 0~5℃ using the heating module, simultaneously with the dehumidification. Temperature and humidity would be different from those at the equipment location, and vary vertically and spatially in greenhouses. Control strategies such as sensor location and equipment operation duration need to be developed considering the variability. First, tests were conducted in a closed chamber so that temperature and humidity not be affected by outside conditions. Next, 34 m^2 small-sized plastic greenhouse was used. Temperature-humidity sensor nodes were located at 3 heights (i.e., equipment height, 0.5 and 1 m from the ground), and 9 sensor nodes were uniformly located at each of those heights. Additional nodes were located around the equipment. Sensor nodes were fabricated using ATmega128 main board and ZigBee communication module. Sensor measurements were obtained for 2 hours after the equipment operation start at a 10-Hz sampling speed. In the closed chamber, the average times required to change the initial conditions (i.e., -5℃, 90% RH) to the target conditions(i.e., 10℃, 70% RH) were 58, 66 and 75 minutes for the heights, respectively. When the initial conditions were varied, the required control time changed, but the pattern by height was similar. Greenhouse tests showed considerable vertical and spatial variability, and the* *pattern also changed by time. Differences by heights were 3~6℃ and 10~20% RH, and those by spatial location were 2~4℃ and 7~15% RH. Results of the study confirmed considerable vertical and spatial variability of temperature and humidity in greenhouses. Further study would be necessary under plant growing conditions, for reliable control strategies of the dehumidifier with a heating module.*

Keywords. *Precision agriculture, Greenhouse, Variability, Temperature, Humidity*

Introduction

Protected horticulture using greenhouses and also recently plant factories is becoming more popular, especially for high-value crops such as paprika, tomato, strawberry, due to year-round production of high yield and better quality crops under controlled environment.

Farmers should be visit and monitor the greenhouse and control the environmental conditions. Recently, remote monitoring and control of the environmental conditions using internet or mobile devices have been reported and commercialized. For example, Hwang et al. (2010) reported an environmental monitoring and control system for paprika greenhouse using sensor nodes with 2.4-GHz RF chips. The environmental control factors are Temperature and humidity, CO_2, EC, pH, wind direction, wind speed, etc. But most of the important factor is temperature and humidity. Temperature and humidity are most important ambient environmental factors for not only optimum crop growth but also disease control.

Variations in environmental factors would be dependent also on ventilation methods. Soni et al. (2005) found a vertical temperature difference caused by natural ventilation in four tomato-growing greenhouses at two plant growth stages from mid-April to late-June. Li and Willits(2008) studied vertical variations of air temperature and humidity in a 6.7 x 12.1 m^2 fan-ventilated sweet pepper greenhouse. Temperature of the greenhouse with automated roof ventilation resulted in greater variation(Tadj et al., 2010). The experiments were performed in the greenhouse of 8.0 x 20.0 m^2 size, in which the heating pipes at the bottom and a heater at the upper were used for heating. In order to compare air velocity, air temperature, and RH by height, measurements were obtained at five heights (0.8, 1.0, 1.5, 2, 2.5 m), and 42 points and 21 points at 1 and 1.5 m heights. When a heater was used, temperature at the upper area of the greenhouse was the highest as 26°C and humidity at the bottom was the highest as 14%. It was pointed out that measuring with only one sensor near the center of the greenhouse would overestimate the average temperature of the entire area(Zhao et al., 2001).

For optimum monitoring and control of environmental variables in a greenhouse, installation of sensors considering the variability would be preferable(Kim et al., 2002). This study was conducted to analyze vertical and spatial variability of temperature and humidity in enclosed chamber for control optimization of a hybrid dehumidifier with a heating module, and to provide basic data useful for monitoring and control of the environments of the enclosed chamber.

Materials and Methods

Construction and development of greenhouse monitoring and control system

Greenhouse monitoring and control system can be divided into three main parts: Sensing, Control and Communication. These three parts have their own function as shown Figure 1.

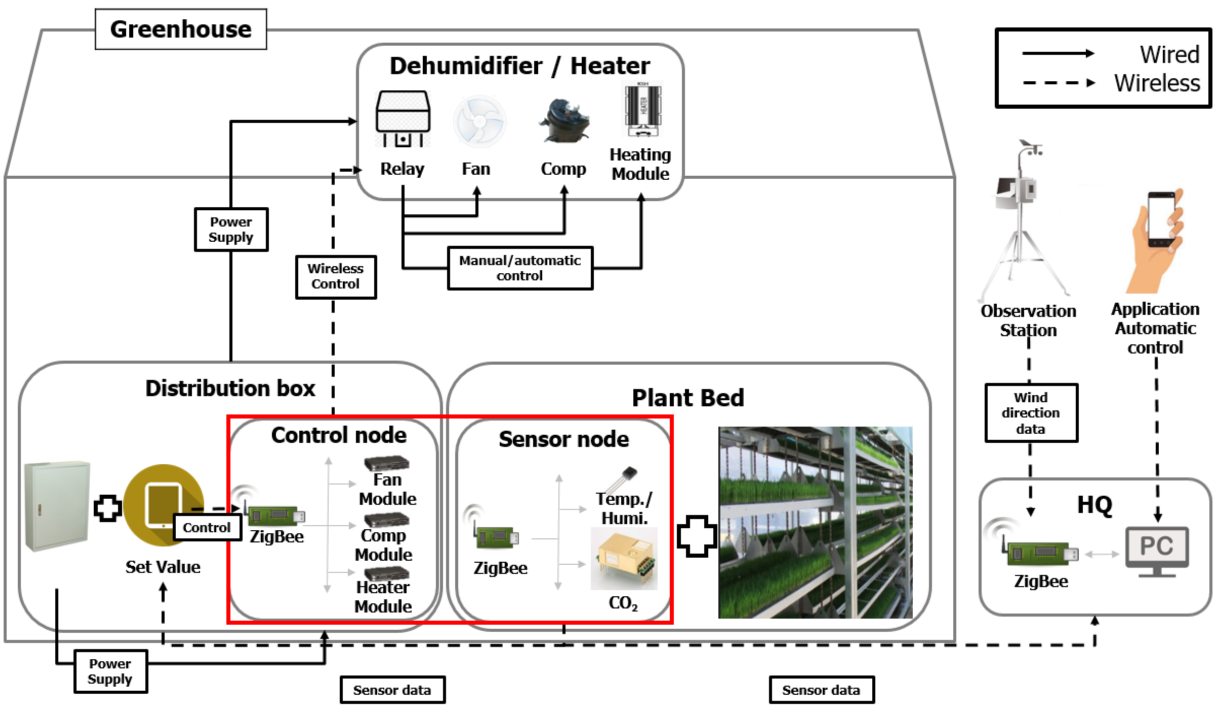


Figure 1. Main components of remote control for dehumidifier combined heating module in greenhouse

The sensing part is the wireless sensor node that consisted of the main board, temperature/humidity sensor and wireless communication device. The wireless sensor node collects the temperature and humidity inside of the greenhouse. Table 1 shows the specifications of the selected devices for the development of the sensor nodes and experiment. The temperature/humidity sensor(CIPCAP-L Sensor, General Electric Company Co. Inc. Niskayuna, NY, USA) measured inside of the greenhouse. CIPCAP-L Sensor uses Integral PTAT(Proportional to Absolute Temperature) silicon transistor for temperature and capacitive polymer sensing technology for humidity. A wireless communication device(ZP24D-250RM-SR, B&B Electronics Co. Inc., Dayton, OH,, USA) having a 2.4GHz band with Zigbee protocol and Modbus protocol was selected in the study. The maximum communication distance between the two wireless communication devices that selected of this study was about 90 m.

Table 1. Specifications of the sensor nodes

Variable	Temperature	Humidity	Communication
Model	CIPCAP-L	CIPCAP-L	Xbee – Pro
Range	-55 ~ 150℃	0 ~ 100%	90 m(5-500m based on environment)
Accuracy	±0.6℃	±2%	±1%

The control part is consisted of the main board, relay and wireless communication device. The main board executes the on/off command of the devices(i.e., dehumidifier, heater, fan) to the relay according to PC and the user's command through the wireless communication devices(i.e., Zigbee). The user can manually control the inside of the greenhouse through the PC's greenhouse environment control program and also control the environment with the set temperature and humidity value through the automatic control functions. In addition, by each point of the temperature/humidity can be checked in real time inside the greenhouse by using the serial LCD module. Table 2 shows the specifications of the selected devices for the development of the greenhouse temperature/humidity control node and experiment.

Table 2. Specifications of the Control node

Model	Manufacturing	Input voltage	Output voltage	Port connection
ATmega128 MCU	Atmel	12 V (DC)	0 ~ 5 V	10 pin
LCD module	COMFILE	12 V (DC)	0 ~ 5 V	UARTO
RS-232	TAL tech	12 V (DC)	0 ~ 5 V	-
4-Chnnels relay	N.T.C	12V, 5V(DC)	-	PCB pattern

Experimental methods

At first, commercial sensors may not provide the same output even in the same environment. So prior to the experiment, the goal is the verifying the output from the sensor, output values from 31 different temperature/humidity sensors at same place: temperatures of 0°C and RH values of 80%.

Field experiments were conducted in the enclosed chamber and the greenhouse. The heating module used for the temperature variation analysis was a fan heater, a sheath heater, a nano surface heating module developed for research and development, and the equipment used for the humidity experiment was a 600 W capacity greenhouse dehumidifier. Table 3 and Table 4 show the specifications of the heating modules and dehumidifier used in the experiment. Experiments were carried out with fan heater, sheath heater and nano surface heating module for 2 hours at 15°C, 20°C, and 25°C environment for the analysis of the temperature change variation in the enclosed chamber and the greenhouse. Humidity variation analysis was conducted by measuring the time required for the target humidity to reach 70% at the 80%, 85% and 90% environments and summarizing the 3 repeated average values. During the experiments, the air flow was blocked so that it was not affected by the external environment.

Table 3. Specifications of the heating module used in the experiment

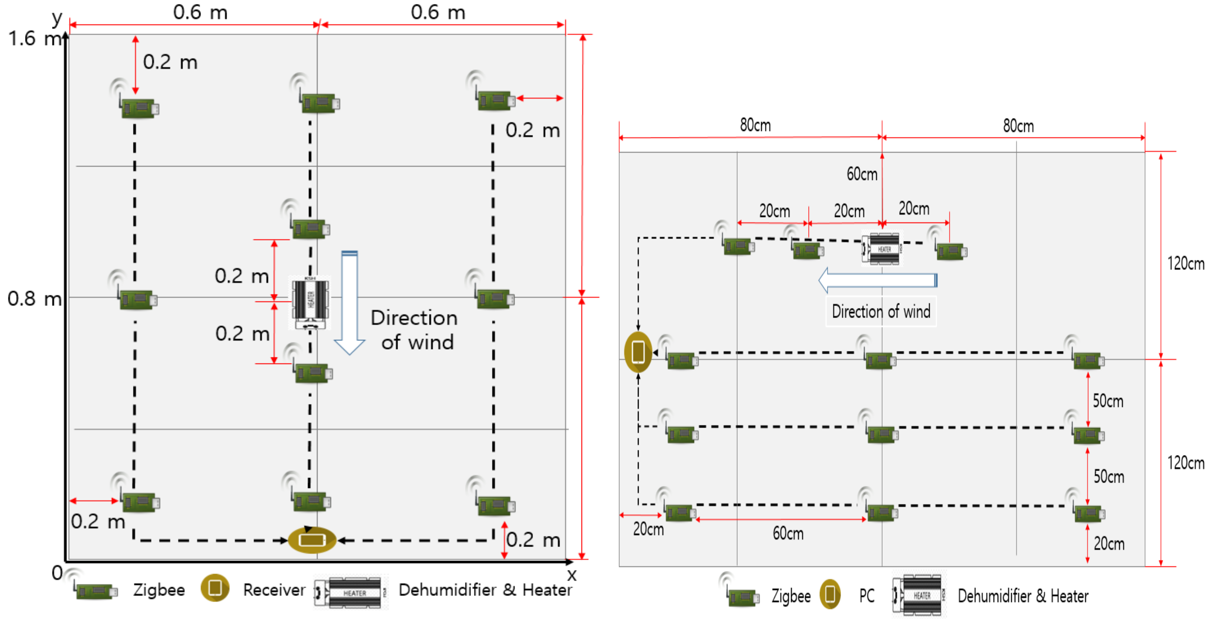
Model	Manufacturing	Capacity	Heating method
Fan heater	TOOLSTAR	3 kW	PTC
Sheath heater	Shinan Green-tech	3 kW	PTC
Nano surface heater	Shinan Green-tech	3 ~ 3.5 kW	PTC

Table 4. Specifications of the dehumidifier used in the experiment

Model	Manufacturing	Capacity	Dehumidification amount
SGD-11S	Shinan Green-tech	600 W	2.5 L/h(20°C, 80% in environment)

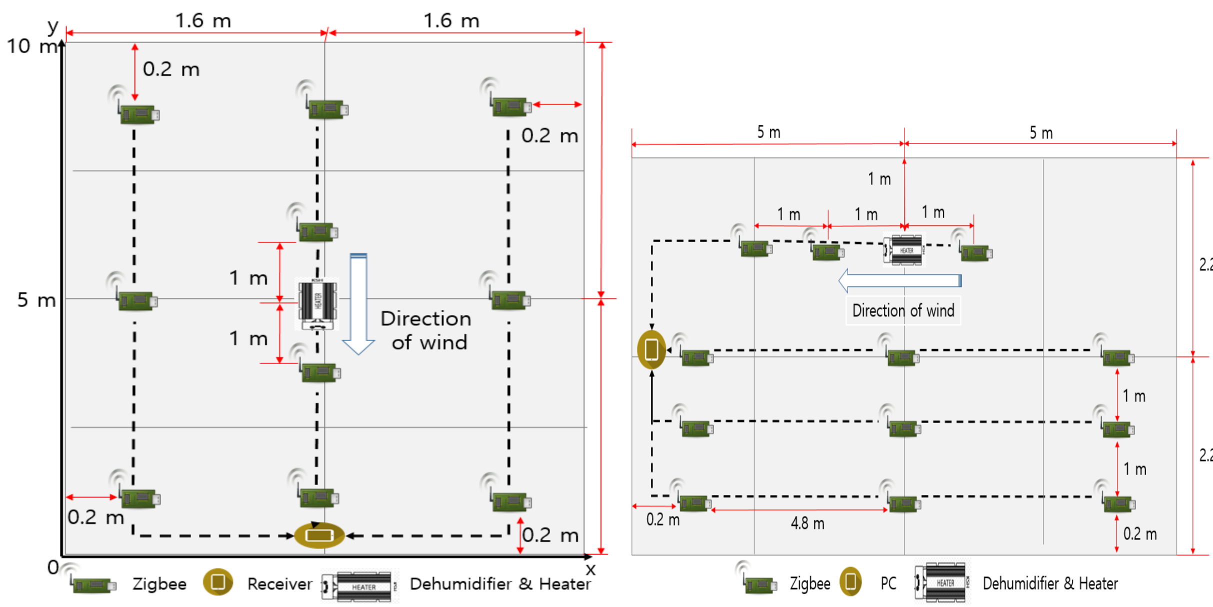
In order to measure the accurate distribution of ambient environment variables in the greenhouse, sensors should be stabilized in the changed condition. Temperature and humidity sensors take measurements in the state of heat balance with the objects, and contact sensors systematically would have some delay time(Kim and Kim, 2002). To determine response time of the temperature and humidity sensors that were not provided in the manufacturers' manuals, a constant temperature & humidity chamber was used. Temperature/humidity sensors were first stabilized in temperature of 22°C±1.5°C and humidity of 40±1%, then placed inside of the chamber and the greenhouse.

Temperature-humidity sensor nodes were located at 3 heights (i.e., 0.2, 0.7 and 1.2m from the ground in the enclosed chamber, 0.2, 1.2 and 2.2m from the ground in the greenhouse), and 9 sensor nodes were uniformly located at each of those heights. Additional nodes were located around the equipment shown as Figure 2 and Figure 3. In addition, during the experiment, the outside temperature and humidity were measured and the difference of temperature and humidity between inside and outside of the greenhouse was analyzed.



(a) (b)

Figure 2. Sensors position in the chamber of top view(a), side view(b)



(a) (b)

Figure 3. Sensors position in the greenhouse of top view(a), side view(b)

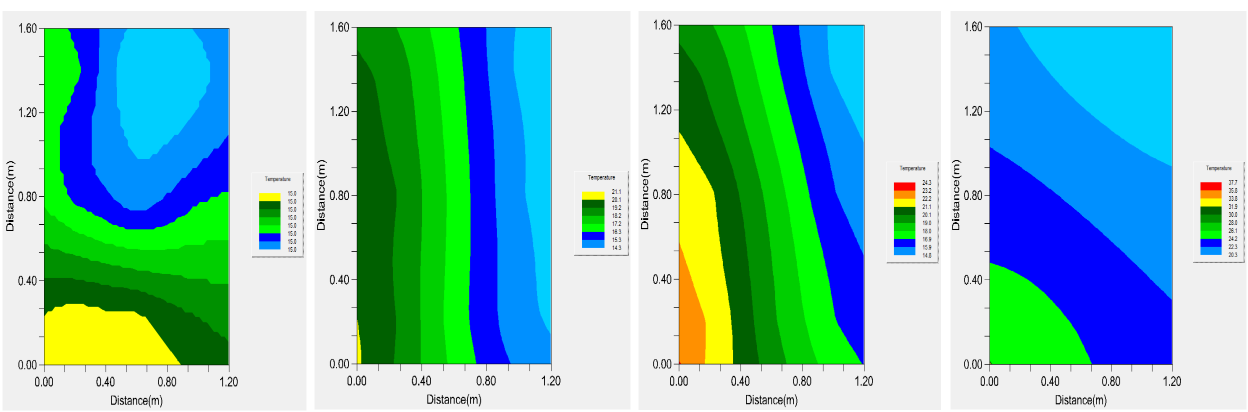
Results and Discussion

Variability of environmental variables in enclosed chamber

Tables 9 shows overall variability of the 9 sensor nodes in the top group of temperature and RH in the enclosed chamber during the experiments with nano surface heater. At the start of the experiment, the average of the sensors is 15.0°C and increased to 21.9°C at 120 minutes. The maximum temperature increased from 15.2°C at start to 23.2°C after 120 minutes. The minimum temperature in the enclosed chamber also increased continuously from 14.8°C at start to 20.9°C after 120 minutes. The humidity inside of the greenhouse at start is 68.2%. It decreased continuously from 68.2% at start to 56.6% after 120 minutes. As a result of in the enclosed chamber temperature and humidity measurement, the average temperature, maximum temperature and minimum temperature of the top group increased by 7°C regardless of the outside temperature is decreased, and the humidity decreased by 12% as the temperature increased. The standard deviation of the after 120 minutes is 0.57. Figure 7 shows overall variability of the 9 sensor nodes in the top group of temperature in the enclosed chamber during the experiments.

Table 9. Variability of the 9 sensor nodes in the in the top group measured air temperature in chamber (Unit: °C)

Time	Average	Maximum	Minimum	Range	Std. Dev.	Humidity
0 min	15.0	15.2	14.8	0.4	0.11	68.2%
30 min	16.8	18.5	15.8	2.7	0.65	61.7%
60 min	19.1	20.8	18.3	2.5	0.61	58.4%
120 min	21.9	23.2	20.9	2.3	0.57	56.6%



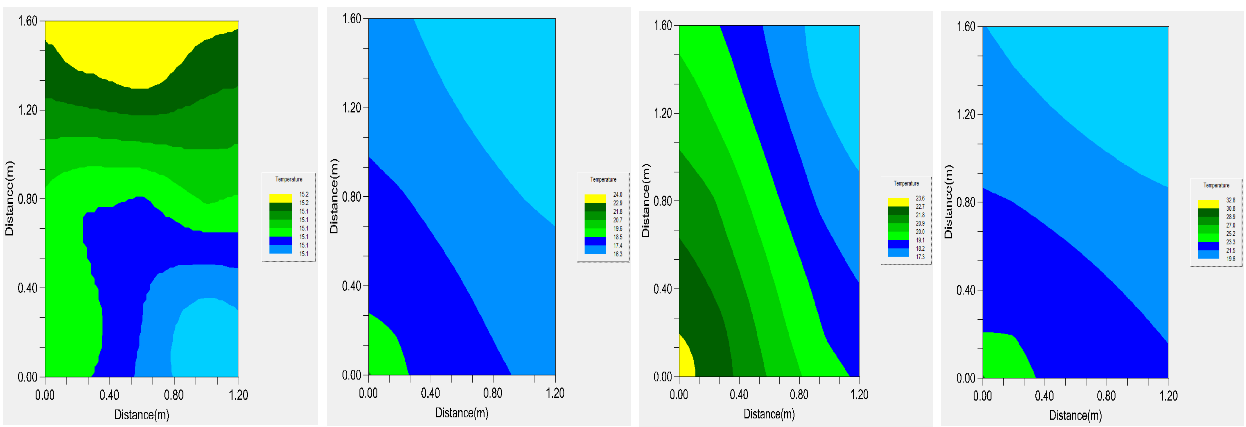
(a) (b) (c) (d)

Figure 7. Spatial distribution of air temperature in the enclosed chamber of the top group: (a) at 0 minute, (b) after 30 minutes, and (c) after 60 minutes, (d) after 120 minutes

Tables 10 shows overall variability of the 9 sensor nodes in the middle group of temperature and RH in the enclosed chamber during the experiments with nano surface heater. At the start of the experiment, the average of the sensors is 15.1°C and increased to 21.2°C at 120 minutes. The maximum temperature increased from 15.2°C at start to 22.6°C after 120 minutes. The minimum temperature in the enclosed chamber also increased continuously from 14.9°C at start to 20.8°C after 120 minutes. The humidity inside of the greenhouse at start is 68.2%. It decreased continuously from 68.2% at start to 56.6% after 120 minutes. As a result of in the enclosed chamber temperature and humidity measurement, the average temperature, maximum temperature and minimum temperature of the middle group increased by 6°C regardless of the outside temperature is decreased, and the humidity decreased by 13% as the temperature increased. The standard deviation of the after 120 minutes is 0.57. Figure 8 shows overall variability of the 9 sensor nodes in the middle group of temperature in the enclosed chamber during the experiments.

Table 10. Variability of the 9 sensor nodes in the in the middle group measured air temperature in chamber (Unit: °C)

Time	Average	Maximum	Minimum	Range	Std. Dev.	Humidity
0 min	15.1	15.2	14.9	0.3	0.08	59.3%
30 min	16.6	17.9	16.5	1.4	0.36	53.2%
60 min	19.1	21.3	18.0	2.6	0.63	51.1%
120 min	21.2	22.6	20.8	1.8	0.45	46.8%



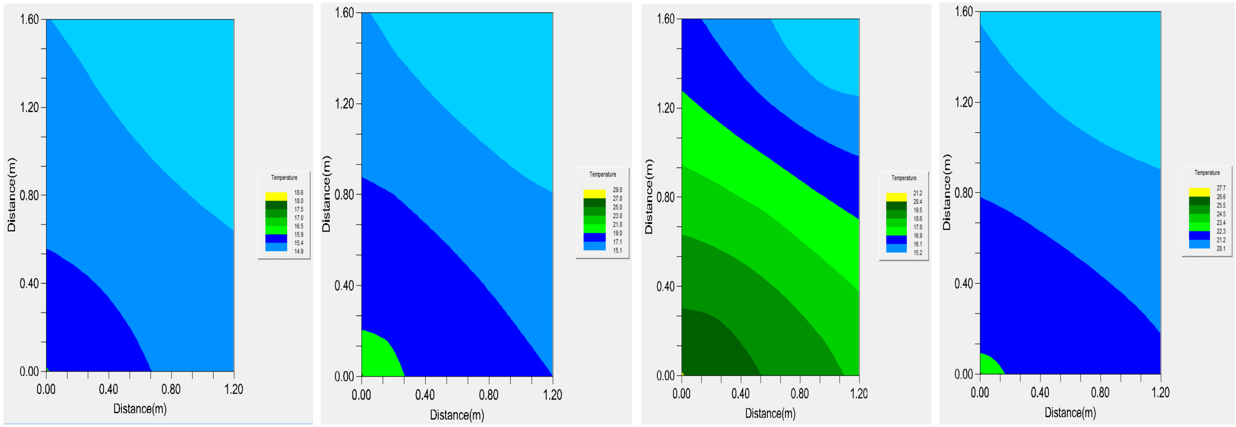
(a) (b) (c) (d)

Figure 8. Spatial distribution of air temperature in the enclosed chamber of the middle group: (a) at 0 minute, (b) after 30 minutes, and (c) after 60 minutes, (d) after 120 minutes

As shown in Tables 11, the average of the sensors at the start of the experiment is 15.0°C and increased to 21.9°C at 120 minutes. The maximum temperature increased from 15.2°C at start to 22.1°C after 120 minutes continuously. Humidity inside of the enclosed chamber at start is 60.9%. It decreased continuously from 60.9% at start to 49.1% after 120 minutes. As a result of in the enclosed chamber temperature and humidity measurement, the average temperature, maximum temperature and minimum temperature of the bottom group increased by 7°C regardless of the outside temperature is decreased, and the humidity decreased by 11% as the temperature increased. The standard deviation of the after 120 minutes is 0.57. Figure 9 shows overall variability of the 9 sensor nodes in the bottom group of temperature in the enclosed chamber during the experiments.

Table 11. Variability of the 9 sensor nodes in the in the bottom group measured air temperature in chamber (Unit: °C)

Time	Average	Maximum	Minimum	Range	Std. Dev.	Humidity
0 min	15.0	15.2	14.8	0.4	0.11	60.9%
30 min	16.4	17.3	15.6	1.7	0.42	58.2%
60 min	20.2	21.3	18.8	1.5	0.40	56.5%
120 min	21.9	22.1	19.6	1.5	0.39	49.1%



(a) (b) (c) (d)

Figure 9. Spatial distribution of air temperature in the enclosed chamber of the bottom group: (a) at 0 minute, (b) after 30 minutes, and (c) after 60 minutes, (d) after 120 minutes

In the experiment using the fan heater in the enclosed chamber, the temperature change did not occur significantly compared to the nanoheater. In the top group, the average temperature increased from 15.1°C at start of the experiment to 16.8°C after 120 minutes continuously. The maximum temperature increased from 15.2°C at the start of the experiment to 16.2°C at the end of the experiment. The middle group and bottom group also increased in average, maximum and minimum temperature. The humidity decreased from 62.2% at start of the experiment to 52.1% as the inside of the enclosed chamber temperature increased. Table 12 shows the temperature and RH in the enclosed chamber variation using the sheath heater.

Table 12. Variability of the sensors measured air temperature and humidity in chamber with Fan heater (Unit: °C)

Variables	Time	Average	Maximum	Minimum	Range	Std. Dev.	Humidity
Top Group	0 min	15.1	15.2	15.0	0.2	0.05	62.2%
	30 min	15.2	17.3	15.1	2.1	0.43	56.8%
	60 min	16.5	18.4	15.9	2.5	0.62	55.4%
	120 min	16.8	18.9	16.3	2.6	0.64	52.1%
Middle Group	0 min	15.0	15.2	14.8	0.4	0.09	62.6%
	30 min	15.3	16.8	15.0	1.6	0.41	51.3%
	60 min	16.2	17.6	15.7	1.9	0.48	56.3%
	120 min	16.4	18.1	15.4	2.7	0.47	55.8%
Bottom Group	0 min	15.1	15.4	15.1	0.3	0.08	61.8%
	30 min	16.2	17.0	15.8	1.2	0.29	57.4%
	60 min	16.4	17.6	16.9	0.7	0.19	56.1%
	120 min	16.4	18.0	17.2	0.8	0.21	55.6%

In the experiment using the sheath heater in the enclosed chamber, the temperature change did not also occur significantly compared to the nanoheater. In the top group, the average temperature increased from 15.1°C at start of the experiment to 20.3°C after 120 minutes continuously. The maximum temperature increased from 15.2°C at the start of the experiment to 21.3°C at the end of the experiment. The middle group and bottom group also increased in average, maximum and minimum temperature. The humidity decreased from 63.2% at start of the experiment to 50.2% as the inside of the enclosed chamber temperature increased. In the experiment using the sheath heater in the enclosed chamber, the average temperature in the enclosed chamber increased about 5°C and overall humidity decreased about 12%. Table 13 shows the temperature and RH in the enclosed chamber variation using the sheath heater.

Table 13. Variability of the sensors measured air temperature and humidity in chamber with sheath heater (Unit: °C)

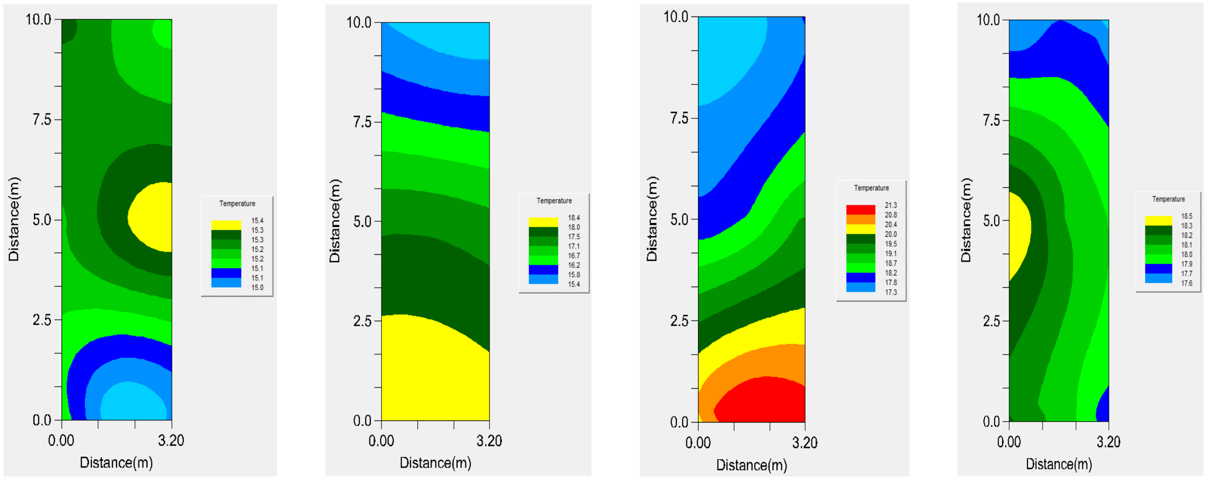
Variables	Time	Average	Maximum	Minimum	Range	Std. Dev.	Humidity
Top Group	0 min	15.1	15.2	15.1	0.1	0.03	63.2%
	30 min	16.1	17.2	15.5	1.7	0.42	55.8%
	60 min	18.4	18.8	16.3	1.9	0.49	53.6%
	120 min	20.3	21.3	18.1	3.2	0.80	50.2%
Middle Group	0 min	15.3	15.1	15.0	0.1	0.03	63.3%
	30 min	16.4	17.1	15.3	1.8	0.45	57.2%
	60 min	18.1	19.3	16.1	3.2	0.81	56.3%
	120 min	19.8	20.5	17.6	2.9	0.75	51.8%
Bottom Group	0 min	15.2	15.0	14.9	0.1	0.02	60.6%
	30 min	16.3	17.1	15.4	1.7	0.41	56.1%
	60 min	17.9	18.6	15.8	2.8	0.75	55.8%
	120 min	19.2	20.2	17.9	2.3	0.62	53.2%

Variability of environmental variables in greenhouse

Tables 5 shows overall variability of the 9 sensor nodes in the top group of temperature and RH in greenhouse during the experiments with nano surface heater. At the start of the experiment, the average of the sensors is 15.1°C and increased to 18.8°C at 60 minutes. The temperature in the greenhouse decreased after 60 minutes while temperature of the outside decreased continuously. The maximum temperature increased from 15.2°C at start to 21.3°C after 60 minutes and decreased after that. However, minimum temperature in the greenhouse increased continuously from 14.9°C at start to 17.8°C after 120 minutes. The humidity inside of the greenhouse at start is 71.2%. It decreased continuously from 71.2% at start to 61.8% after 120 minutes. In other words, the overall temperature of the top group increased about 3°C as the outside temperature decreased, the overall temperature decreased from 1 hour after the start of the experiment. However, the internal temperature of the greenhouse after 2 hours was lower than the temperature after 30 minutes and 1 hour after the start of the experiment, and the standard deviation was 0.22. Figure 4 shows overall variability of the 9 sensor nodes in the top group of temperature in greenhouse during the experiments.

Table 5. Variability of the 9 sensor nodes in the in the top group measured air temperature in greenhouse (Unit: °C)

Time	Average	Maximum	Minimum	Range	Std. Dev.	Humidity
0 min	15.1	15.2	14.9	0.3	0.08	71.2%
30 min	16.3	18.6	15.4	3.2	0.82	63.6%
60 min	18.8	21.3	17.3	4.0	0.97	56.4%
120 min	18.1	18.6	17.8	0.8	0.22	61.8%



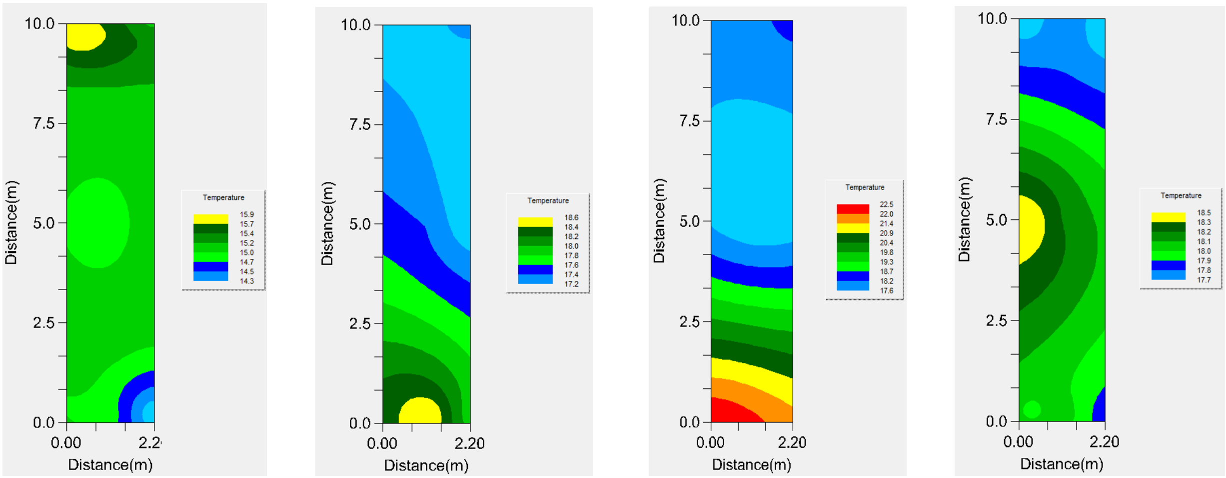
(a) (b) (c) (d)

Figure 4. Spatial distribution of air temperature in the greenhouse of the top group: (a) at 0 minute, (b) after 30 minutes, and (c) after 60 minutes, (d) after 120 minutes

Tables 6 shows overall variability of the 9 sensor nodes in the middle group of temperature and RH in greenhouse during the experiments. At the start of the experiment, the average of the sensors is 15.1°C and increased to 19.9°C at 60 minutes. The temperature in the greenhouse decreased after 60 minutes while temperature of the outside decreased continuously. The maximum temperature increased from 15.9°C at start to 22.5°C after 60 minutes and decreased after that. However, minimum temperature in the greenhouse increased continuously from 14.3°C at start to 17.7°C after 120 minutes. The humidity inside of the greenhouse at start is 71.6%. It decreased continuously from 71.6% at start to 61.2% after 120 minutes. In other words, the overall temperature of the top group increased about 3°C as the outside temperature decreased as similar top group, the overall temperature decreased from 1 hour after the start of the experiment. However, the internal temperature of the greenhouse after 2 hours was lower than the temperature after 30 minutes and 1 hour after the start of the experiment, and the standard deviation was 0.21. Figure 5 shows overall variability of the 9 sensor nodes in the middle group of temperature in greenhouse during the experiments.

Table 6. Variability of the 9 sensor nodes in the in the middle group measured air temperature in greenhouse (Unit: °C)

Time	Average	Maximum	Minimum	Range	Std. Dev.	Humidity
0 min	15.1	15.9	14.3	1.6	0.36	71.6%
30 min	17.9	18.6	17.2	1.4	0.32	60.4%
60 min	19.9	22.5	17.6	4.9	1.22	52.8%
120 min	18.1	18.5	17.7	0.8	0.21	61.2%



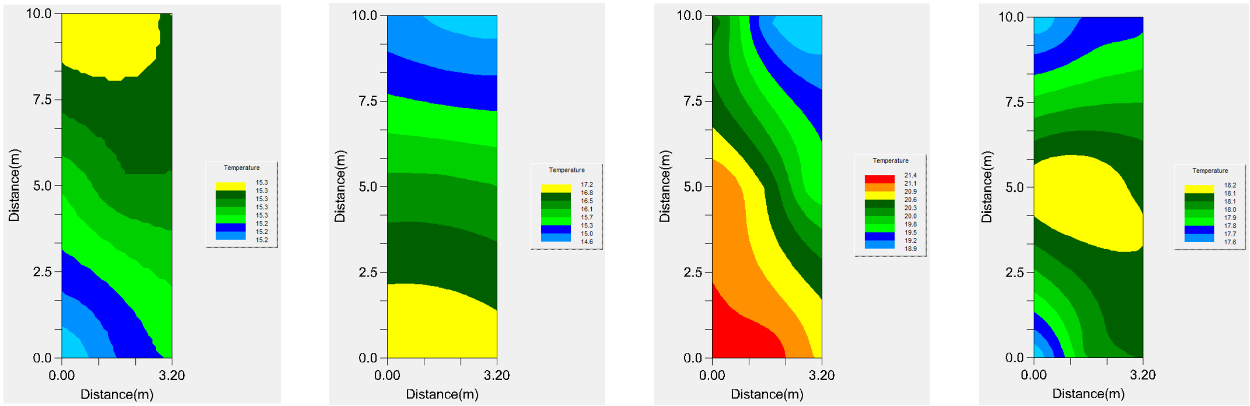
(a) (b) (c) (d)

Figure 5. Spatial distribution of air temperature in the greenhouse of the middle group: (a) at 0 minute, (b) after 30 minutes, and (c) after 60 minutes, (d) after 120 minutes

As shown in Tables 7, the average of the sensors at the start of the experiment is 15.2°C and increased to 20.1°C at 60 minutes. The temperature in the greenhouse decreased after 60 minutes while temperature of the outside decreased continuously. The maximum temperature increased from 15.3°C at start to 21.4°C after 60 minutes and decreased after that. In bottom group, minimum temperature in the greenhouse decreased continuously from 18.9°C after 60 minutes to 17.6°C after 120 minutes. It is different that upper group and middle group that the minimum temperature is continuously increased. Humidity inside of the greenhouse at start is 70.9%. It decreased continuously from 70.9% at start to 61.3% after 120 minutes. In other words, the overall temperature of the top group increased about 3°C as the outside temperature decreased as similar top group, the overall temperature decreased from 1 hour after the start of the experiment. In addition, unlike the upper and middle groups, the minimum temperature of the internal greenhouse decreased after 60 minutes. The standard variation of the after 120 minutes is 0.16. Figure 6 shows overall variability of the 9 sensor nodes in the bottom group of temperature in greenhouse during the experiments.

Table 7. Variability of the 9 sensor nodes in the in the bottom group measured air temperature in greenhouse (Unit: °C)

Time	Average	Maximum	Minimum	Range	Std. Dev.	Humidity
0 min	15.2	15.3	15.2	0.1	0.24	70.9%
30 min	16.0	17.2	14.6	2.6	0.65	66.4%
60 min	20.1	21.4	18.9	2.5	0.62	50.7%
120 min	17.9	18.2	17.6	0.6	0.16	61.3%



(a) (b) (c) (d)

Figure 6. Spatial distribution of air temperature in the greenhouse of the bottom group: (a) at 0 minute, (b) after 30 minutes, and (c) after 60 minutes, (d) after 120 minutes

In the experiment using the fan heater, the temperature change did not occur significantly compared to the nanoheater. In the top group, the average temperature increased from 15.1°C to 16.6°C after 60 minutes from the start of experiment, but decreased to 15.2°C after 120 minutes. The maximum temperature increased from 15.2°C to 17.6°C, but decreased from 120 minutes to 16.3°C. The humidity decreased from 70.6% at start of the experiment to 60.8% as the inside of the greenhouse temperature increased, but decreased to 68.5% as dropped after 60 minutes. Table 7 shows the temperature variation using the fan heater.

Table 7. Variability of the sensors measured air temperature and humidity in greenhouse with Fan heater (Unit: °C)

Variables	Time	Average	Maximum	Minimum	Range	Std. Dev.	Humidity
Top Group	0 min	15.1	15.2	14.9	0.3	0.07	70.6%
	30 min	15.8	17.1	15.0	2.1	0.51	63.2%
	60 min	16.6	17.6	15.3	1.3	0.42	60.8%
	120 min	15.2	16.3	15.1	1.2	0.32	68.5%
Middle Group	0 min	15.0	15.2	14.5	0.7	0.19	71.9%
	30 min	16.1	17.8	15.2	2.6	0.65	65.4%
	60 min	16.5	17.6	15.9	1.7	0.44	61.1%
	120 min	15.6	16.1	15.4	0.7	0.18	66.2%
Bottom Group	0 min	15.2	15.4	15.1	0.3	0.08	70.8%
	30 min	16.2	16.9	15.8	1.1	0.29	64.2%
	60 min	16.4	18.4	17.9	0.5	0.13	61.0%
	120 min	15.4	15.9	15.2	0.7	0.19	67.7%

In the experiment using the sheath heater, the temperature change did not occur significantly compared to the nanoheater. In the upper group, the average temperature increased from 15.1°C to 16.6°C after 60 minutes from the start of experiment, but decreased to 15.2°C after 120 minutes. The maximum temperature increased from 15.2°C to 17.6°C, but decreased from 120 minutes to 16.3°C. The humidity decreased from 70.6% at start of the experiment to 60.8% as the inside of the greenhouse temperature increased, but decreased to 68.5% as dropped after 60 minutes. Table 8 shows the temperature variation using the sheath heater.

Table 8. Variability of the sensors measured air temperature and humidity in greenhouse with sheath heater (Unit: °C)

Variables	Time	Average	Maximum	Minimum	Range	Std. Dev.	Humidity
Upper Group	0 min	15.1	15.2	14.8	0.4	0.11	70.2%
	30 min	16.1	17.1	15.2	1.9	0.48	65.6%
	60 min	19.4	19.8	16.9	2.9	0.72	59.7%
	120 min	17.3	17.6	15.5	2.1	0.52	63.5%
Middle Group	0 min	15.3	15.5	14.9	0.6	0.16	71.4%
	30 min	16.4	17.1	15.2	1.9	0.49	65.5%
	60 min	19.1	21.3	15.9	5.4	1.31	60.9%
	120 min	17.6	18.6	15.4	3.2	0.80	66.1%
Bottom Group	0 min	15.2	15.4	14.4	1.0	0.26	70.6%
	30 min	16.2	17.4	15.8	1.6	0.39	63.2%
	60 min	19.4	20.6	17.9	2.7	0.44	60.1%
	120 min	17.8	18.2	16.2	2.0	0.48	65.3%

Conclusion

This study was conducted to measure and analyze the variation of air temperature, humidity. Experiments were conducted in an enclosed chamber and greenhouse using same temperature/humidity sensors. In the experiment of enclosed chamber, experiments using nano heater showed 20% better than sheath heater and 40% better than fan heater in terms of temperature increase. Unlike the analysis of temperature and humidity variation in the greenhouse, the temperature continuously increased after 60 minutes in the chamber, and the humidity also decreased accordingly. Prior to the measurements in greenhouse, sensor accuracy and response time were all set the same. In each experiment, the largest change in the temperature rise was the nano heater. The temperature rise of the nano heater was 20% faster than that of the conventional sheath heater, and the average temperature inside the greenhouse was also high. The sheath heater showed a higher temperature rise rate than the same capacity of fan heater sold in the market, but it did not reach the target temperature of 5°C. This experiment confirmed the basic air flow inside the enclosed chamber and the greenhouse. This result would provide basic data useful to the repeated experiment, theoretical analysis of the existing heat flow and the CFD flow analysis program in the future.

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