

# Validity Testing of a Heat Transfer Model in a Greenhouse

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**Abstract** – An experiment was conducted to apply a developed heat transfer model to simulate temperatures in a greenhouse, and to test the validity of the developed model by matching measured temperatures data against the predicted ones. The developed, tested model which was used in simulating air temperatures inside the greenhouse was an un-dimensional conductive heat transfer one. This model was processed using Excel 2007 software package. A greenhouse of a Quonset type with dimensions of 40 m \* 8.5 m \* 2.5 m was used for carrying out the experimental work used in the model validation, by recording temperatures inside the greenhouse during the period from 15/3 to 25/4/2014 for (morning 08:00 am and afternoon 13:00 pm) periods. Results showed that there is a good coincidence between measured and simulated temperatures. Statistical analysis showed that the average model error, the average absolute difference and standard error of estimate for morning period were -0.0309, 1.0167 and 1.244 °C respectively. While for the afternoon period they were -0.0386, 1.157, 1.398 °C respectively. This indicates that the developed heat transfer model simulated the temperatures in the greenhouse successfully and lies within the experimental error bounds.

**Keywords** – Validity Testing, Heat Transfer, Modelling, Greenhouses.

## I. INTRODUCTION

The world scenario for agriculture has been changed from plentiful to limited resource application, extensive to intensive farming practices, and indiscriminate use of chemicals to judicious application. This situation led to the adoption of innovative technologies to face the ever-increasing demand for food crops in response to increasing world population. Moreover, the need arose, also, for developing new techniques for off- season production of food crops in response to consumer demands. The increasing demand for non-seasonal fruits, vegetables and other agricultural products needs controlled environments where it is possible to grow them irrespective of the ambient seasonal conditions (Sharam and Salokhe, 2006). The greenhouse technology satisfactorily answers most of the above- mentioned circumstances. Instead of being merely a sustainable practice, greenhouse technology empowers agriculture as a profession giving more marginal returns to the input. A widely accepted reason for growing plants in a greenhouse rather than outside is its ability to control the environment (Sharam and Salokhe, 2006).

A greenhouse is a closed space which surrounded by transparent walls to allow better internal environmental conditions than the natural ones. Greenhouses are widely used in the whole world due to their low cost. The variation of airflow temperatures is basically dependent upon outside external conditions. In addition, it protects inside crops from extreme temperature, high wind, heavy rains, destructive storms, insects and diseases. The greenhouse cultivation, as the current trend, extends the growing and crop production season, which maximizes the equipment utilization, expands the export season span, increases the annual yield per unit area with efficient use of inputs supplied, and thus eventually increases profitability (Tiwari, 2003). Commercial greenhouses may

be classified into several different ways. One of these classifications is into free-standing and gutter-connected house. Freestanding types are further classified according to form into Quonset, Gable and Gable arch greenhouses. Gutter-connected houses are series of gable or low-arch structures connected together at the gutter level. The individual bays vary from 32.8 to 81.9m in width and usually have a minimum clearance of 26.2m under the gutter (Mohammed, 2015).

Sustainable greenhouse systems can be obtained through an efficient management of climatic parameters, using renewable energy sources, using innovative greenhouse covering materials, optimizing the water and nutrient delivery to the cultivation and with an integrated management of pest and diseases. The climatic greenhouse environment relies on many factors such as solar radiation, air temperature, relative humidity and carbon dioxide concentration, so as to enhance suitable growing condition for the crop, safety condition for the workers and energy savings (Von Zabeltitz, 1999; Vox et al., 2010).

Temperature is one of the parameters that affect the plant physiology. In fact, over a limited range at which plant growth occurs, the rate of chemical processes will commonly be multiplied for every 10°C rise in temperature. The rate of respiration and photosynthesis increases with the increase in temperature; however, increase in photosynthesis is limited after a rise in temperature, which may be due to available energy and carbon dioxide concentration.

Transpiration is also affected by temperature. A rise in leaf temperature will lead to increased vapor pressure inside the leaf, thereby, increasing the transpiration rate, assuming that outside vapor pressure remains constant. The growth of different parts of the plant is dependent on the temperature. It is clear that root growth differs from stem growth with variation in the temperature. Thus, there is a particular temperature (or a range of temperature) at which optimum plant growth occurs under a particular type of climatic condition. These temperatures are referred to as optimum temperatures for plant growth (Sharam and Salokhe, 2006). Other factors, which affect greenhouse environment, include solar radiation, air exchange, wind speed, carbon dioxide concentration, humidity and relative humidity (Mohammed, 2015). Ventilation is the main climatic control method of greenhouses.

Natural ventilation is the system generally used to control the internal environment of the greenhouse. It needs less energy, less equipment operation and maintenance and it is much cheaper than other systems of controlling greenhouses air temperature. Cooling is the most effective for lowering air temperature in dry climates and can be used even in humid climates during the hottest part of the day when relative humidity may be significantly below saturation. Evaporative cooling systems are preferred over mechanical refrigeration systems, because they are much less expensive. As well as they have the beneficial effect of raising the humidity, this reduces plant wilting (James, 1979). Fan and pad system proved to be an economical to build and operate. The building must be relatively air tight to force all incoming air to flow through pad.

Fan and pad cooling systems provide good air distribution when properly designed (Osama, 2000). Computer models of greenhouse environments and crop responses have been successful in explaining major features of crop performance and defining better-protected crop environments. There has recently been an increasing argument that models can be of direct use for environmental control (Day, 2002). High productivity and product quality of modern greenhouse can be accomplished only through optimum control of the greenhouse environment and the nutrients fed to the plants. It is not surprising therefore, that considerable attention is being

focused on the difficult problem of greenhouse environment control, an area that has become the object of intense research activity (Goggos, 2000). In a greenhouse, the air temperature can control the rate of development of plants/crops such as the leaf-unfolding rate, flower development, auxiliary bud development, and flower-forcing time. Air temperature may also be used to control the shape or morphology of the plant (Theo, 2002). To measure this factor a lot of equipment and labor are required. Computer simulation of such a parameter could be one of the solutions to monitor the environmental factors inside the greenhouse. Therefore, the objectives of the present study are:

1. To apply a developed mathematical heat transfer model to simulate temperatures in a greenhouse;
2. To test the validity of the developed model by comparing the measured temperatures data with the predicted ones.

## II. MATERIALS AND METHODS

### 2.1. Experiment

The experimental work was concerned with collecting data of dry-bulb temperatures inside and outside the greenhouse in the morning (08:00 am) and the afternoon (13:00 pm). These temperature data were used for testing the validity of a developed conductive heat transfer model. The experiment was conducted in a greenhouse at palm Technology company, Agricultural Research Corporation, Shambat- Khartoum- North, Sudan. The experiment site has a Latitude 15 40N and Longitude 32 32 E.

### 2.2. Materials and Equipment

#### (i) Dry Bulb Thermometer:

For measuring dry bulb temperature.

#### (ii) Personal Computer (PC):

A personal computer with specifications of processor, of 2.2 GHz and a RAM of 2.00 GB, was used for running the computer programme, which simulates the temperatures in the greenhouse.

#### (iii) Greenhouse:

A greenhouse of a Quonset type with dimensions of 39m\* 8.5m\*2.5m was used for conducting the experimental work. The greenhouse was made from galvanized pipe with aluminum extrusion. The cover was made from plastic film and the house was cooled by evaporative cooling system (Fan and Pad type). The wetted pad was fixed along the western side of the greenhouse, while the exhaust fans were installed along the eastern side (see Figure11.1).

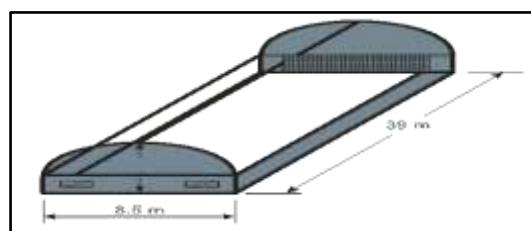


Fig. 1. Schematic diagram of the experimental greenhouse.

### 2.3. Methodology

The experimental work done in this research was intended to measure dry bulb temperatures inside and outside the greenhouse to verify and simulate a developed conductive heat transfer model. The greenhouse was subdivided into four sections. In each section inside air, temperatures were recorded in three equidistant locations along the width of the greenhouse. This indicates that, the temperatures were recorded in three locations within each section. The average of temperatures was calculated for each section and so for the whole house. Therefore, this means that, the dry bulb temperatures in the greenhouse (See Figure.2).

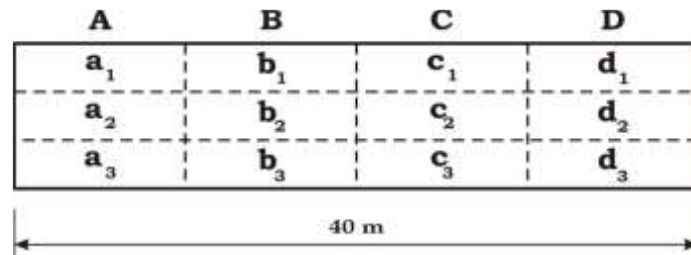


Fig. 2. Positions of Temperatures Measurements in the Experimental Greenhouse.

### Modelling Heat Transfer in the Greenhouse

#### Model Development

The developed mathematical heat transfer model was based on the following assumptions.

#### Assumptions

- (i) Heat transfer is due to conduction only (no convection and no radiation).
- (ii) Heat will transfer from outside into the greenhouse through sidewalls and the roof of the greenhouse only.

#### Model Equations Derivation

The following equations were derived for model development.

Firstly, the surface area of the greenhouse through which heat energy will be transferred as mentioned in assumption (ii) was calculated by the following equation.

$$A = (2\pi HL + 2\pi H^2) \quad (1)$$

Where:

A = The area of the greenhouse, m<sup>2</sup>

H = The height of the house, m

$\pi$  = Constant = 3.142

L = Length of the house, m

Equation 3.1 can be rewritten in the following simplified form as follows:

$$A = \pi H(L + H) \quad (2)$$

The overall heat transfer equation by conduction as stated in assumption (i) has the following form:

$$q = \frac{T_o - T_i}{R_T} \quad (3)$$

Where:

$Q$  = The rate of heat transfer through the greenhouse, W.

$T_o$  = The outside air temperature °C.

$T_i$  = The inside air temperature, °C.

$R_T$  = Total thermal resistance of the greenhouse wall, °C/W.

The total thermal resistance ( $R_T$ ) for the problem in consideration is given by:

$$R_T = R_1 + R_2 + R_3 \quad (4)$$

Where:

$R_1$  = Thermal resistance of the outside air film ( $R_1 = \frac{1}{h_o \times A}$ ), °C/W.

$R_2$  = Thermal resistance of wall material ( $R_2 = \frac{x}{k \times A}$ ), °C/W .

$R_3$  = Thermal resistance of the inside air film ( $R_3 = \frac{1}{h_i \times A}$ ), °C/W.

Values of  $h_o$  (coefficient of convection of outside air) and  $h_i$  (coefficient of convection of inside air) were obtained from literature as follows 33.3333 W/m<sup>2</sup>°C and 8.3333 W/m<sup>2</sup>°C respectively. The value of the thermal conductivity ( $k$ ) of the plastic film was obtained, and found to be 0.048 W/m°C, according to James (1983). Manipulating equation [3.3] and putting  $T_i$  as a formula the equation can be written as:

$$T_i = T_o - (\bar{q} \times R_T) \quad (5)$$

Where:

$\bar{q}$  = average of the rate of heat transfer through the greenhouse, W/day.

### *Simulation of Heat Transfer*

A computer program was processed using Excel 2007 software package and then it was run on a PC to simulate temperatures in the greenhouse for a period of 42 days (March 15<sup>th</sup> to April 25<sup>th</sup> 2014) at 08:00 am (morning) and 13:00 pm (afternoon) daily.

### *Statistical Analysis*

Microcal Origin V.7 package was used in statistical analysis of obtained results, in order to verify the developed heat transfer model. This analysis was carried out, firstly by calculating average model error (A.M.E.) average absolute difference (A.A.D.) and standard error of estimates (S.S.E.) and secondly by executing independent t-test as another means of analysis.

## **III. RESULTS AND DISCUSSION**

The results of measured and predicted temperatures are presented in the following sections in addition to the statistical analysis of the obtained results in order to validate the developed heat transfer model.

### Graphical Presentation of Measured and Predicted Temperatures

Figures (3, 4 to 5) were drawn from the tabulated data shown in Mohammed (2015). They show the comparison between measured and predicted temperatures in (a) morning and (b) afternoon periods. Generally, it is clear that, from these figures there is a close agreement between measured and predicted temperature in both morning and afternoon periods. These graphs reveal that; the model is successful in simulating temperatures in the greenhouse. However, the apparent discrepancy between the measured and predicted temperatures may be due to the following sources of errors:

1. There might be an effect of other means of heat transfer such as convection and radiation, which were not incorporated in the model assumptions.
2. The thermal conductivity of greenhouse covering material ( $k$ ) and values of outside and inside coefficients of convection heat transfer ( $h_o$  and  $h_i$ ) were taken from textbooks and they were not real experimental data.

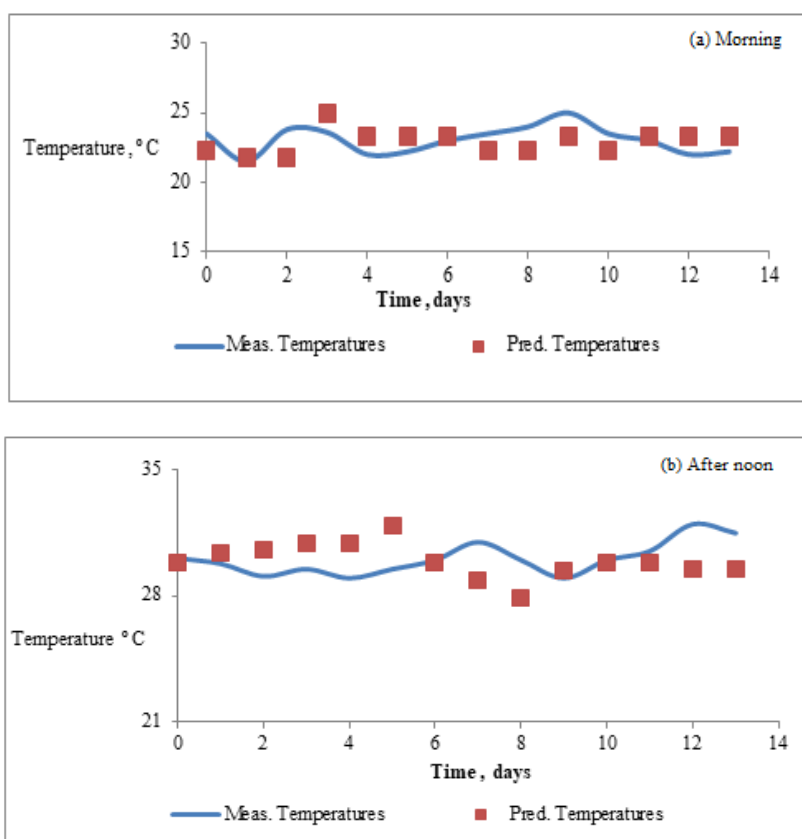
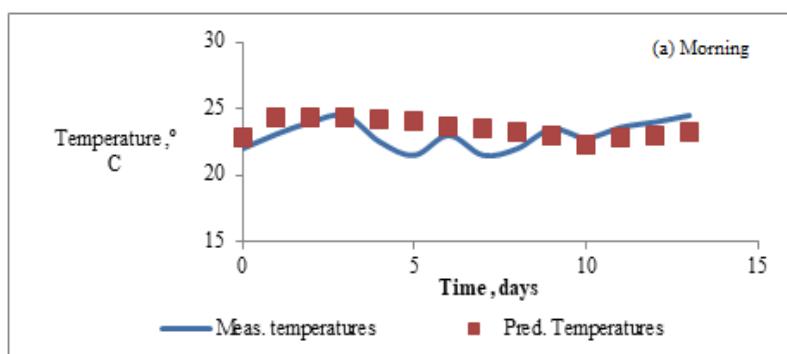


Fig. 3. Measured and predicted temperatures in the greenhouse for the first and second weeks.



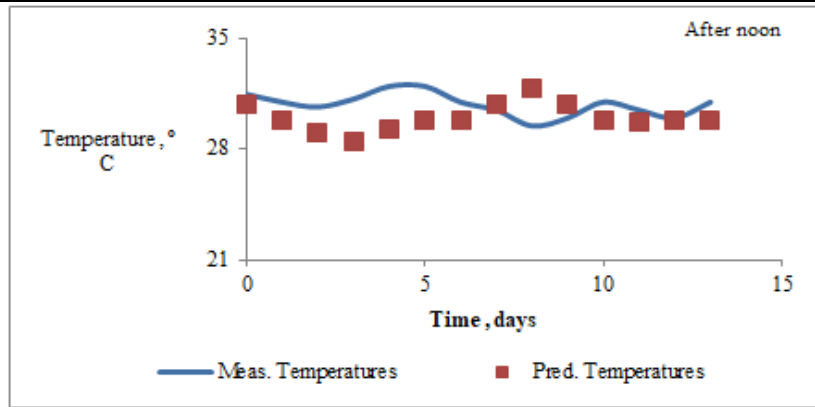


Fig. 5. Measured and predicted temperatures in the Greenhouse for the fifth and sixth weeks.

### Statistical Analysis of the Heat Transfer Model Validation

The parameters used in the statistical validation of the developed model include the followings:

$$1\text{- Average model error (A.M.E.)} = \frac{\sum(\text{measured}-\text{predicted})}{n} \quad (6)$$

$$2\text{- Average absolute difference (A.A.D.)} = \frac{\sum \text{abs}(\text{measured}-\text{predicted})}{n} \quad (7)$$

$$3\text{- Standard error of estimate (root mean square of the error) (S.S.E.)} = \sqrt{\frac{\sum_{i=1}^n (\text{measured}-\text{predicted})^2}{n}} \quad (8)$$

Where:

Measured = measured temperatures.

Predicted = predicted temperatures.

n = number of observations.

The above-mentioned parameters were calculated using Microsoft Office Excel Software (Ver. 2007). Abbouda (1984) stated that, an accurate model should have an (A.M.E.) and (A.A.D.) close to zero and small (S.S.E.). Table (11.1) presents the parameters of equations 6, 7 and 8. The (A.M.E.), the (A.A.D.) and (S.S.E.) for morning period are -0.0309, 1.0167 and 1.244 respectively. While for the afternoon period they are -0.0386, 1.157, and 1.398 respectively.

Table 1. The (A.M.E.), the (A.A.D.) and (S.S.E.) between measured and predicted temperatures at the two times.

Time Periods	Average Model Error	The Average Absolute Difference	The Standard Error of Estimate
Morning	-0.0309	1.0167	1.244
Afternoon	0.0386	1.157	1.398

This indicates that, the developed heat transfer model simulated the temperatures in the greenhouse almost successfully and within the experimental error limits. Table (11.2) shows the sample independent t-test. It is clear from this table that, the null hypothesis ( $H_0: \mu_1 = \mu_2$ ) holds true i.e.  $|t_o| < t_1$  at the two periods. Based on the sampling in each of the two methods of temperature determination there is insufficient evidence to reject the null hypothesis. Again, this confirms that, the developed heat transfer model is excellent in simulation of air

temperatures in the greenhouse. These results coincide with Mohammed Kheir (2005) findings. It is generally approved by the graphical presentation and the statistical validation of the present study that; the developed model and its parameters are successfully applicable in simulating dry air temperatures in greenhouses under similar environmental conditions.

Table 2. Two sample independent t-test in the sample means of measured and predicted temperatures for morning and afternoon periods.

Time periods	95% CI For $\mu_1 = \mu_2$	$\mu_1 = \mu_2$ vs. $\mu_1 \neq \mu_2$			
		$t_0$	$t_1$	P	Df
Morning	-34,079	0.79	1.990	0.43	82
Afternoon	-038,038	Zero	1.990	1.00	82

Note:

$\mu_1$  = population mean of the measured temperatures, °C.

$\mu_2$  = population mean of the predicted temperatures, °C.

$t_0$  = calculated value of the test statistic.

$t_1$  = tabulated value of the upper  $\alpha/2$  percentage point of the t-distribution.

df = degrees of freedom.

P = probability or % risk of being wrong if the null hypothesis ( $H_0$ ) is rejected.

#### IV. CONCLUSION AND RECOMMENDATIONS

This study concluded that **the** predicted temperatures were close to those measured ones during the experimental course and the developed heat transfer model simulated temperatures in the greenhouse satisfactorily and within the experimental error limit. The standard error of estimate between measured and predicted temperatures was 1.244-1.398 (temperature range 23-41°C), it was also concluded that the developed heat transfer model could be used to predict temperatures in the greenhouses satisfactorily. This study has come out with several recommendations. These recommendations are as following:

- i. A mathematical model, which incorporates convection and radiation, should be developed to see if there is an improvement in the temperature prediction inside greenhouse;
- ii. Other environmental factors such as air relative humidity and ventilation rate could also be modeled;

Further studies concerning the importance and share of greenhouses in food security programs must be investigated.

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