Development and Evaluation of a New Greenhouse Energy Model with Data from Four Ontario Greenhouses

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OBJECTIVES

In this study, a lumped capacitance thermal model is developed to simulate greenhouse interior conditions based on exterior weather and operating settings. Heat and moisture transport equations were applied to each layer of the model, with the corresponding change in temperature or absolute humidity calculated at each time step. The measured interior temperature and relative humidity data were used to evaluate the accuracy of the model simulations, while other measured data, such as wind speed and solar radiation, were used as model inputs. The studied greenhouses included two operational greenhouses and two smaller, passive greenhouses in southern Ontario. Once validated, the model can be used to evaluate potential energy saving scenarios for growers. This could include adjusting the schedule for supplementary heating or lighting. It can also be used to predict the impact of installing additional technology on energy usage, such as phase change materials (PCMs).

MATERIALS & METHODS

A generalized model was developed that could accommodate all four greenhouses by changing the inputs based on site conditions (such as presence of curtains, ventilation). The model steps forward in time and finds the change in temperature and moisture concentration of each layer at each time step. A combination of conductive, convective and radiative heat transfer was accounted for, as well as latent energy from water phase changes (crop transpiration, evaporation from soil). Greenhouse 4 is shown below in Fig. 1, and had data from three bays in the spring, summer and fall.

Figure 1: Greenhouse 4

Figure 2: Greenhouse 3

Figure 3: Greenhouse 2

Figure 4: Greenhouse 1

MATERIALS & METHODS (CONT'D)

Table 1: Description of four greenhouses used in the study

Greenhouse	Surface area (m^2)	Crop	Roof	Ventilation	Curtains	Dehumidification	Cooling Pad	Temperature Range (° C)
1	2815	Tomato	Glass (single)	Roof vents	Blackout	No	No	19-28
2	12	None	PE (single)	None	None	No	No	0-25
3 (Fig. 6)	133	None	PE (single)	None	None	No	No	-10-30
4 (Fig. 5)	1684	Potted flowers	PE (double)	Exhaust fans	Energy curtains	Yes	Yes	20-28

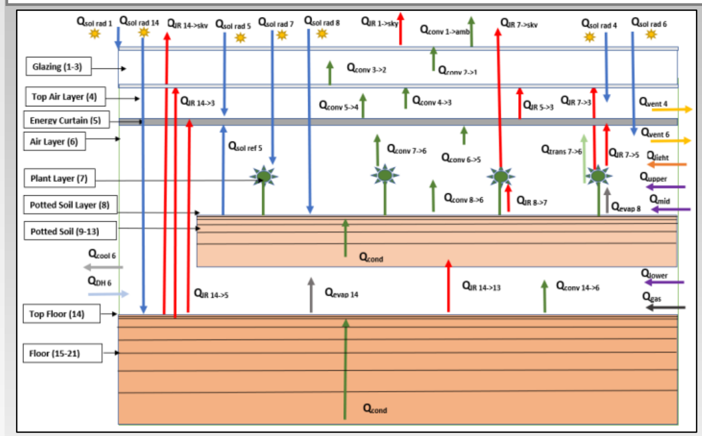

Figure 5: Schematic diagram of Greenhouse 4 model

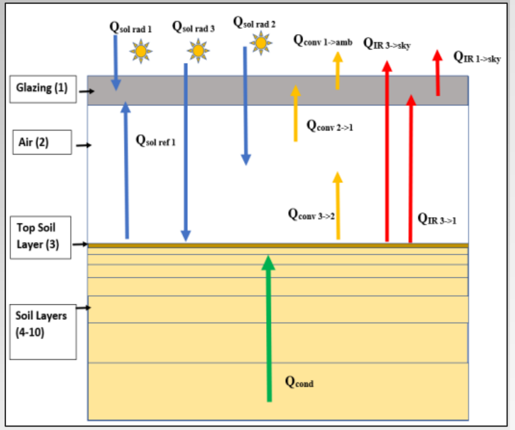

Figure 6: Schematic diagram of Greenhouse 3 model

RESULTS

The root mean squared errors (RMSE) and mean absolute errors (MAE) between measured and simulated temperatures and relative humidities are presented below for each greenhouse. Greenhouse number 4 had data sets in the spring (x2), summer (x1) and fall (x1) for three greenhouse bays. Only one set of results are shown in the table below, but all had temperature errors below 2 ° C and RH errors below 10%.

Table 2: Overall model error predicting measured data for each test greenhouse

Greenhouse	Dates of experimental measurements	RMSE Air Temperature (° C)	MAE Air Temperature (° C)	RMSE Plant/Soil Temperature (° C)	MAE Plant/Soil Temperature (° C)	RMSE RH (%)	MAE RH (%)
1	April 15-21, 2019	1.92	1.53	Not measured	Not measured	7.23	5.84
2	Nov 24-29, 2020	1.98	1.49	0.89 (soil)	0.70 (soil)	6.67	4.75
3	March 5-10, 2014	2.99	2.43	3.02 (soil)	2.48 (soil)	N/A	N/A
4 (S4 spring) 4 (S3 fall)	March 19-26, 2019 Oct 25-Nov 7, 2019	1.17 0.98	0.90 0.79	1.43 (plant) Not measured	1.15 (plant) Not measured	7.13 5.68	5.46 4.52

RESULTS (CONT'D)

For example, Figs 7 and 8 below show the model results for air temperature and absolute humidity for Greenhouse 4 (spring S4)

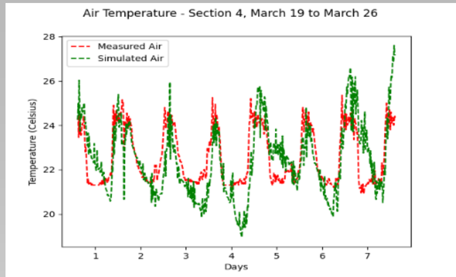

Figure 7: Air temperature in Greenhouse 4 (spring)

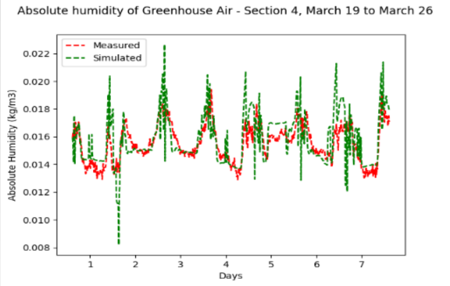

Figure 8: Absolute humidity in Greenhouse 4 (spring)

CONCLUSIONS

The generalized model was able to successfully simulate the microclimate of four greenhouses that varied widely in complexity. Moving forward, the model will be used to evaluate the impact of changing the existing operating settings of the greenhouse on overall energy use, as well as estimating the impact of installing additional technology, such as phase change materials and earth-air heat exchangers.

ACKNOWLEDGEMENTS & CONTACT

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