Investigation of Potential Energy-saving Strategies in Ontario Greenhouses Using a New Greenhouse Simulation Model

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OBJECTIVES

In this study, a greenhouse energy model developed by the research team was used to estimate energy-saving strategies for growers. The model has been extensively validated in each climatic season at seven unique greenhouse sites in Ontario. It can predict indoor air temperature and relative humidity based on site conditions and weather data. Expected energy savings from using three dehumidification technologies (mechanical refrigeration; MRD, liquid desiccant; LDD, and heat-recovery ventilation; HRV) were assessed against a baseline test case (dehumidification by heating-venting) in fall, winter and spring in the southern Ontario context. The expected energy-savings from switching to LEDs from HPS lighting was also examined. Both electrical and heating (natural gas) energy required for crop production was quantified for these studies. Possible cost ($CAD) savings were also calculated using different rates for electricity and natural gas. The findings indicate that financial savings are highly dependent on rates paid by growers. The results from this study represent a practical application of the greenhouse energy model. Model results may vary for sites with different weather or site properties, such as crop type.

MATERIALS & METHODS

The greenhouse energy model used for these studies has been described in detail in previous work (Nauta et al., 2022). Typical meteorological year (TMY) data from Vineland, ON was used to provide weather data for the case studies presented below. A test greenhouse with three separate bays was used, with site properties summarized in Table 1. A schematic of one of the greenhouse bays (Section A) can be seen below in Figure 1. The moisture removal rates and power consumption of the three dehumidification units can be seen in Table 2. For each dehumidification unit, the power consumption was assumed constant based on analysis of available data, while the moisture removal rate was assumed constant for the MRD and LDD units. Specifications for two LED lighting fixtures that were used in the simulation study can be seen in Table 3, along with the current HPS lights used at the site.

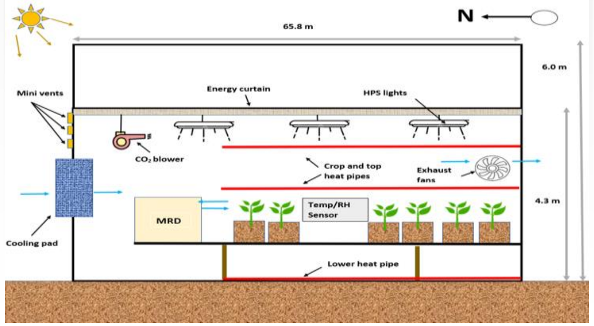

Figure 1: Schematic diagram of Section A

MATERIALS & METHODS (CONT'D)

Table 1: Description of greenhouse bays used in the study

	Section A	Section B	Section C
Area (m^2)	1684	1684	2527
Gutter height (m)	4.3	4.3	4.3
Crop type	Potted rose	Potted rose	Potted rose
Roof material	Double layer PE	Double layer PE	Double layer PE
Dehumidification type	MRD	LDD	HRV

Table 2: Specifications of dehumidification units used in study (n = number of data points used in analysis)

Unit	n	Unit Power (kW)	Error (+/-)	Moisture Removal Rate ($kg \cdot hr^{-1}$)	Error (+/-)
MRD	1934	10.00	1.64	35.80	6.32
LDD	614	2.40 (electrical) 18.9 (hot water)	0.28 3.20	12.96	1.80
HRV	673	0.780	0.036	N/A	N/A

Table 3: Specifications of lighting units used in study

	Efficacy ($\mu mol\ PAR \cdot J^{-1}$)	Photosynthetic photon flux ($\mu mol\ PAR \cdot s^{-1}$)	Electrical input (W)	Number of fixtures required
LED #1	4.06	2436	600	47
LED #2	2.80	1745	626	66
HPS (Existing)	1.60	950	600	120

RESULTS

Results for MRD case studies in fall and spring can be seen below in Table 4, while the LED/HPS results for winter and summer can be seen in Table 5. A range of cost savings are expressed based on two electrical rates ($0.127/kWh and $0.055/kWh) and three natural gas rates ($4.80/GJ, $10.00/GJ and $14.00/GJ). Running the MRD saves heating energy, but increases electrical energy compared to the baseline test case. If electrical rates are high, and natural gas rates are low, negative cost savings may occur, even if cumulative energy savings are found. However, with expensive natural gas and cheaper electricity, the cost savings in fall could be as high as $2.28/m².

Table 4: Expected energy loads for MRD versus control (heating-venting)

Season	MRD Status	Electrical energy consumption (kWh/m^2)	Natural gas energy consumption (kWh/m^2)	$kg\ CO_2\ e/m^2$	Energy saved with MRD (kWh/m^2)	Range of Savings (CAD/m^2)
FALL	ON	80.3	75.4	17.9	46.7 (23.1 %)	-0.49 to 2.28
	OFF	68.5	134	27.9		
SPRING	ON	56.5	38.2	9.91	29.5 (23.8 %)	-0.60 to 1.42
	OFF	46.4	77.8	16.5		

Table 5: Expected energy loads for HPS versus LED assimilation lighting

Season	Light Type	Electrical Energy (kWh/m^2)	Natural gas energy (kWh/m^2)	$kg\ CO_2\ e/m^2$	Energy saved compared to baseline HPS (kWh/m^2)	Range of Savings (CAD/m^2)
WINTER	HPS (Current)	64.4	163	32.9	N/A	N/A
	LED #1	25.7	211	39.6	-9.44	-0.28 to 4.07
	LED #2	36.8	200	38.1	-9.07	-0.32 to 2.87
SUMMER	HPS (Current)	44.9	14.9	5.07	N/A	N/A
	LED #1	20.5	19.0	4.52	20.3	1.14 to 3.03
	LED #2	27.5	18.2	4.75	14.1	0.79 to 2.15

RESULTS (CONT'D)

The simulated controller used to dictate heating, lighting, ventilation and dehumidification schedules was validated against experimental data from the site for each dehumidification unit. Percent differences between predicted and measured heating (kWh) and electrical (kWh) energy was less than 7 % for all cases, while mean absolute error (MAE) between measured and simulated air temperatures and RH was less than 1 ° C and 4 %, respectively.

It was found that the MRD, LDD and HRV units could save energy in spring, fall and winter compared to the baseline case. However, financial savings were highly dependent on rates paid by growers for electricity and natural gas. Some important findings include,

- LDD unit could save 17.5 % of total energy requirements in fall, and was more insulated against fluctuating rates due to the unit consuming both electrical and natural gas (regenerative) energy
- HRV saved the least amount of energy of the three units (< 4%), but required the lowest amount of electricity to operate. Effectiveness of the unit was highly dependent on outside weather conditions
- MRD could save the highest amount of heating energy of three units considered, but consumed the most electricity. Benefits of MRD and LDD units include condensing water vapor directly inside greenhouse, contributing latent and sensible heat

Switching from HPS to LED lighting was found to increase the heating load and decrease the electrical load in all seasons, while delivering the same PAR flux.

- Financial savings were guaranteed in every season except winter by switching to LEDs, with seasonal savings as high as $4.07/m² if cheap natural gas and expensive electricity was assumed. Due to the low DLI requirement of rose crops, these savings could be higher with more light-intensive crops, such as tomatoes.

CONCLUSIONS

It was found that all three dehumidification units could save heating energy in spring, fall and winter at greenhouses in southern Ontario, while switching from HPS to LED lights could significantly reduce electrical energy required for crop production. However, for each technology, the rates being paid by growers for electricity and natural gas have a large impact on the feasibility of installing these units.

ACKNOWLEDGEMENTS & REFERENCES

Nauta, A., Lubitz, W., Tasnim, S., & Han, J. (2022). Methodology and Validation of a New Climate Prediction Model for Commercial and Small-scale Greenhouses. *Proceedings of 2022 Responsible Engineering and Living Symposium.* Windsor, Ontario, Canada.

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