Cooling Capacity Assessment of Semi-closed Greenhouses

Wee Fong Lee, Peter P. Ling, Harold M. Keener
Department of Food, Agricultural and Biological Engineering

Abstract

Leading Dutch researchers have reported significant benefits of closed greenhouse systems. Ooteghem (2007) predicted reduced heating fuel consumption and increased crop yield. Opdam et al. (2005) found 19% primary energy use saving, 22% tomatoes production increase, 80% chemical reduction, and 50% irrigation water saving can be achieved in a closed greenhouse. This research proposes to develop a design analysis tool to determine cooling/dehumidification needs, and proper cooling capacity needed to minimize greenhouse ventilation economically for northern climate. A preliminary analysis shows it is expensive to keep greenhouses in Ohio closed year round. Further analysis suggests better return maybe achieved with semi-closed greenhouse designs instead of fully closed operation. For example, a 50% peak load design can meet cooling needs 90% of the time yearly. The proposed tool can be used to specify internal cooling capacity requirements for desired greenhouse closure level.

Introduction

A closed greenhouse is a greenhouse that has no venting operation or air exchange with outside air. When closed greenhouse is discussed, most of the researchers looked at the effect of energy saving efficiency and cost reduction efficiency on a year-round operation basis. Therefore, energy saving and cost reduction became not very efficient as a consequence of high cooling requirement for summer operation. Although Dutch researchers have carried out the closed greenhouse operation for a whole year with success, the reason was apprehended to be the mild weather and availability of aquifers. Thus, it could be a challenge for northern climate regions, such as Ohio to economically achieve year-round closure, for the reason of extreme weather and lack of accessibility of aquifers. Despite of high cooling energy requirement for summer closed greenhouse operation and for economic-wise decision, a completely closed greenhouse might be too costly if sizing a full capacity cooling system is required. Therefore, a concept of semi-closed greenhouse is commenced. The percentage of time a greenhouse requires no ventilation is an indicator of greenhouse closure. A completely closed greenhouse has a 100% closure rate, and a semi-closed greenhouse's closure percentage is less than that. The goal of this project is to evaluate if the closed greenhouse concept is feasible for greenhouse operations in Ohio and other northern climate regions.

Objectives:

1. Determine cooling/humidity capacity needed to keep the greenhouse closed using practical models
2. Determine recoverable exhaust heat from cooling for heating
3. Design an efficient cooling/dehumidification system for desired greenhouse closure

Rationale:

One of the reasons this project is started is due to the ***benefits of closed greenhouse*** listed below:

• Enrich CO_2	- Increase crop yield - Reduce CO_2 loss
• Optimal climate control	- Improve crop quality
• Conserve heat/prevent heat loss	- Reduce fuel consumption
• Recycle/Store heat	- Reduce fuel consumption
• Prevent harmful insects	- Reduce pesticide use
• Conserve/Recycle water	- Reduce water use - Reduce disease problem in water - Reduce nutrient contamination

Besides, to adopt the closed greenhouse concept for Ohio and US northern climate region applications, some parameters must be considered, such as Ohio has larger temperature variation, US greenhouse operations are mostly mid- or small-sized, and feasibility of underground aquifer storage.

A major deliverable of this project is a greenhouse closure efficiency decision support system targeted for common commercial growers. This system will allow growers to predict their greenhouse closure efficiency using their operation specific parameters, such as greenhouse structure, climate data, plant type and etc.

Conclusions and Discussion

Since Ohio has larger climate variation than Netherlands has, it would be more challenging for Ohio to adopt closed greenhouse concept developed by Dutch researchers, especially in cost-effectively sizing equipments for greenhouse climate control. However, it was found beneficial for Wooster, Ohio conditions. Significant savings were obtained from less CO_2 loss through the elimination of ventilation requirement and the potential of recovering exhaust heat from cooling operations for heating. Proper sizing of cooling equipment and heat storage capacity is important to determine the feasibility of semi-closed greenhouse in Ohio and other northern regions. Our analysis shows that it is more feasible to use a lower cooling load compared to a higher or peak load, given that the lower cooling load provides a significant coverage of the cooling requirement. The higher cooling load gives an insignificant marginal increase in coverage of cooling requirement. Considering the additional investment needed to maintain a closed greenhouse, it is economically wiser to partially close a greenhouse. Therefore, it is important to develop a decision support tool for growers in Ohio and northern climate regions to determine their greenhouse closure efficiency economically.

References

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Materials and Methods

- ***Determine cooling/humidity capacity needed to keep the greenhouse closed using practical models***
  As for cooling capacity prediction, straight forward heat transfer equations, including infiltration and conduction heat loss are used. As for humidity capacity calculation, HORTITRANS (Jolliet, 1994), a model of water mass balance, including transpiration, condensation and infiltration inside a greenhouse is used. Greenhouse structure and crop property calculation is adopted from Aldrich and Bartok (1989). Cooling and dehumidification needs for closed greenhouse are therefore compared with conventional ventilation greenhouse. Subsequently, $C0_2$ saving from closed greenhouse is calculated.
- ***Determine recoverable exhaust heat from cooling for heating***
  Excess heat contributed by cooling operation and heating requirement are calculated based on heat contribution from solar radiation and heat loss due to infiltration and conduction. Thereafter, recoverable exhaust heat from cooling is determined from several designed thermal storage capacities.
- ***Design an efficient cooling/dehumidification system for desired greenhouse closure***
  A fan and perforated poly-tube system is installed in the greenhouse for air distribution. A heat exchanger is installed between fan and air distribution system. Despite of energy source, a design of two water tanks to operate as energy storage device is evolved. This system can provide not only the cooling needs, but also the dehumidification and heating needs. Heat exchanger is to provide space cooling or heating to the greenhouse. Chiller is to maintain the temperature in cold and warm water tank. Two water tanks are to serve as storage of cold and warm sources separately.

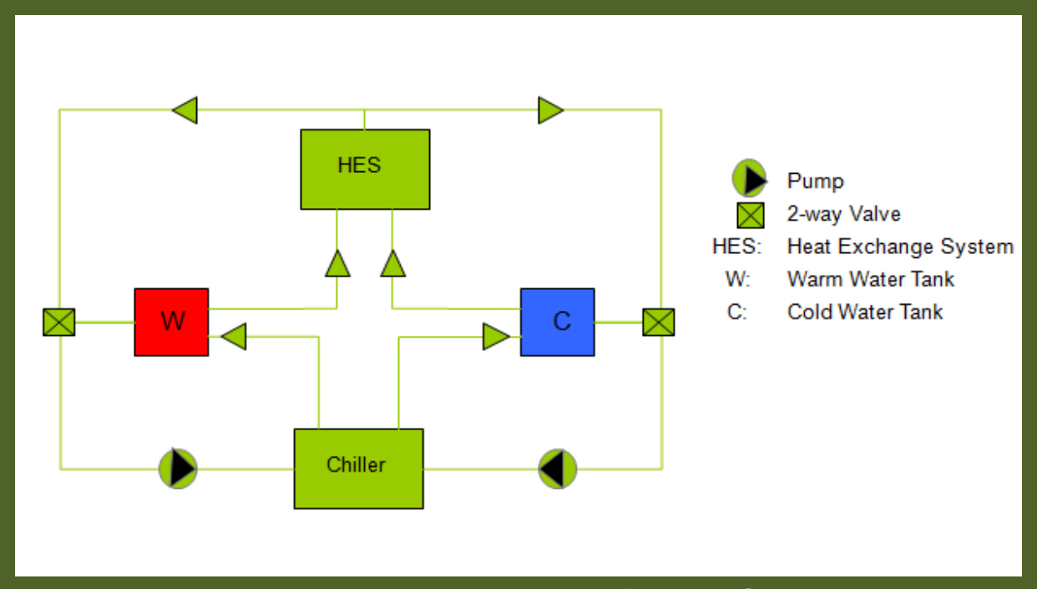

Figure 1: An Example of Water Loop Design of Cooling and Heating Source.

Results

Comparing Ohio and Netherlands weather data, the analysis suggests that it is important to consider local climate in evaluating greenhouse closure designs for northern climate regions, as it showed that Ohio has larger climate variation, where the maximum temperature difference is not smaller than 2 °C than that of the Netherlands. However, under Ohio condition, our analysis shows a closed greenhouse has several benefits over conventional greenhouses that use ventilation to cool and purge moisture for temperature and humidity control. For plant production under elevated CO_2 environment (800 ppm), a closed greenhouse can save around 75% to 84% of the CO_2 usage. It is also possible to manage both temperature and humidity for plant production year round using an internal cooling/dehumidification system while a conventional greenhouse would be too warm and/or too humid for about 412 and 2753 hours, respectively, for year round plant production. Furthermore, the heat recovered from cooling operations can be used for heating. Its contribution to heating needs depend on thermal storage capacity design. With 12-hr, 1-day, and year round thermal storage capacities, the recovered heat can contribute up to 8%, 12%, and 85%, respectively, of total heating needs of the year. To meet cooling requirements economically, instead of meeting cooling requirement 100% of the time with a 100% peak load design approach, a design based on 50% peak cooling load was found to be sufficient for ~90% of the year.

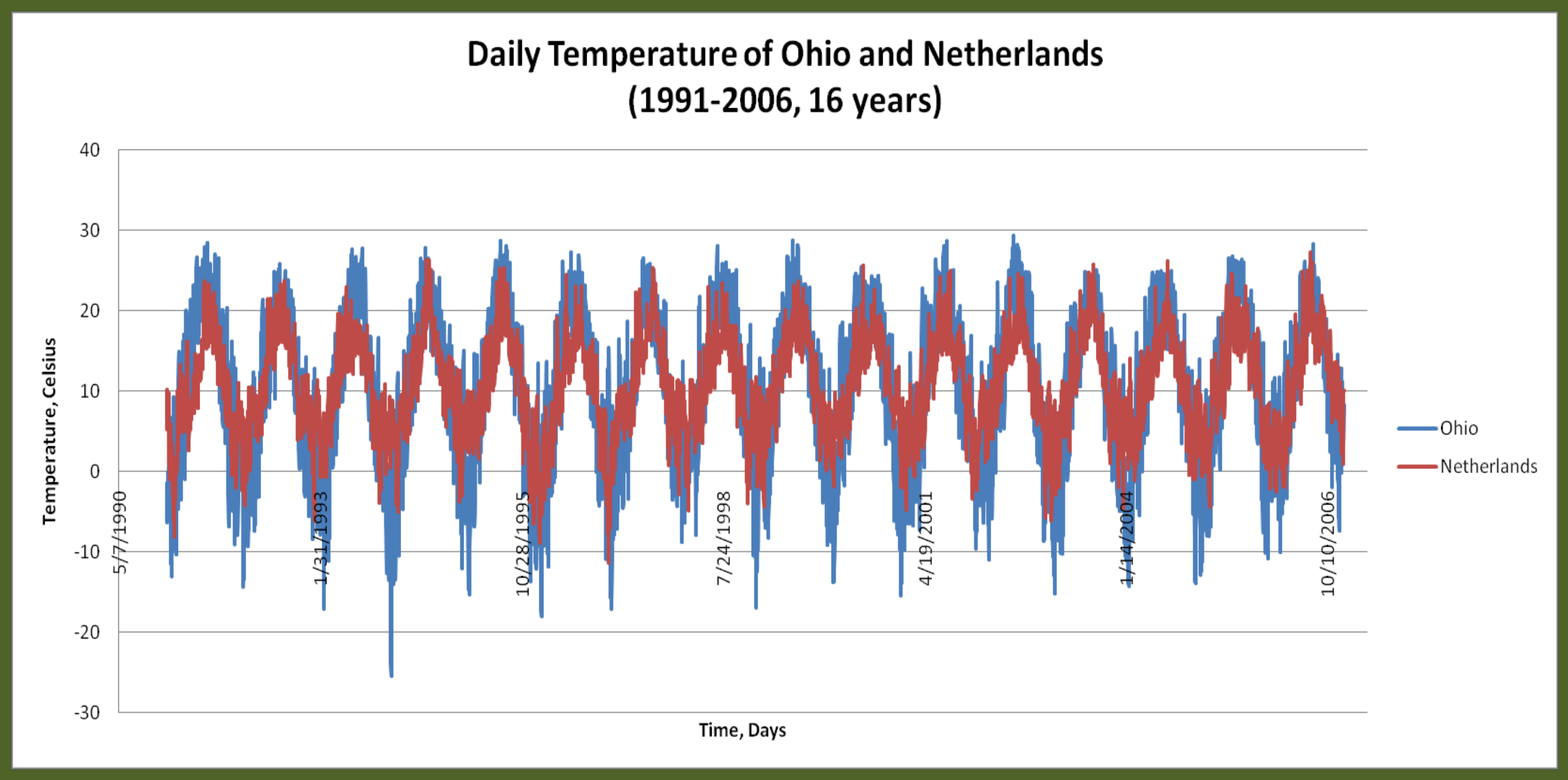

Figure 2: 16-years Temperature Comparison between Wooster, Ohio and Rotterdam, Netherlands. Maximum Daily Temperature is 29 °C and 27 °C respectively. Minimum Daily Temperature is -25 °C and -11 °C respectively.

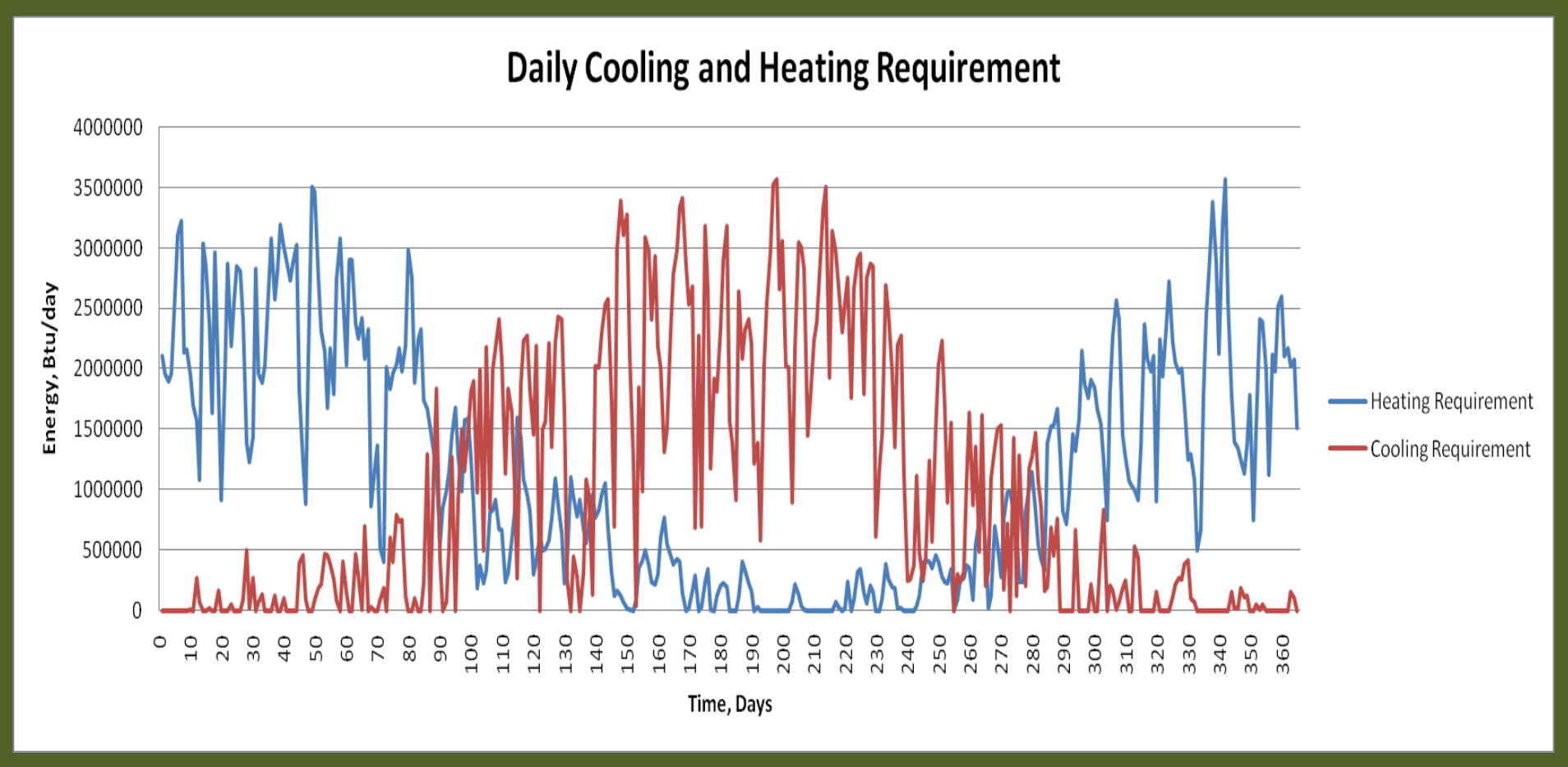

Figure 3: Daily Cooling and Heating Requirement at Wooster, Ohio in 2006. Cooling Set-point is 80 F, 85% RH. Heating Set-point is 65 F, 85% RH

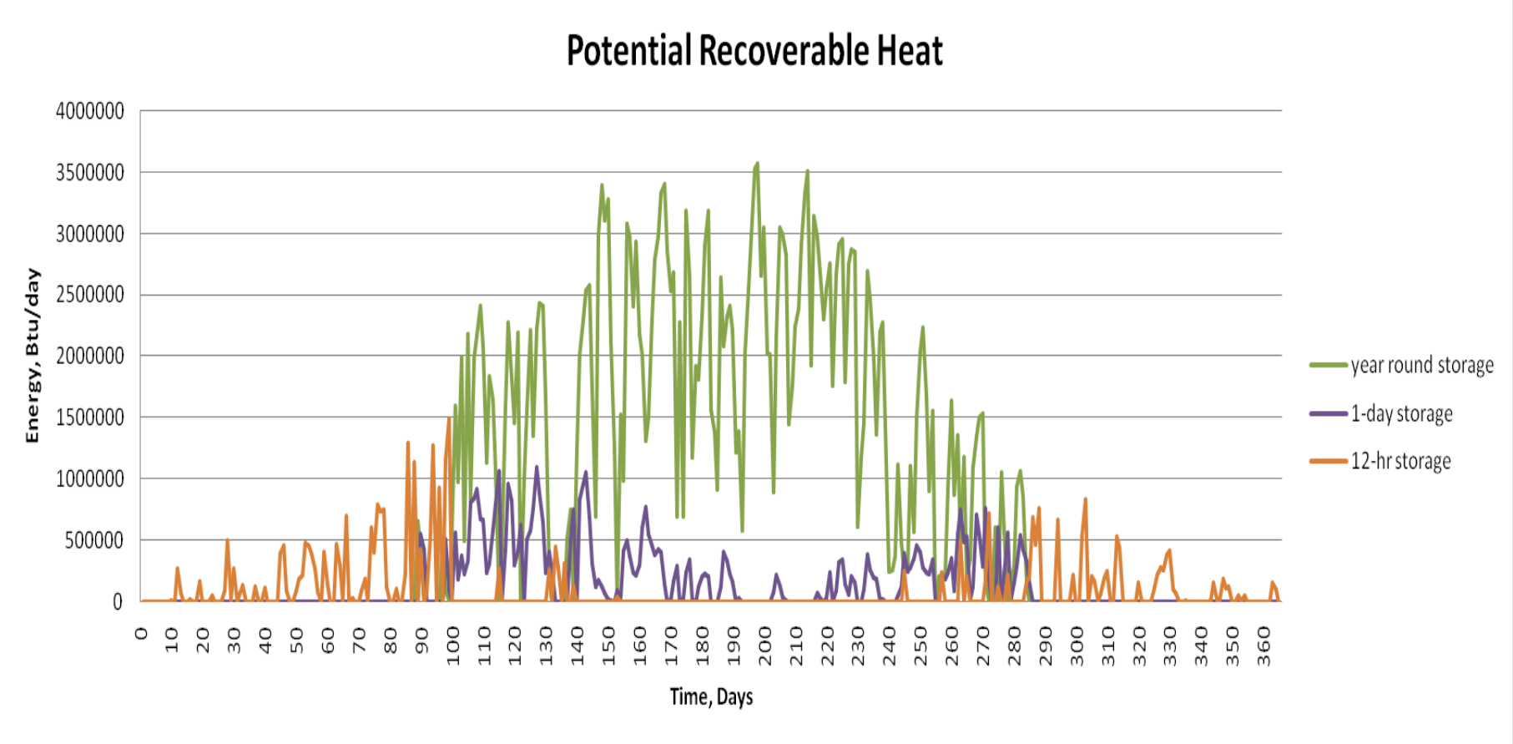

Figure 4: Potential Recoverable Heat with 12-hr, 1-day and Year Round Storage at Wooster, Ohio in 2006. Cooling Set-point is 80 F, 85% RH. Heating Set-point is 65 F, 85% RH

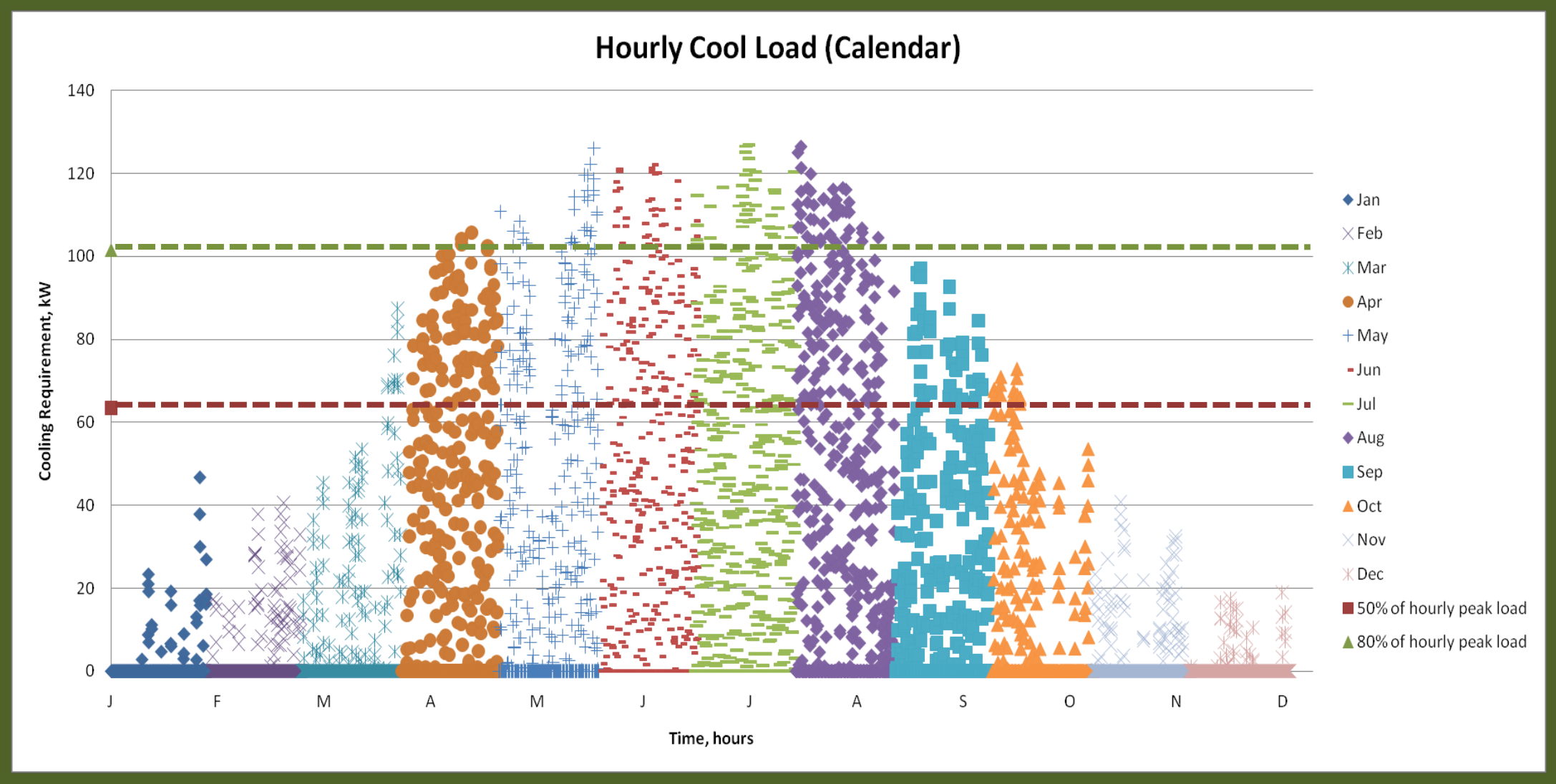

Figure 6: Hourly Cooling Load of a 96'x23'x8' Greenhouse at Wooster, Ohio in 2006. 50% hourly peak load (red line) can meet ~90% cooling requirement of the year, while 80% hourly peak load can meet ~98%

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