Best Management Practices

Managing Nighttime Greenhouse Light Emissions

The objectives of this document are to:

1. Outline the latest research in greenhouse light emissions management.
2. Recommend best management practices (BMP) for using greenhouse light abatement curtains.
3. Provide information on managing nuisance complaints should they arise.

The document is based on a multi-year project launched in 2020 to understand greenhouse light emissions and the effect of light abatement curtains on the greenhouse environment and crops. It summarizes results from multiple research projects and includes recommendations for BMP.

Key Research Findings:

- Nighttime light emissions from greenhouses depend on the intensity of the light fixtures, the level of vegetation in the greenhouse and closure of light abatement curtains.
- The effect of greenhouse light emissions on skyglow is variable depending on several factors such as location, moon elevation and cloudiness levels.
- Greenhouse light abatement curtains cause fluctuation in humidity levels and air and plant temperatures.
- Long-photoperiod, low-intensity light recipes may reduce fluctuations in the greenhouse environment under light abatement curtains.

Ministry of Agriculture, Food and Agribusiness

Ontario

Recommendations for Best Management Practices

Light abatement curtains are beneficial for reducing nighttime light emissions when supplemental lighting is used in greenhouses. They also have the added benefit of increasing energy efficiency by reducing heat loss to the outside environment. Alongside the benefits of light abatement curtains, there may be some impacts on the growing environment, such as fluctuations in temperature and humidity which can impact crop physiology. These impacts can be managed by:

BMP #1

Gapping ceiling light abatement curtains to ventilate the greenhouse and maintain ideal growing conditions. This is the most common way that producers manage the increase in temperature and humidity that is observed in some greenhouses by allowing the heat and water vapour to escape. This strategy, however, also reduces energy efficiency by allowing other elements of the growing environment to escape. Gapping light abatement curtains up to 10% may not cause significant increases in light emissions or skyglow.

BMP #2

Employing a long-photoperiod low-intensity lighting strategy to reduce fluctuations in the growing environment under light abatement curtains. By using lower intensity lighting and longer photoperiods, producers can reduce the temperature and humidity fluctuations allowing for easier management of the greenhouse environment under light abatement curtains.

BMP #3

Lighting before sunrise (2:00 a.m. to 6:00 p.m.) rather than after sunset (8:00 a.m. to midnight) to reduce the amount of time light abatement curtains are used and allow producers to manage the greenhouse environment more easily. Producers can take advantage of changes in sunrise and sunset times in autumn and winter months to reduce the amount of time that light abatement curtains are used. This also allows the producer to manage the greenhouse environment more easily, because temperatures outside the greenhouse are lower before sunrise than after sunset.

Introduction

An increase in the use of supplemental lighting in greenhouses has been accompanied by an increase in the amount of light emitted from greenhouses at night mostly during autumn and winter months. Without proper management strategies, light emitted from greenhouses during nighttime hours can potentially be disruptive to neighbours. The purpose of this BMP document is to maintain successful, optimal production system conditions while minimizing impact of nuisance light.

Why is Supplemental Lighting Necessary in Greenhouse Production?

Shorter days in the autumn and winter seasons and low light levels during cloudy days in the spring and summer seasons make the use of supplemental lighting necessary for the production of high-quality greenhouse crops year-round in Ontario. Greenhouse producers may use supplemental lighting throughout the year for a variety of reasons based on the crops they produce, such as:

1. To increase the amount of light (intensity) and/or duration of light (photoperiod) a plant receives during a day and ensure optimal growth. This can be achieved through **day length extension** by using lights before sunrise or after sunset. Lights may also be used during the day to provide increased light intensity on cloudy days or during sunrise and sunset.
2. To **control flowering in ornamental and cannabis plants**. Night interruption may be used to control flowering time in ornamental crops by providing a brief period of light during the dark/night period. Certain species of cannabis need a fixed light period to promote the transition from vegetative growth to flowering.
3. There are two common types of supplemental lighting used in greenhouse production. **High pressure sodium (HPS)** lights are the most common because they were available first, but the transition to more energy efficient **light-emitting diodes (LED)** is ongoing. LED fixtures also allow producers to use different spectra of light to optimize plant development. The lower amount of heat generated by LEDs also allows them to be placed closer to the crop, and where appropriate, within the crop canopy (inter-lighting).

Supplemental lighting is most commonly delivered from above the crop with fixtures hung from greenhouse trusses. This **overhead** supplemental lighting is typically used to extend the day length in the autumn and winter months, but it can be used year-round to increase the amount of light a crop receives. **Inter-lighting**, where lights are placed within the canopy of vine vegetable crops like tomatoes, peppers and cucumbers, can also be used year-round to improve light delivery to shaded areas of the canopy where the plant develops fruit.

What are Greenhouse Curtains and How are they Used?

Greenhouse ceiling curtains are commonly used in greenhouses to diffuse and scatter sunlight for a more even distribution of light, to reduce sunlight intensity and to control the temperature within the greenhouse. Light diffusion, energy conservation and shade are some of the primary uses for greenhouse curtains and many curtains have multiple functions. For example, some curtains retain thermal energy at night and provide cooling shade to the crop during the day.

Unlike greenhouse shade curtains, which are intended to allow a certain amount of sunlight through, light abatement curtains are designed to prevent light from passing through the curtain. This keeps light produced by supplemental lighting fixtures from escaping the greenhouse. Light abatement curtains are mainly used to reduce light emissions when supplemental lights are on during nighttime hours. Light abatement curtains are similar to blackout curtains, but where light abatement curtains are designed to keep light inside the greenhouse blackout curtains are designed to keep light from entering the greenhouse.

Ceiling light abatement curtains span the gap between the walls above the crop production area (Figure 1A). They act as a semi-permeable barrier between the lower portion of the greenhouse and the attic. Some light abatement curtains are specifically designed for sidewalls and endwalls of greenhouses. These wall light abatement curtains are placed vertically on greenhouse walls to reduce light emissions from the side of greenhouses (Figure 1B). Wall light abatement curtains are typically heavier than ceiling light abatement curtains, but their light transmission and energy saving properties are similar, depending on the model.

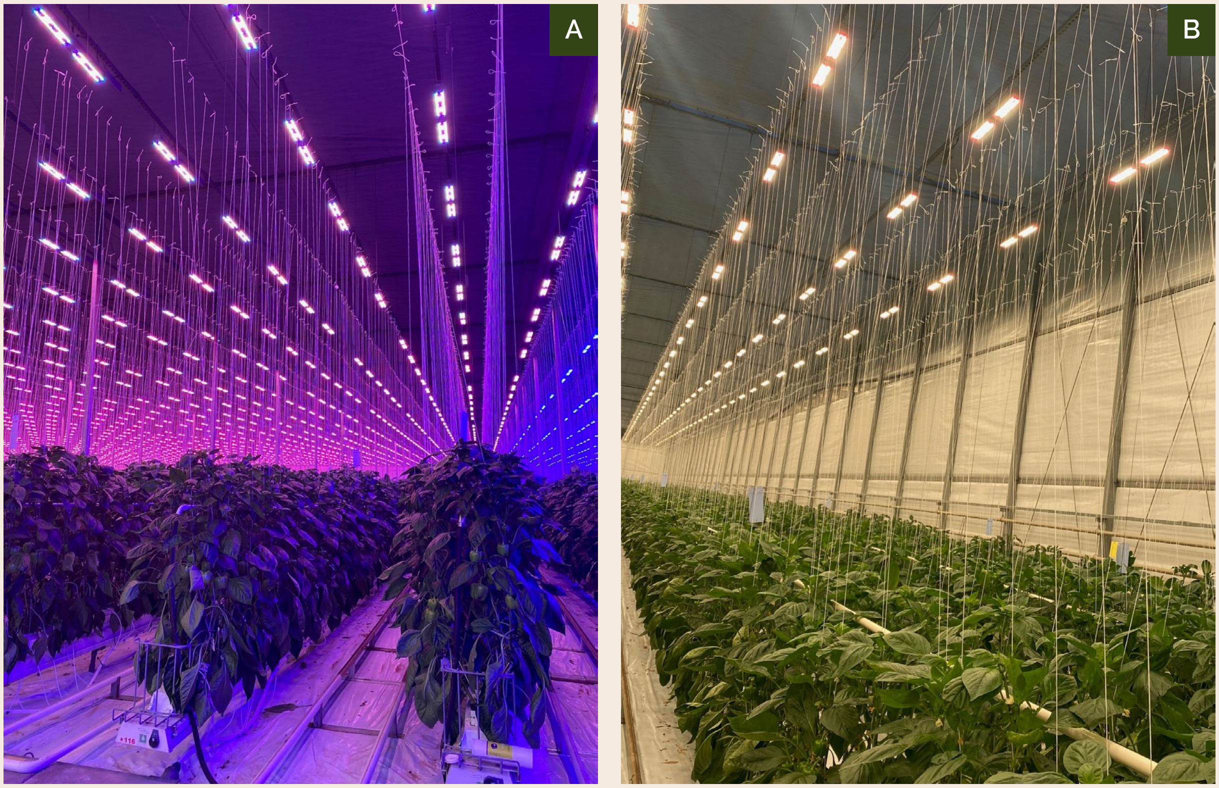

Figure 1. Fully-closed ceiling light abatement curtains (A) and wall light abatement curtains (B) in a pepper greenhouse.
Source: Gene Ingratta, Allegro Acres.

Greenhouse light abatement curtains are made from an opaque material with reflective properties. They are composed of polyester, polyolefin or a mixture of the two. These materials are resistant to water, wind, light and heat. They combine well with other fibres allowing them to be more easily modified to suit unique needs. Producers should verify that all their curtains are fire retardant and are installed and operated as per the manufacturer's instructions (Table 1).

Table 1. Examples of Available Light Abatement Curtain Models and their Manufacturer Specifications[1]

Model	Ceiling or wall curtain	Material	Weight (g/m^2)	Fire retardant	Light transmission (%)	Energy savings (%)
A	Ceiling	Polyester	67	Yes	1	50
B	Wall	Polyolefin	252	Yes	0.01	70
C	Ceiling	69% Polyolefin, 31% Polyester	109	Yes	0.5	51
D	Ceiling	61% Polyolefin, 39% Polyester	127	Yes	0.5	58
E	Wall	Polyester	255	Yes	2	45

[1] This is not a comprehensive list.

When light abatement curtains are being installed in a greenhouse, they may have additional features like fastening strips, zippers or magnetic closures to minimize light leakage from gaps. They may be layered on top of other curtains to provide greater versatility according to the needs of the producer. Light abatement curtains are typically installed with an automated system that is controlled by the greenhouse environment management computer system to open and close the curtains.

When the light abatement curtains are fully closed, they can reduce light emissions by more than 99%. They also function as an energy or thermal curtain by reducing heat loss from the greenhouse to the nighttime environment by around 50%. Furthermore, the white reflective surface facing the interior of the greenhouse reflects light from lighting fixtures back to the crop, resulting in improved light use and therefore more energy savings. Light transmission and energy saving properties of ceiling and wall light abatement curtains vary depending on the model.[6],[7],[8],[15]

Research Results

Nighttime Greenhouse Light Emissions

The amount of light emitted from greenhouses using supplemental lighting at night depends on light intensity, closure of light abatement curtains and amount of greenhouse vegetation.

Light Intensity of the Fixtures Installed in the Greenhouse

In general, crops that produce fruits like high-wire vegetables or large flowers such as cannabis require more light than potted ornamental plants or lettuce.[4] The use of higher intensity supplemental lighting in greenhouses is associated with higher light emissions when light abatement curtains are not being used.[18]

Amount of Vegetation in the Greenhouse

More light is emitted from walkways and areas with less plant volume than areas in full production. This is most likely due to more light being reflected by surfaces than plants.[18]

Closure of Light Abatement Curtains

There are many models of light abatement curtains on the market that are made of different materials to suit the needs of greenhouse producers for managing the greenhouse environment for the crop (Table 1). These curtains reduce the amount of light emitted from greenhouses by reflecting the light back into the greenhouse. Current ceiling light abatement curtains allow less than 1% light transmission and wall light abatement curtains allow less than 2% light transmission when fully closed. This allows for greater use efficiency of the supplemental lighting since most of the light is contained inside the greenhouse to be used by the crop.

Light emitted from the sides and ceiling of greenhouses using supplemental lighting at night may impact neighbouring land uses. These light emissions can be minimized by using ceiling, side and end wall light abatement curtains. Research showed that as ceiling light abatement curtains are opened to different gapping degrees (10%, 20% gapping, etc.), there is an increase in the amount of light emitted that is somewhat proportional with the gapping (Table 2).[13],[17]

Table 2. Effectiveness of Greenhouse Curtains at Reducing Light Emissions

Site	0% Gap (Fully Closed)[1]	10% Gap[1]
Greenhouse with Light Abatement Curtains		
Greenhouse 1	99.7%	90.3%
Greenhouse 2	95.8%	86.8%
Greenhouse with Energy Curtains (No Light Abatement Curtains)		
Greenhouse 3	67.9%	52.9%
Greenhouse 4	28.4%	27.8%

[1] Light emission reduction compared to fully open curtains.
Note: These results are based on data collected using a sky quality meter (light sensor) attached to a drone that was flown over greenhouses at nighttime. This is an excerpt from a more complete dataset that can be found in Snow et al (2021).[17]

Skyglow

1 The following research supports the recommendations for BMP #1: Gapping ceiling light abatement curtains to ventilate the greenhouse and maintain ideal growing conditions.

Light emitted from the top of greenhouses that use supplemental lighting at night may be observed farther from the source due to illumination of the night sky. This is known as **skyglow**. Research showed that sky brightness when light abatement curtains are opened to a 10% gap may not change much compared to when they are fully closed. However, as light abatement curtains are fully opened, sky brightness may increase significantly near the greenhouse (Figure 2). Closing curtains sometimes markedly reduced sky brightness near a greenhouse, while at other times, the impact of curtain closure on sky brightness was variable or negligible.[16]

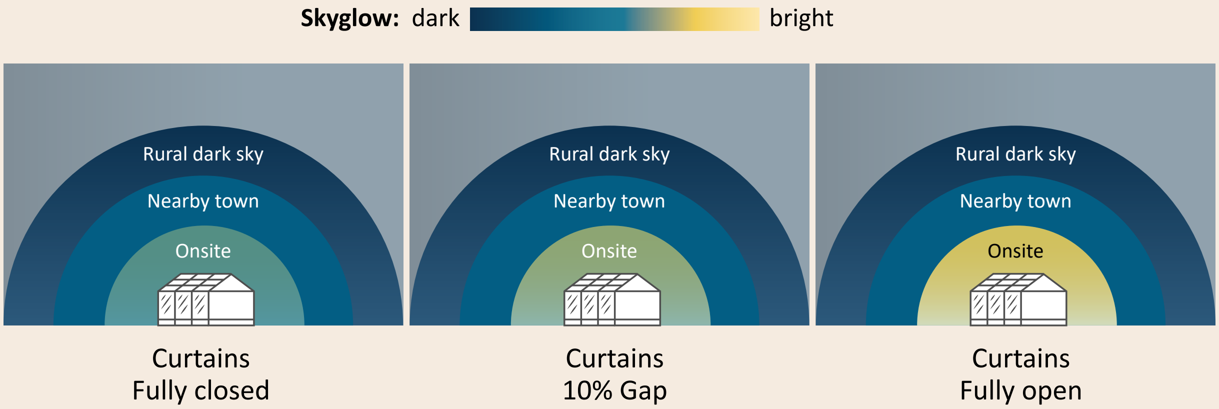

Figure 2. Depiction of average sky brightness (skyglow) measured from an upward facing car-mounted sky quality meter (SQM) light sensor, with greenhouse light abatement curtains at 0%, 10%, and 100% open, compared to the average measured for rural dark sky and/or nearby town. No significant changes were observed in sky brightness of rural dark sky or nearby town in any scenario.

In another study between November 2022 and April 2023, nighttime sky brightness measurements were collected at four different locations in southwestern Ontario:

1. a remote rural location
2. an urban location in the city of Windsor
3. a small town location within the town of Leamington
4. a rural area with several nearby greenhouses and urbanization

While the urban area was the brightest and rural area was the darkest, the outside town area with some greenhouses using supplemental lighting was as bright as the urban area. An increase in sky brightness at 2:00 a.m. was noticeable. This coincided with many greenhouses turning on their lights.

Overall, there was a pattern of increasing sky brightness with increasing moon elevation (brighter skies with fuller moon) and with cloud cover.

The authors caution readers not to over-interpret the data or results because the results are case studies (i.e., not in a controlled laboratory environment) and it is difficult to make general conclusions because results may vary depending on location. Also, a number of factors can contribute to skyglow:

- The moon increases sky brightness when it is present, in both clear and cloudy conditions: this effect would be difficult to quantify and remove.
- The study region contains many greenhouses, other industrial facilities and commercial and residential developments, all of which produce light emissions that contribute to local sky brightness. It would be difficult to identify the contribution of a single facility or light source to regional sky brightness, unless that source was the only light source.[9]

Overall, the research showed an increase in light emissions that was proportional to the gapping of ceiling light abatement curtains, but the effect of a 10% gap on skyglow was variable and depended on other external factors. Therefore, a maximum 10% gap is recommended for ventilating greenhouses under light abatement curtains while minimizing skyglow impacts.

Effect of Light Abatement Curtains on the Greenhouse Environment and Crop Physiology

Stratification of Air Temperature

1 The following research supports the recommendations for BMP #1: Gapping ceiling light abatement curtains to ventilate the greenhouse and maintain ideal growing conditions.

Maintaining consistent growing conditions throughout the greenhouse, horizontally and vertically, is important for optimal production. To understand the potential effect of ceiling light abatement curtains on the greenhouse environment, modeling was conducted by researchers at the University of Guelph to investigate potential differences that could occur between the air layers above and below fully closed light abatement curtains. The model assumed that the greenhouse air was exchanged once per hour, and the simultaneous use of a light abatement curtain and an energy curtain.

Fully closed curtains created a barrier between the attic area above the curtains and the growing area below the curtains resulting in differences in air temperature and humidity. This climate heterogeneity within the greenhouse — variations in climate between the upper and lower portions of the interior — can lead to abnormal or inefficient plant growth. During cold weather periods with curtains closed, attic air can become much cooler overnight than air below the curtains in the growing area.[10] **Care must be taken to open curtains slowly in these conditions, so plants are not shocked by large volumes of cold air descending suddenly from the cooled attic.**

The location of air vents in the greenhouse and the amount of gapping in the ceiling curtains will impact the degree and nature of air temperature stratification. When curtains are closed, roof air vents located above the curtains, which are typical in modern greenhouses built for high-wire vine crops, allow mixing of the air layer in the attic but not in the growing area. Conversely, in greenhouses with air vents located in walls below the curtains, it is possible to observe mixing of the air layer in the growing area and not the layer in the attic.[11] **Experience suggests that gapping of curtains to different degrees allows for more air circulation between attic and growing area and reduces air stratification.**

Some of the modeling results were verified with a case study using air temperature data from a commercial vegetable greenhouse in southwestern Ontario. Similar to the model, this site also used an energy curtain and light abatement curtain simultaneously. As expected, stratification of air temperature developed when the curtains were fully closed. At night, warmer air was present in the growing area and cooler air was present in the attic. The temperature of the air in the attic and the growing area converged when the curtains were fully opened (Figure 3). This air temperature stratification was more pronounced during months when curtains were used more frequently and outside temperatures were lower than months when curtains were used less frequently and outside temperatures were higher.[10],[12]

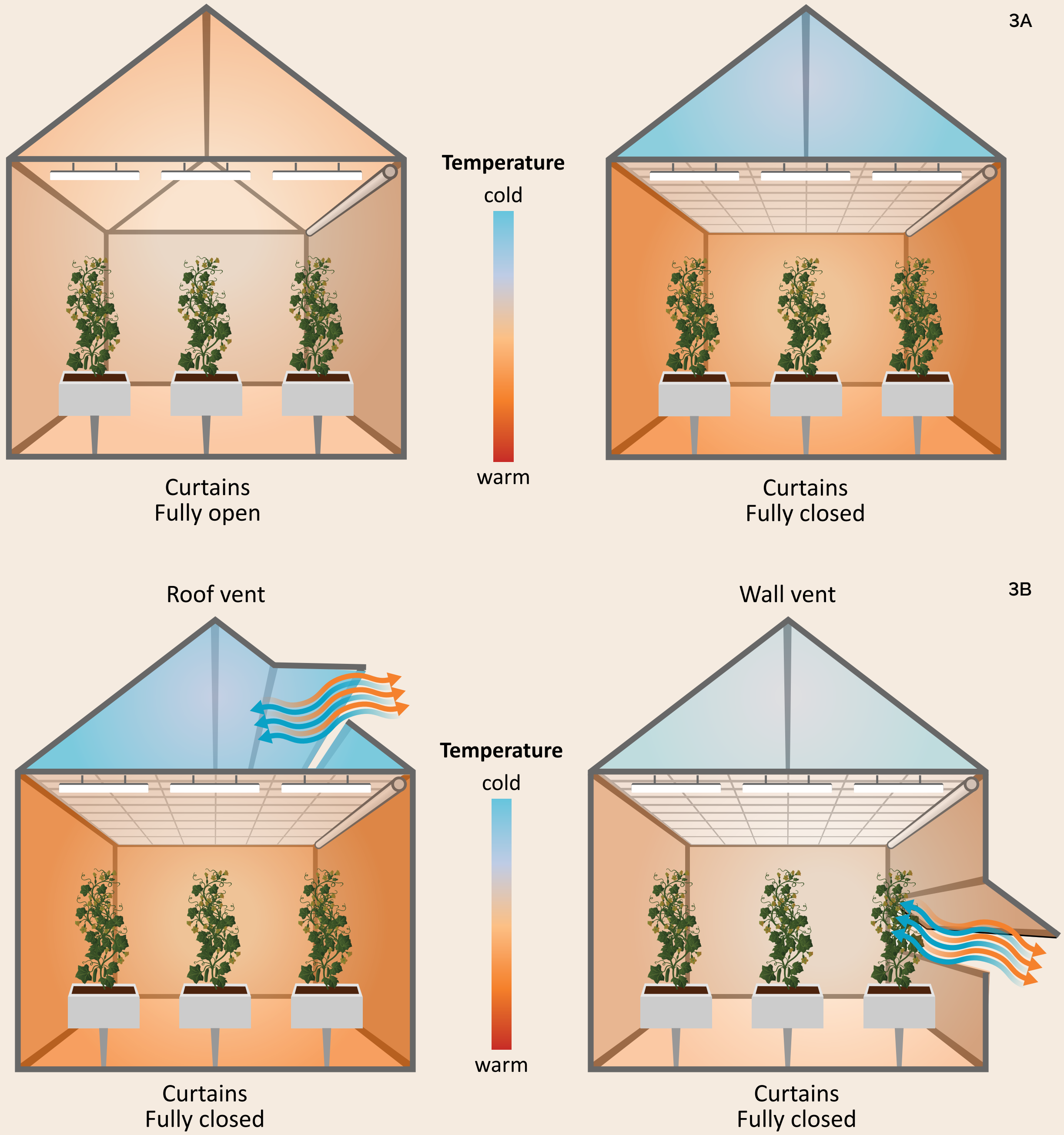

Figure 3. Depiction of the effect of (A) an open and closed ceiling light abatement curtain and (B) roof and wall vents, on air temperature in the attic above the curtain and in the growing area below the curtain.

Increase in Greenhouse Air Temperature and Plant Temperature

1 The following research supports the recommendations for BMP #1: Gapping ceiling light abatement curtains to ventilate the greenhouse and maintain ideal growing conditions.

To investigate the effects of light abatement curtains on greenhouse relative humidity, air temperatures and plant temperatures, researchers at Agriculture and Agri-Food Canada's Harrow Research and Development Centre (Harrow) used four mini-greenhouses (50 m² each) outfitted with light abatement curtains to grow tomatoes in the winter of 2021/2022 (December 2021–April 2022). Two mini-greenhouses had high pressure sodium (HPS) lights and the other two had light-emitting diode (LED) lights. One mini-greenhouse with HPS lights and one with LED lights used light abatement curtains. The other two mini-greenhouses did not use light abatement curtains. The light abatement curtains were fully closed when the lights were on between 2:00 a.m. and 6:00 p.m.

Increases in air temperature were observed under both HPS and LED lights when light abatement curtains were closed. As expected, this increase in air temperature was more pronounced under HPS lights compared to LED lights. The temperature of the tomato plants was also higher when grown under light abatement curtains compared to plants that were not grown under light abatement curtains. This increase in plant temperature was observed under both HPS and LED lights. The increase in air and plant temperatures under LED lights and light abatement curtains was accompanied by higher relative humidity, whereas under HPS lights and light abatement curtains there was a drop in relative humidity levels (Figure 4).[2],[14]

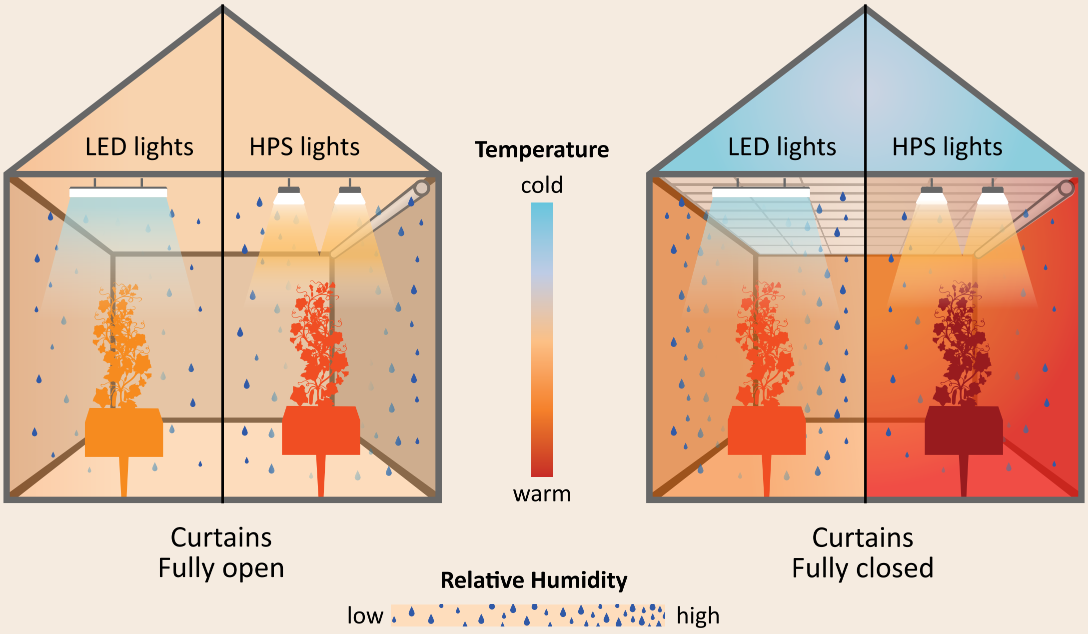

Figure 4. Depiction of air and plant temperatures, and relative humidity levels in experimental mini-greenhouses with and without light abatement curtains under HPS and LED lights.[2]

2 The following research supports the recommendations for BMP #2: Employing a long-photoperiod low-intensity lighting strategy to reduce fluctuations in the growing environment under light abatement curtains.

Between December 2022 and May 2023, another experiment was conducted in Harrow, where two mini-greenhouses with LED lights and light abatement curtains used different lighting strategies:

1. Typical 16-hour lighting strategy (2:00 a.m.–6:00 p.m. with 250 μmol/m²/sec).
2. Long photoperiod (24 hour) low-intensity lighting strategy (2:00 a.m.– 6:00 p.m. with 200 μmol/m²/sec and 6:00 p.m.–2:00 a.m. with 100 μmol/m²/sec).

The daily light integral (DLI) in both mini-greenhouses was equal (14.4 mol/m²/day), and the light abatement curtains were fully closed between sunset and sunrise for both lighting treatments. There were fluctuations in air temperature under both treatments between warmer daytime temperatures and colder nighttime temperatures, but the fluctuations under the longer photoperiod low-intensity lighting strategy were less pronounced during some days (Figure 5). Although the yield of the tomato plants grown in both greenhouses were similar, the longer photoperiod low-intensity growing strategy requires less light fixtures thereby saving money for greenhouse producers.[3],[14]

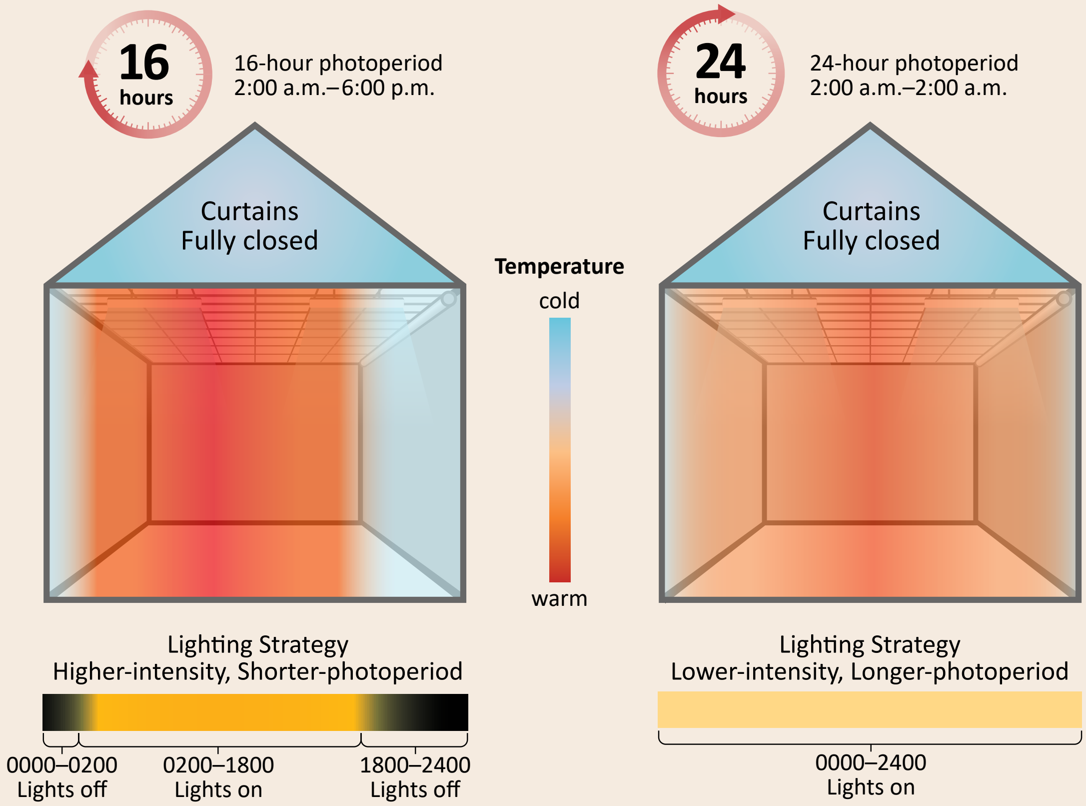

Figure 5. Depiction of air temperature fluctuations with time in experimental mini-greenhouses using a conventional 16-hour higher-intensity lighting recipe or a 24-hour lower-intensity lighting recipe under light abatement curtains. Less air temperature fluctuations over time with the 24-hour lighting strategy is ideal.

Lighting Before Sunrise Reduced Use of Light Abatement Curtains

3

The following research supports the recommendations for BMP #3: Lighting before sunrise (2:00 a.m. to 6:00 p.m.) rather than after sunset (8:00 a.m. to midnight) to reduce the amount of time light abatement curtains are used and allow producers to manage the greenhouse environment more easily.

Most vegetable greenhouses in Ontario use supplemental lighting between 2:00 a.m.–6:00 p.m. during winter production, but some producers prefer to extend the daylength after sunset rather than before sunrise. But, does extending the day by lighting before sunrise or after sunset affect the length of time that producers need to close their light abatement curtains and manage the resulting changes in the greenhouse environment? To answer this question researchers in Harrow used sunrise and sunset data for southwestern Ontario to calculate how long light abatement curtains would be closed under each scenario. It was assumed that light abatement curtains would be closed only when lights were on between sunset and sunrise, and that lights were on from 2:00 a.m.–6:00 p.m. in the "before sunrise" scenario and 8:00 a.m.–12:00 a.m. for the "after sunset" scenario using a typical 16-hour photoperiod. The length of time that light abatement curtains would be closed was calculated for each month between October 2022 and March 2023.

It was found that using supplemental lighting before sunrise reduced the amount of time that light abatement curtains would be used in each month. The biggest difference was observed in December when using supplemental lighting before sunrise resulted in light abatement curtains being closed 1 hour and 25 minutes less than using supplemental lighting after sunset (Figure 6). When the researchers looked at the outside temperature for the same period of time under the two lighting scenarios, it was found that there was a greater difference in temperature between the greenhouse environment (assumed to be 21˚C) and the temperature outside the greenhouse before sunrise as compared to after sunset. **This temperature gradient suggests it would be easier for producers to reduce the heat buildup in their greenhouses under light abatement curtains if they use supplemental lighting before sunrise rather than after sunset**. This would allow producers to manage the greenhouse environment more easily.[3],[14]

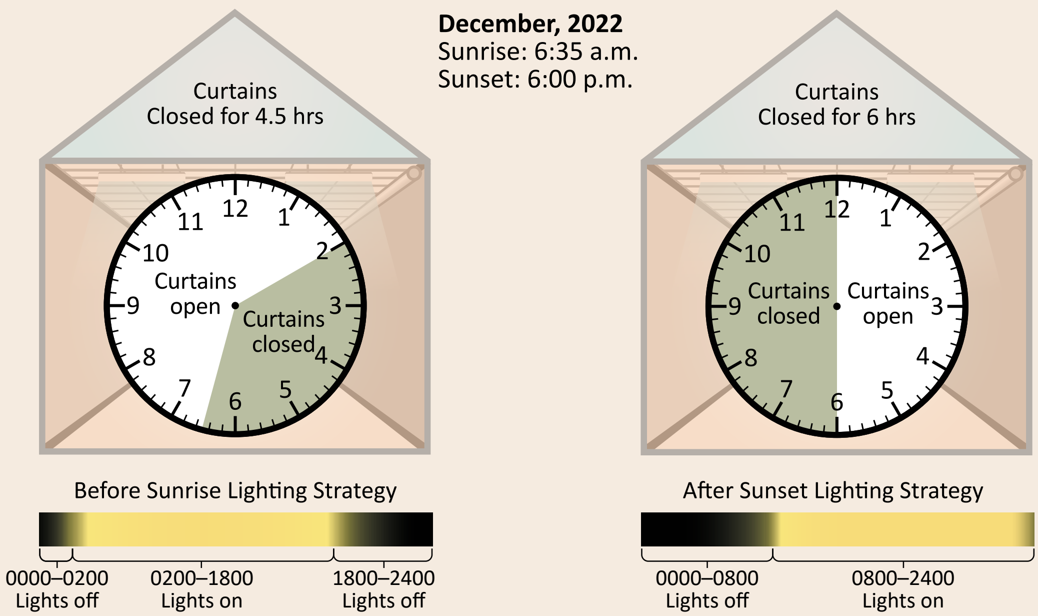

Figure 6. Depiction of the amount of time light abatement curtains would have to be closed in December, 2022, using "before sunrise" and "after sunset" lighting strategies.

Other Technology Considerations

Other technologies that may also help producers maintain a consistent environment under light abatement curtains include through-curtain fans. Through-curtain fans are typically installed in the growing area below the ceiling curtains with a duct leading through the curtain to the attic space. They blend air from above and below the light abatement curtains when curtains are fully closed. Cooler air from the attic is pulled into the fan where it is mixed with warmer air from the growing space to achieve the desired temperature before the mixed air is blown back into the growing space (Table 3). The use of this technology in Ontario greenhouses is currently being studied.

Table 3. Examples of Available Through-Curtain Fans and their Manufacturer Specifications

Model	Ventilation Capacity (m^3/hr)	Installation	Air Flow Direction under Curtain
A	Up to 5,200	Side of truss, hole in screen cloth is needed	Horizontal
B	Up to 5,200	On truss, no hole in the screen cloth needed	Horizontal
C	Up to 5,500	Side of truss, hole in screen cloth may not be needed as it is thin	Horizontal and vertical

Note: This is not a comprehensive list.

Dehumidification technologies may also provide additional climate control in the greenhouse and energy savings in the autumn and winter months;[1],[5],[11] or when outside ventilation is limited by curtain closure. However, the use of dehumidification technology needs to be tested in greenhouses with light abatement curtains.

Public Concerns Around Greenhouse Light Emissions:

Municipality By-laws and the *Farming and Food Production Protection Act, 1998*

When neighbours express concerns about light emissions, it is in the interest of both parties to resolve issues and maintain good neighbour relations. While it is best to take a proactive approach to managing light emissions from greenhouses, there may be times when complaints are received even by the best managed operation.

When complaints are received, producers can take a number of steps:

1. Document the complaint:
   - time and date the complaint is received
   - time and date the light or other impact was experienced by the complainant
   - contact information for the complainant (if not anonymous)
2. Note details of the complaint:
   - perceived light intensity
   - outside conditions such as any fog that may amplify the perception of stray light levels
   - operational information including factors which may impact light emissions, such as light intensity settings, gaps in curtains or structure any other relevant information
3. Respond to the complainant in a professional and timely manner with a brief acknowledgement that their complaint has been received and heard.

4. Make any necessary or possible adjustments needed to address the issue. It may not be possible to make immediate changes, but consider future changes to address the concerns.

5. Provide the complainant with additional information such as any changes that have been made or are anticipated to address the concerns. If the complaint has been received through a municipality or other agency, ensure the information about the complaint and response is also communicated to them.

Producers should be aware that if a resolution cannot be reached between a producer and their neighbours, either party can contact OMAFA to initiate the Farm Practices Conflict Resolution Process by contacting the Agricultural Information Contact Centre at 1-877-424-1300 or ag.info.omafa@ontario.ca.

Legislation, Municipal By-Laws and FFPPA

It is in the provincial interest that in agricultural areas, agricultural uses and normal farm practices be promoted and protected in a way that balances the needs of the agricultural community with health, safety and environmental concerns. To establish this balance, Ontario passed the *Farming and Food Production Protection Act* (FFPPA) in 1998. The FFPPA established that agricultural operations are protected from liability associated with normal farm practices. The FFPPA also does not permit by-laws to restrict normal farm practices.

Normal farm practice is defined as one which:

- Is conducted in a manner consistent with proper and acceptable customs and standards, as established and followed by similar agricultural operations under similar circumstances.

- Makes use of innovative technology in a manner consistent with proper advanced farm management practices.

Farmers must still comply with other legislation such as the *Environmental Protection Act, 1990 Pesticides Act, 1990, Health Protection and Promotion Act, 1990* and the *Ontario Water Resources Act, 1990.*

Municipalities can establish by-laws that require agricultural operations to apply for permits or set guidance around agricultural practices. If an agricultural operation feels a by-law restricts their normal farm practice, they should engage with their municipality to better understand the by-law and to confirm if their farm practice can accommodate the municipal by-law.

If neighbours have concerns about the practices of a farming operation or an agricultural operation (including greenhouses) feels a municipal by-law restricts their normal farm practice, they can contact the Agricultural Information Contact Centre at 1-877-424-1300 or ag.info.omafa@ontario.ca to learn about the Farm Practices Conflict Resolution Process and the Normal Farm Practices Protection Board. For more information on the *Farming and Food Production Protection Act*, *1998* and nuisance complaints, please visit www.ontario.ca/page/farming-and-food-production-protection-act-1998-and-nuisance-complaints.

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Ministry Resources

Supplementary information is available at ontario.ca or ONGreenhouseVegetables.ca.

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Acknowledgements

Research was funded by OMAFA and Ontario Greenhouse Vegetable Growers (OGVG).

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Illustrations
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Photo Credit (Cover)
Gene Ingratta, Allegro Acres

Published by the Ministry of Agriculture, Food and Agribusiness

ISBN 978-1-4868-8281-6 (Print)
ISBN 978-1-4868-8282-3 (PDF)

Cette publication est aussi disponible en français.