Cooling of a South-Facing Wall Using a Double-Skin Green Façade in a Temperate Climate©

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Green façades made of metal wire screens and mounted to the walls of buildings to support trellised vegetation is increasingly looked to as a means of urban greening and as a sustainable building technology. Here we examine the thermal cooling performance of three candidate vine species (hops, Virginia creeper, and riverbank grape) on a 3-dimensional welded wire frame against a south-facing wall in a temperate climate. We found that from May to September, the green façades kept the wall surface on average 1.84°C (3.31°F) cooler, with grape as the best performer reducing surface temperatures by 2.91°C (5.24°F) in September. In all three species, wall cooling increased with vegetated cover, which increased over the growing season. The effect of vegetated cover on wall cooling was most apparent in hops which re-grows from root stock and basal stems to cover much of the trellis by the end of the growing season, whereas grape and creeper foliage re-grows from stems that remain attached to the trellis, achieving more heterogeneous covering earlier in the growing season. These findings contribute to a growing body of research on green façades and their functional performance as components of the building envelope and as architectural materials.

INTRODUCTION

Vegetation, including vining plants trellised up against or directly on the surface of structural walls has been a feature in landscape design and architecture to mask unaesthetic surfaces and increase building cooling via shading and evapotranspiration (Di and Wang, 1999; Akbari et al., 2001; Köhler, 2008; Susorova et al., 2014). Different types of vine trellising structures have been implemented, but most fall within the single skin (abutting up against the building without a gap between the building wall and the trellis) or double skin (set off from the wall creating a pocket of air between the building wall and the planed trellis) types (Stec et al., 2005; Hunter et al., 2014). Wong et al. (2010) in Singapore simulated the cooling load for a building with walls entirely covered with vegetation was 10% greater than bare walls. Di and Wang (1999) in Beijing determined that thick ivy covering a west facing wall can reduce the peak cooling by 28% in a clear summer day. In a modeling exercise, Susorova et al. (2014) estimated the effective thermal resistance of a plant layer to be up to 0.7 $m^2 \cdot K \cdot W^{-1}$ and determined that the thermal behaviour of green façades are (in order of importance): solar radiation, wind speed, relative humidity and outdoor air temperature. Needless to say, trellising vegetation (hereafter referred to as vine façades) is one effective means of cooling building to reduce energy costs during warm weather periods.

Vine façades are rarely incorporated into new development and in landscape architecture, due to the length of time it can take for a mature vine to grow, the amount of soil volume required for the vine, and the perceived potential damage done by vining plants to building infrastructure (for example, eroding wood or brick walls due to the attachment of vine tendrils). However, vine façades can convey an attitude of environmental awareness and as mentioned have been both theoretically and empirically demonstrated to have some cooling benefit (Hunter et al., 2014). Other recent studies have estimated the cost savings of vine façades resulting from building thermoregulation (Alexandri and Jones, 2008; Wong et al., 2010; Ottelé et al., 2011). This has created interest in industry to design vine façade products that optimize the survival, growth, movement and cover of vining plants to maximize their benefits.

Aside from vine survival and the life-cycle costs of implementing different vine façade designs and materials, the most studied benefits of façades have been thermal performance in warm seasons and in Mediterranean climates (Kontoleon and Eumorfopoulous, 2010; Pérez et al., 2011; Perini et al., 2011; Ottelé et al., 2011; Hunter et al., 2014). Literature on green façades in Canadian regions or those with similar climates is scarce compared with that on green roofs (Dunnett and Kingsbury, 2010; Sutton, 2015). One study in Maryland used a three-dimensional trellis system and four vine species in combination on East and West facings and found vine façade walls an average of 7°C cooler than bare walls (Tilley et al., 2012). However, few studies have compared thermal performance between different vine species, which can vary considerably in absorption of water, reflectivity of solar radiation, transpiration rates and cooling potential, among other variables that impact leaf energy balance and reduction in heat energy transfer (Holms, 1989). As building density and height increase in Canadian cities, so does the proportion of bare wall surfaces and associated building inefficiencies. Since trellising vine façades are not constrained by load and other structural issues that green roofs provoke, they are more easily included in the retrofit of existing buildings to achieve goals addressed by green infrastructure. Vine façades are also more visible to the public from ground and so could be more attractive to clients uncertain as to whether or not they should commit to greening the building envelope during development or renovation. The objectives of the research of this study were to gather baseline information on wall cooling potential of vine façades using the greenscreen® three-dimensional double skin trellising system in Toronto. The trellis system consists of three different vine species and vegetation-free controls. This information is critical for increasing knowledge of vine façades in temperate climates and for determining how different vine species might interact to complement and enhance overall vegetative cover.

METHODS

Site

The Green Roof Innovation Testing (GRIT) Lab is located on the roof of the five-storey Daniel's Faculty of Architecture, Landscape, and Design building at the University of Toronto St. George Campus, in Toronto, Ontario (43°39'42"N, 79°23'42"W). Further construction details and description of the facilities is given in MacIvor et al. (2013) and available at the website (www.grit.daniels.utoronto.ca). The double skin façade wall under study is located on this roof and comprised of a south-facing 3D greenscreen trellis against a building wall containing heated office and storage space. These trellises were 2.15 m in height and set 6 cm from the exterior wall creating an insulating layer (Hunter et al., 2014) (Fig. 1).

Three vine species were used in the set up, Nugget hops (*Humulus lupulus* 'Nugget') (hops), Virginia creeper (*Parthenocissus quinquefolia*) (creeper), and river bank grape (*Vitis riparia*) (grape). Each grape was planted with a short 60-cm stake to enable the vine to touch the trellis during establishment. All three species were planted in monoculture in groups of 6 into the façade modules as 1-gal pots in June 2012. Each module measures 102.2×31.8×29.2 cm in dimension and is raised 39.4 cm from the roof surface. Each module comprised of an "organic" growing medium ("EcoBlend" Bioroof™ Systems, Burlington, Ontario) (Table 1). The media was set atop a 25-mm layer of sand, filter cloth and biovoid retention mat (Bioroof, Toronto, Canada) as well as waterproofing membrane and trimmed with aluminum flashing (Tremco, Toronto, Canada) (Fig. 2).

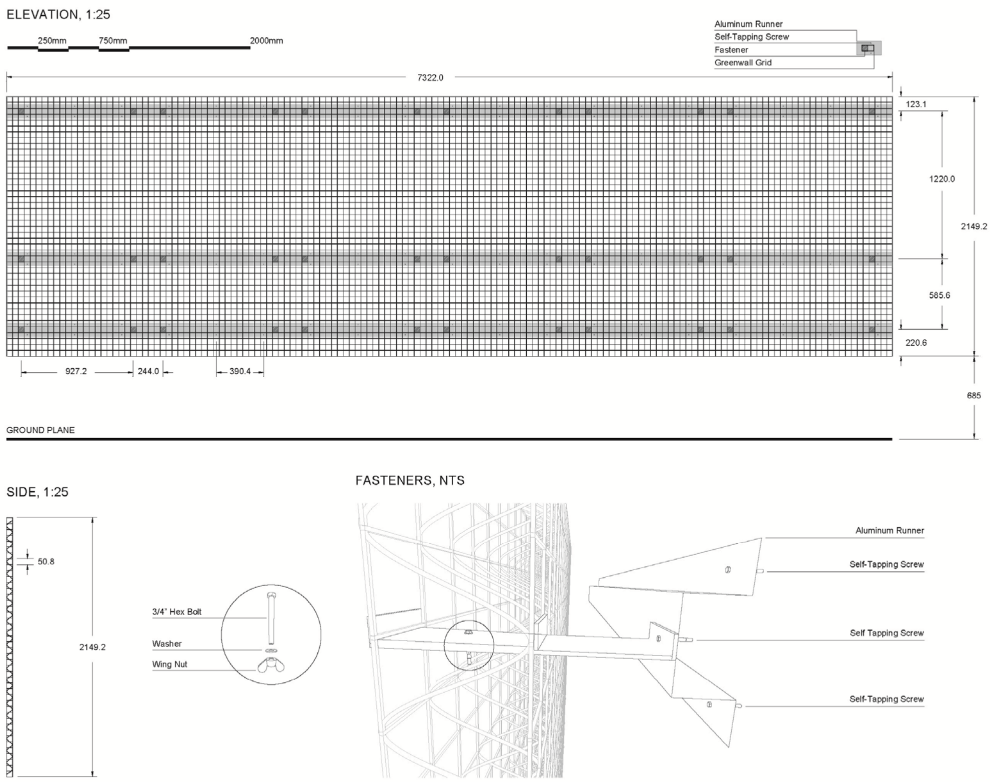

Fig. 1. A drawing of the greenscreen® 3D welded wire panel system.

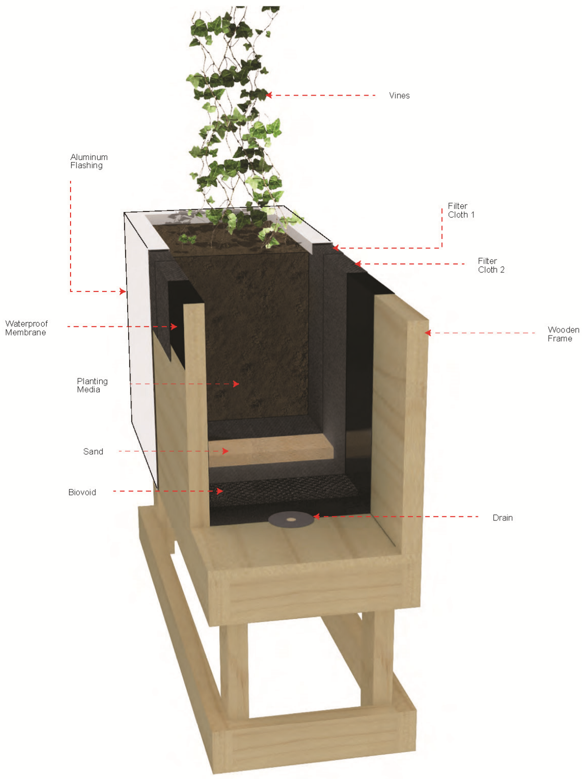

Fig. 2. Annotated drawing of the planter module.

Table 1. Properties of the growing medium used in this study.

Standard	Property	Bioroof Eco-blend
Porosity (ASTM E2399)	Pore volume	>60%
	Air filled porosity	>10%
	Saturated hydraulic conductivity	>0.01 cm/s
Moisture (ASTM E2399)	Max. water holding capacity	>60%
Density (ASTM E2399)	Max media density at saturation	1.10 g/cm^3
	Dry density	0.58 g/cm^3

Each façade module was overlaid with interconnected drip-irrigation line (DH Water Management; The Toro Company, Canada) set up with a pressure of 25 kPa and an emission rate of 0.063 L/emitter/min., to ensure an efficient use of water. Approximately 5 min of water beginning at 8 AM was provided daily. No fertilizer was added during the course of the study. The vine façade modules were weeded regularly and the primary colonizers arriving with growing media or colonizing spontaneously included: chickweed (*Cerastium* sp.), horseweed (*Conyza canadensis*), tree of Heaven (*Ailanthus altissima*), lamb's quarter (*Chenopodium album*), and dandelion (*Taraxacum officinale*). Golden tickseed (*Coreopsis tinctoria*), black eyed susan (*Rudbeckia hirta*) and several *Sedum* species were also colonizers of the façade modules and presumably arrived via green roof test beds sharing the same roof space where these species were planted intentionally.

Cover

Vegetated cover was measured non-destructively using digital image analysis (Olmstead et al., 2004) using photos taken with a Canon SLR and analyzed in Adobe Photoshop. Photos were taken at 1.70 m from the roof surface and 2 m from the façade on the first and third week of each month on a sunny day. The image from the third week of each month from Region 1 was cropped to include only the façade area, and in Photoshop, the "sampled colours" and "localized colour clusters" were selected, the fuzziness set to 60, the range set to 100%, before the eyedropper function and the "add to sample" function were used to select the desired vegetation colour range. The number of vegetated pixels in the image was divided by the total number of pixels in order to get a % vegetated cover value for each façade.

Thermal

A single temperature probe (110 PV Surface Mount Thermistor, Campbell Scientific) was attached to the surface of the exterior wall centered, and immediate behind each of the vine façades and the three control façades (trellis, but vegetation-free) (Fig. 3). Each thermistor recorded temperature (°C) at five-minute intervals from May to September 2013 (and continuously thereafter). To compare thermistor data recorded from the façade walls, GRIT lab weather station ambient air temperature (°C) and relative humidity (%) (HMP45C Probe, Campbell Scientific), as well as solar radiation (W/m^2) (Kipp and Zonen CMP 11 Pyranometer) data were downloaded for the same time intervals.

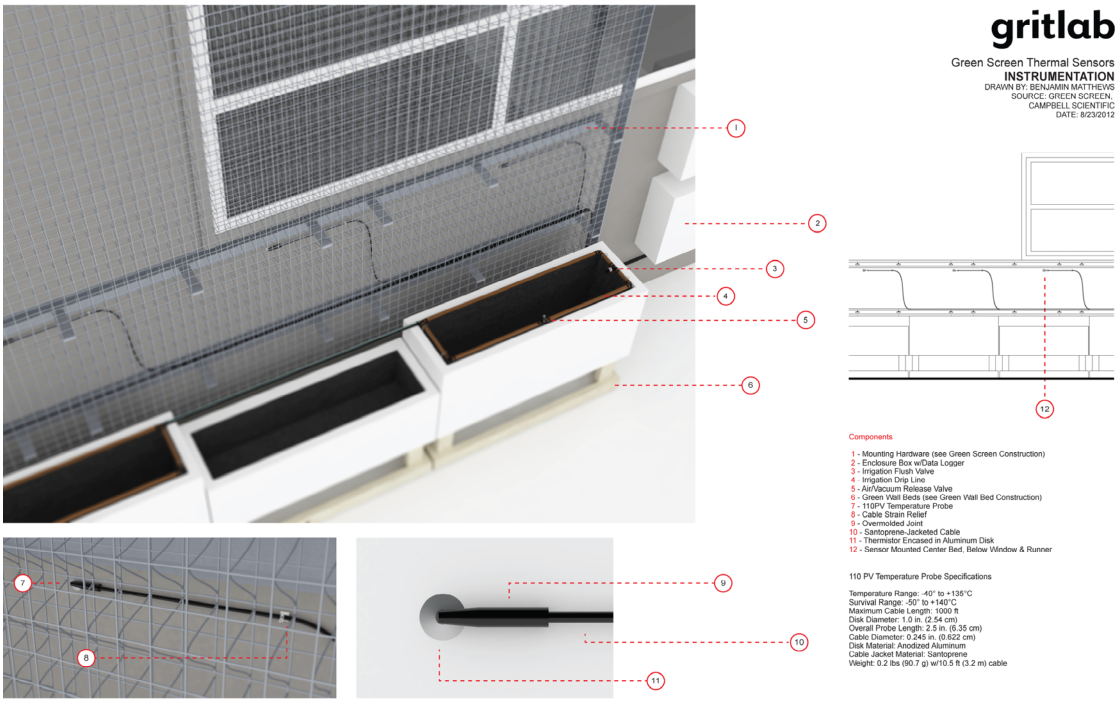

Fig. 3. Annotated drawing of the planter module.

Statistics

Data from the temperature probes and weather station were subset by day and night using positive solar radiation readings (>0 W/m^2) as an indicator of daytime. Daytime data was then converted to monthly averages for comparison with vegetated façade cover data for each of the three species. A paired t-test was used to compare wall surface temperatures between vegetated façades and non-vegetated controls. In SPSS, an analysis of variance (ANOVA) (α=0.05) with post hoc analysis was used to examine the effect of cover and vine type on surface building wall cooling and the change in temperature reduction over the growing season.

RESULTS

Of the three vine species, all reached maximum over 50% cover by the end of the study period with grape reaching over 70% cover. The t-test revealed that from May to September, vegetated façades significant reduced wall surface temperature over non-vegetated façade controls (t=-8.576, df=14, t<0.001) (Fig. 4). However analysis of variance revealed no significant difference in reduction in wall surface temperature among the different vine types (F-1.35, df=2, p=0.30). Vegetated façades resulted in a 6-11% reduction in wall surface temperature.

The reduction in surface temperature by vegetated façades increased significantly over the sampling period with the greatest reduction achieved in September [almost 3°C (5.24°F) reduction] (F=5.04, df=4, p=0.017) (Fig. 4). Increasing vegetative cover led to significant reductions in wall surface temperatures (t=-11.169, df=14, t<0.001) (Fig. 5), however since the physiological adaptability to light conditions in vining plants is related to their climbing mechanics (Carter and Teramura, 1988), each vine species displayed a distinct and different growth pattern (Figs. 6 and 7).

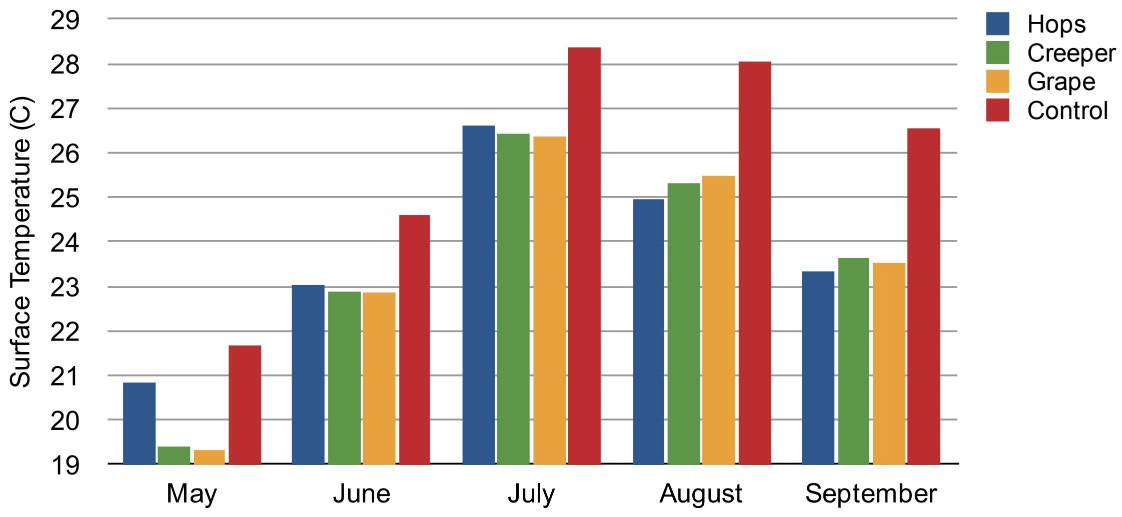

Fig. 4. Change in surface temperature over May to September 2013 behind the vegetated façades and the non-vegetated control walls.

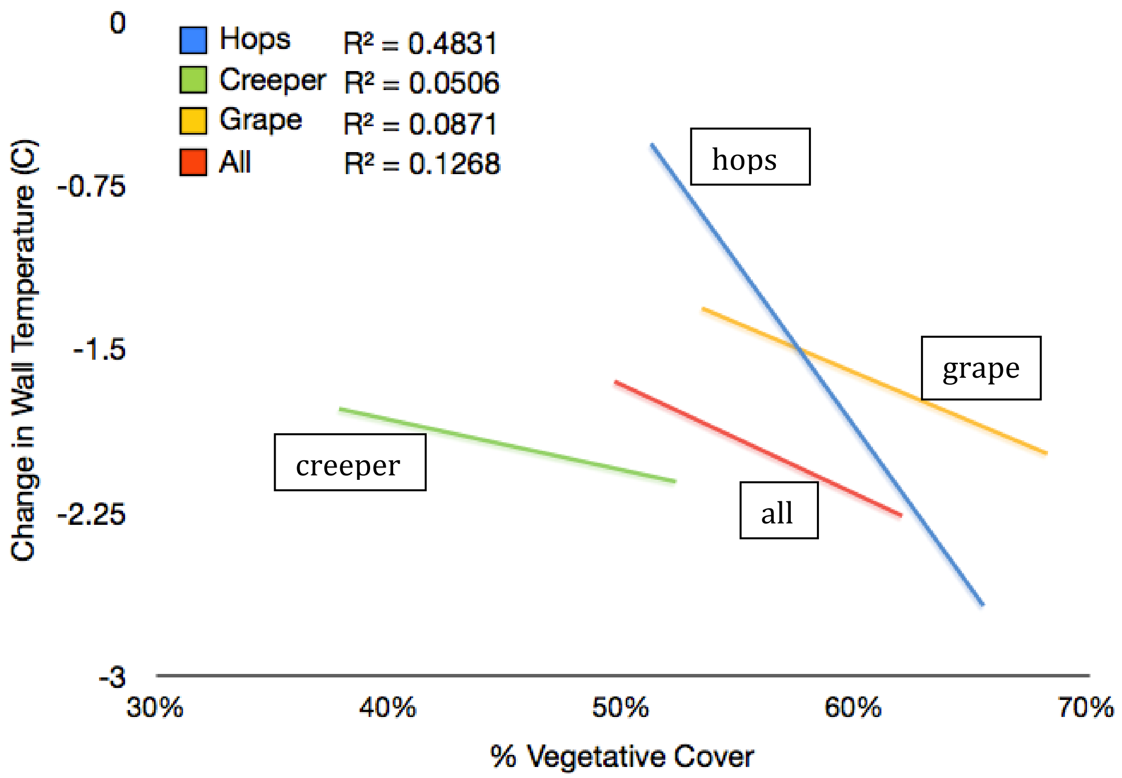

Fig. 5. Change in wall temperature (from the non-vegetated façade controls) plotted against % vegetative cover of all three species and the average change of the species combined.

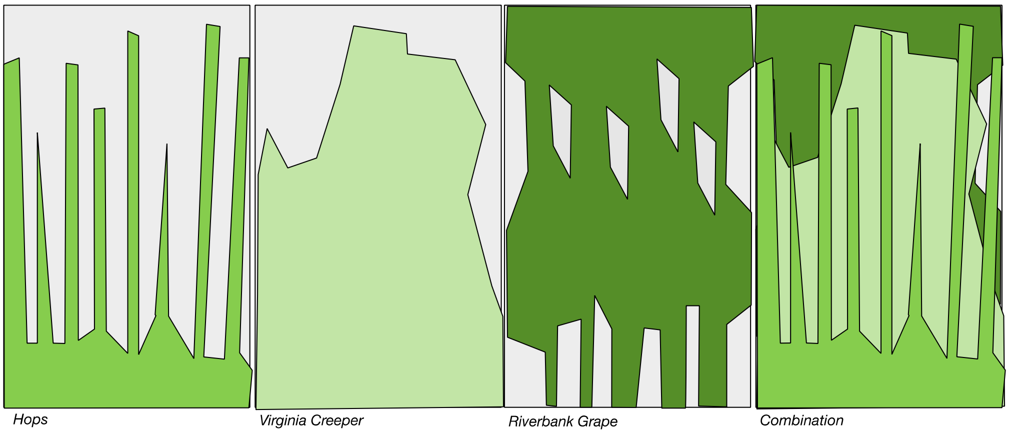

Fig. 6. Conceptual drawing of growth pattern of each of the three vine species on the greenscreen® trellises and a conceptual pattern of all three species in combination.

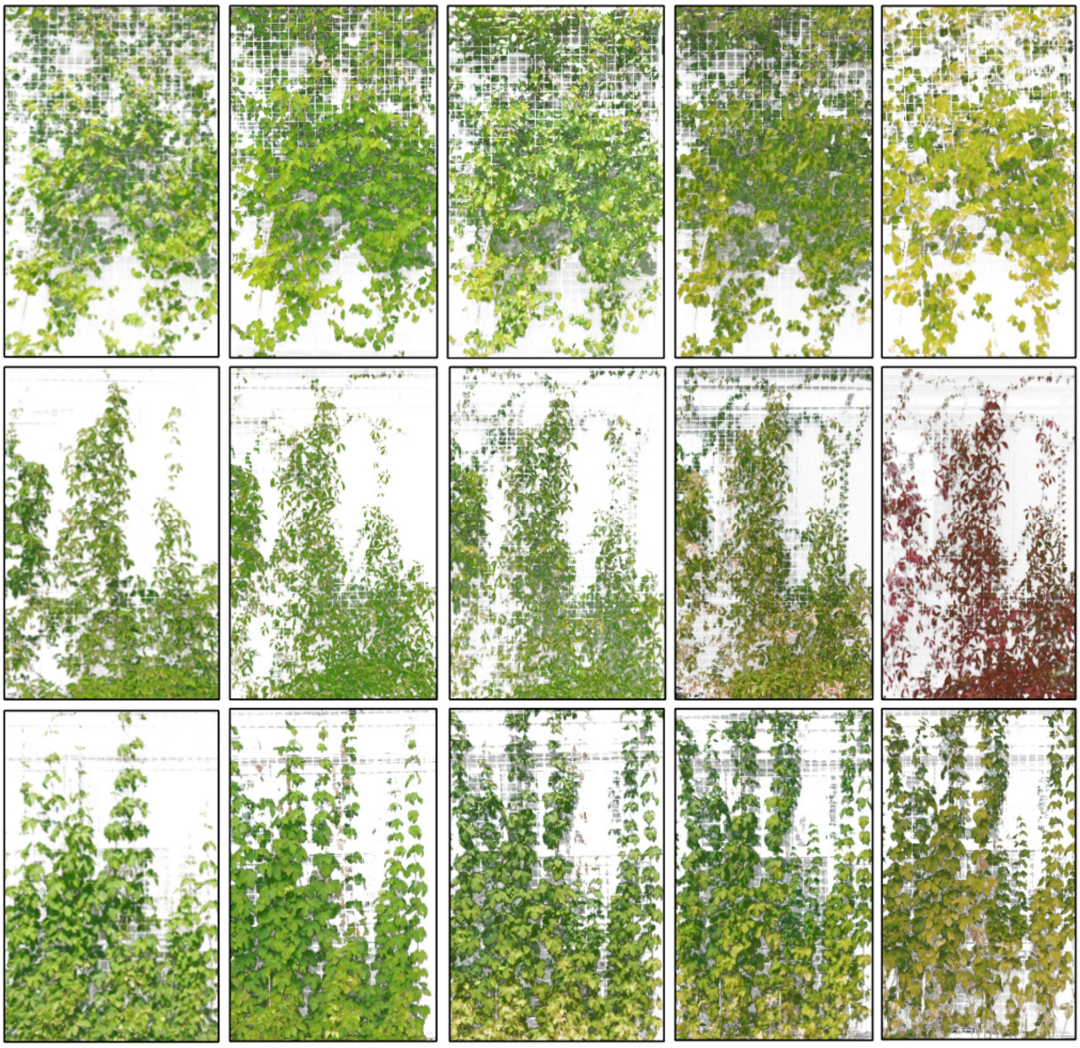

Fig. 7. Cover images for each of the three vine species in Region 1 (South-facing 3D greenscreen® façade wall against a building wall). From top to bottom: hops, Virginia creeper, grape.

DISCUSSION

Our study indicates there was no difference in wall cooling potential of the three vine species examined, but that vine façades cooled the building wall to a temperature significantly lower than the bare wall. This cooling effect increased over the season and was correlated with increasing vine growth over time. Our finding that vine façades reduced surface temperature by 6-11% is comparable to the temperate climate green façade temperature reduction values determined in Alexandri and Jones (2008) using common Ivy (*Hedera helix*). However, the cooling potential recorded in our study was less than that recorded by Tilley et al. (2012) where the weather is warmer (Maryland, USA) and vine growth enhanced by additional fertilizer, greater available soil depth, and greater volumes of supplemental irrigation. Moreover, our study set up was located on a rooftop experimental testing site whereas most others are carried out on façades immediately adjacent to ground level where conditions are presumably less extreme than in rooftop environments (Oberndorfer et al., 2007).

Hops

In this non-adhesive tendril deploying species as cover increased over the season, the reduction in surface temperature compared with non-vegetated wall surfaces significantly increased (Fig. 5). Hops had a different growth pattern than both grape and creeper, not only in form, but also phenology; hops grows quickly, but dies back over winter. Because of the dieback, it begins the season with low cover at basal stems that quickly increases from spring to summer using the trellis to support itself. Because of the winter dieback, hops might be a good choice for maximizing multi season thermal benefits of vine façades, as in cold seasons, absorption of solar radiation through building walls will be preferred. However, in application, this species would require more maintenance cleaning dead stalks and restringing new vines in the spring.

Virginia Creeper

Virginia creeper kept most of its foliage into the winter, eventually it falls but unlike hops, leaves regrow from stems spread about the trellis from previous year(s). As a result, less change in vegetated cover over the study period (2012-2013) was observed, and wall surface temperature was significantly cooler than non-vegetated walls. One potential issue with Virginia creeper in vine façade applications is that it tends to not conform to the trellis. As an adhesive-tendril climbing vine, it grows through the trellis and can attach to bare exterior wall surfaces. Re-stringing can be accomplished in maintenance visits but gaining access to behind installed trellises can be difficult, adding to maintenance requirements. Since Virginia creeper is an understory vine that is adapted to low light conditions (Carter and Teramura, 1988), the slightly more shaded conditions behind a trellis might be preferred, continuing this issue over time and warranting more research on the vine species in trellised applications. One other interesting observation was that as Virginia creeper foliage turns red by September, this apparently has no significant effect on temperature reductions (Fig. 7). The colour change greatly increases visual interest, especially in combination with the other two species.

Anecdotally, we noted that Virginia creeper was more resistant to weeds than the other two vine species. This was perhaps because its foliage tended to cover the growing media surface within the module right away, potentially blocking incoming seeds from germinating. This differed from the other two vine species that had mostly bare substrate areas, and as such, more weeds. If including grapes or hops in a vine façade, it might be useful to include natural mulch or maintain grass or wildflower plantings to suppress weeds.

Grape

Grape had the greatest overall cover among the three vine species after 2 years (Fig. 5). Grape vine tended to bunch half way up the trellis at the point where the stalking used to support the vines in Year 1 ended, and at the very top of the trellis, at which point the vines would begin to drape down (Fig. 6). Grape grew aggressively on the trellis so much so that maintenance to re-string the non-adhesive vine tendrils back within the boundaries of the façade module was necessary nearer the end of the growing season. Grape vines also produced berries in the second year, which are attractive to birds, but also to invasive paper wasps (*Polistes fuscatus*) and could be perceived to be a nuisance as staining by berries on the surrounding ground adds to maintenance and avoidance of the area by building users. Grape was also attractive to beneficial insects: leaf cutter bees cut circles out of the leaves to use as nest building materials, which has little impact on plant cover or survival. Grape, like Virginia creeper displays a mix of colour in its leaves over the season, adding to visual interest. Given the colour range and growth patterns of the three vine species examined, aesthetically it would be interesting to combine these in vine façade applications. Further, studies that combine all three species in an experimental setup could interpret whether diversity can improve thermal benefits of vine façades.

CONCLUSIONS

This study provides much needed evidence of performance benefits of vine façade infrastructure in a temperate climate where demand is high but application rate and success is lower than that in tropical and Mediterranean regions. Although climbing vines on buildings have long been a part of human societies, there is increasing need to quantify their contribution to building cooling in contemporary designs as they become more commonplace in architectural designs.

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Literature Cited

Akbari, H., Pomerantz, M. and Taha, H. 2001. Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Solar Energy 70:295-310.

Alexandri, E. and Jones, P. 2008. Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. Building and Environ. 43:480-493.

Carter, G.A. and Teramura, A.H. 1988. Vine photosynthesis and relationships to climbing mechanics in a forest understory. Amer. J. Bot. 75:1011-1018.

Cheng, C.Y., Cheung, K.S. and Chu, L.M. 2010. Thermal performance of a vegetated cladding system on facade walls. Buildings and Environ. 45:1779-1787.

Di, H.F. and Wang, D.N. 1999. Cooling effect of ivy on a wall. Experimental Heat Transfer 12:235-245.

Dunnett, N. and Kingsbury, N. 2004. Planting Green Roofs and Living Walls. Timber Press, Portland, Oregon.

Ellin, N. 2013. Integral urbanism: a context for urban design. In: S.T.A. Pickett, M.L. Cadenasso and B. McGrath (eds.), Resilience in Ecology and Urban Design. Springer, New York.

Holm, D. 1989. Thermal improvement by means of leaf cover on external walls: a computerized simulation model. Energy and Buildings 14:19-30.

Hunter, A. M., Williams, N.S., Rayner, J.P., Aye, L., Hes, D. and Livesley, S.J. 2014. Quantifying the thermal performance of green facades: a critical review. Ecol. Engineer. 63:102-113.

Köhler, M. 2008. Green facades—a view back and some visions. Urban Ecosystems 11:423-436.

Kontoleon, K.J. and Eumorfopoulous, E.A. 2010. The effect of the orientation and proportion of a plant-covered wall layer on the thermal performance of a building zone. Building and Environment 45:1287-1303.
MacIvor, J.S., Margolis, L., Puncher, C.L. and Carver-Matthews, B.J. 2013. Decoupling factors affecting plant diversity and cover on extensive green roofs. J. Environ. Manage. 130:297-305.
Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R., Doshi, H., Dunnett, N., Gaffin, S., Kölher, M., Liu, K. and Rowe, B. 2007. Green roofs as urban ecosystems: Ecological structures, functions, and services. BioSci. 57:823-833.
Olivieri, F., Neila, F.J. and Bedoya, C. 2010. Energy saving and environmental benefits of metal box vegetal facades. p.325-335. In: C.A. Brebbia, N. Jovanovic and E. Tiezzi (eds.), Management of natural resources, sustainable development and ecological hazards II. Second International Conference on Management of Natural Resources, Sustainable Development and Ecological Hazards, Ravage of the Planet II.
Olmstead, M.A., Wample, R., Greene, S. and Tarara, J. 2004. Nondestructive 836 measurement of vegetative cover using digital image analysis. HortSci. 39:55-59.
Ottelé, M., Perini, K., Fraaij, A.L.A., Haas, E.M. and Raiteri, R. 2011. Comparative life cycle analysis for green facades and living wall systems. Energy and Buildings 43:3419-3429.
Pérez, G., Rincón, L., Vila, A., González, J.M. and Cabeza, L.F. 2011. Green vertical systems for buildings as passive systems for energy savings. Applied Energy 88:4854-4859.
Perini, K., Ottele, M., Fraaij, A.L.A., Haas, E.M. and Raiteri, R. 2011. Vertical greening systems and the effect on air flow and temperature on the building envelope. Energy and Buildings 46:2287-2294.
Stec, W.J., van Paassen, A.H.C. and Maziarz, A. 2005. Modelling the double skin facade with plants. Energy and Buildings 37:419-427.
Susorova, I., Azimi, P. and Stephens, B. 2014. The effects of climbing vegetation on the local microclimate, thermal performance, and air infiltration of four building facade orientations. Building and Environ. 76:113-124.
Sutton, R. 2015. Introduction. In: R. Sutton (ed.), Green Roof Ecosystems. Springer-Verlag
Tilley, D., Price J., Matt, S. and Marrow, B. 2012. Vegetated walls: thermal and growth properties of structured green facades (UM-09040836).
Wong, N.H., Kwang Tan, A.Y., Chen, Y., Sekar, K., Tan, P.Y., Chan, D. and Wong, N.C. 2010. Thermal evaluation of vertical greenery systems for building walls. Building and Environ. 45:663-672.