STUDY ON THERMAL FUNCTION OF IVY-COVERED WALLS

Mr. Liao Zaiyi, Dr. Niu J.L

Dept. of Building Services Engineering
The Hong Kong Polytechnic University
Hunghum, Kowloon, Hong Kong
E-mail: bejlniu@polyue.edu.hk

ABSTRACT

This paper presents a mathematical model yielding a simplified representation of the thermal behaviors of ivy-covered walls. The model is integrated with a CFD program to implement simulation. Experimental results have been used to form the boundary conditions of numerical simulations. A series of parametric sensitivity analyses have been carried out for identifying the key factors that affect ivy-coverings' potential for reduction on cooling load of the buildings. These analyses indicate that ivy-coverings can considerably reduce the heat flux through the external walls that its cover. Three key parameters have been identified as relevant for ivy-covered wall design: green density (d), covering ratio (r), the supporting grid's geometrical characteristics.

INTRODUCTION

Over centuries have natural cooling techniques been employed, but their application has been very scarce in recent decades when mechanical cooling devices have become the standard alternative [1]. This results in a great energy expenditure and extra anthropogenic heat emission from buildings. To improve energy efficiency of buildings, researches have been focused on improving efficiency of devices and enhancing thermal insulation of buildings. Recently, due to the increasingly serious energy shortage and global environmental pollution, requirement on building energy efficiency has been becoming higher. So application of natural cooling techniques becomes very important and researchable.

The potential of vegetation to significantly reduce building cooling loads has been reported in a number of studies. In 1980's, Huang [6] [7] and his group in Lawrence Berkeley Laboratory conducted a study on "the potential of vegetation in reducing summer cooling loads in residential buildings". The results indicated that vegetation is beneficial to energy conversation, creating a potential for up to 25% of energy saving. However many technical details are still not well understood. This is reflected by the fact that there is a lack of technical information supporting landscaping that addresses energy and thermal performance issues. As a result of this gap in research, architects and planners have not fully exploited the benefits of landscaping [10].

Ivy-coverings on buildings, as a pleasant architectural feature, can be found throughout China, especially in it's sub-tropical regions [8]. It is one of the most important styles of how vegetation exists in buildings in this region. A proper arrangement of ivy-coverings on buildings not only proves psychological effects but also improves unfavorable microclimatic conditions. Figure 1 presents a sample of ivy-covered walls in Hong Kong. The original design concern of this ivy-covered wall was that the designers tried to evolve and to adopt external planting outside windows that has been a vernacular practice in urban dwellings in Hong Kong. However it is difficult, if not impossible, to quantitatively assess the actual effectiveness and figure out failures for future improvement because technical tool for such assessment is inadequate. When architects and planners design a thermal environment, they require the available data that can indicate the effects of each climatological use of plants. However, little such data has been available for the quantitative analysis of how planting techniques affects the building's thermal environment or how it produces energy savings in air-conditioned buildings. The value of ivy-coverings as a technique to reduce air-conditioning loads has neither been well understood nor documented.

Figure 1: An ivy-covered wall in Hong Kong
(source: Dept. of Architecture, CUHK, Hong Kong)

Ivies as pavement on buildings, can protect the external walls from direct solar radiation and could cool it through enhanced evaporation. It is furthermore compatible with the functional, aesthetic and ecological criteria applied to design of the surroundings [1]. Ivies convert over 70% of solar energy that its absorb into bio energy via photosynthesis, without greatly increasing its temperature [8] [9]. This results in a much lower long-wave radiation between foliages and the surfaces of external walls that are shaded underneath ivies. Vu and Asaeda [2] found that temperature of green leaves could be 23 °C lower than the asphalt and concrete surfaces under same level of solar radiation. Liao [8] in his site measuring has found a similar result. The preliminary result indicates that ivy-covered walls can reduce solar loads by up to 30% [8]. In 1980s', Akira Hoyano conducted an experimental study on effects of an *ivy sunscreen* [3] covering a west wall. He reported that ivy-coverings (fully) could reduce heat flux through the external walls by 3 quarters [3]. He has also figured out the highly inverse correlation between solar transmittance and ivy growth conditions (including foliage geometric characteristics and covering ratio) [3].

However, the technical information supporting a *technical ivy-covering treatment* that can optimize the climatological effects of ivy-coverings is still scarce. This study aims to develop a mathematical model for simulating thermal behaviors of ivy-covered walls and assessing the potential for savings in cooling energy. The model in detailed represents the mechanism of how ivy-coverings interact with the wall to create a microclimate. The key relevant parameters that greatly affect the thermal function of ivy-coverings will be addressed to identify the criteria for ivy-covering design and treatment.

MATHEMATICAL MODEL

Figure 2a and 2b show a sample of ivy-covered wall (ICW). No extra supporting structures are built to hold ivies. The ivies just naturally climb upward on the wall. Obviously, three major components can be distinguished in an ivy-covered wall: the ivy canopy (leaves), the root grid, and the wall. The foliages basically form the canopy that shades the wall that would otherwise be exposed directly to the sun and the surroundings.

Figure 2a: An Ivy-covered Wall

Figure 2b: A Close-up of ICW

The root grid, climbing upward on the wall, links the leaves and the wall together. In this study, an extra structure enhancing such linkage is proposed: a metal grid supporting roots. It is embedded into buildings' external wall, providing grids that stabilize ivies' climbing on the wall. So the ICW model, as illustrated in figure 3, is derived from three models: ivy canopy, supporting grid (SG), and external wall. In this paper, the ICW is supposed to be horizontally large enough to assum horizontal homogeneity. Therefore a 2-dimentional model will be developed.

<u>Ivy Canopy Model</u>

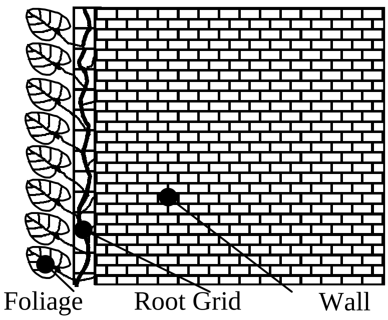


Figure 3a Structure of ICW

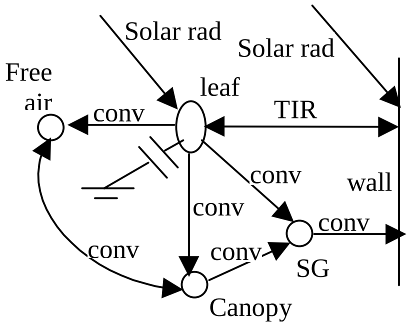


Figure 3b Representation of the model

The ivy canopy is basically composed of the leaves and the air within the leaf cover. The complexity of a canopy as a system of sources and sinks of heat and mass is such that an exact description of its physical behavior is almost impossible. In this paper, a canopy is treated as one homogeneous layer, which is characterized by:

(1) one identical value of leaves temperature;
(2) and one identical value of temperature and moisture content of the air within the leaf cover;

The ivy canopy is geometrically characterized by the following factors that determine the growth condition of ivies:

(1) covering ratio (r) : the percentage of the wall surface covered;
(2) green density (d): the surface area of leaves within the control volume. For a certain level of covering ratio, a higher green density means a better growing condition of the ivy.
(3) leaf shapes: simple leaf, dissected leaf, and compound leaf [4].

The major processes contributing to the determination of the canopy's thermal state include:

(1) solar radiation absorbed by the leaves;
(2) long-wave radiative exchange (TIR) between the leaves and the sky and the surroundings;
(3) convective heat transfer between the free air (outside the canopy) and the air within the canopy;
(4) convective heat transfer between the leaves and the air (both free and within the canopy);
(5) transpiration in the leaves;

(6) photosynthesis that converts solar energy absorbed into bio-energy.

So, the heat balances of the leaves and the air in the canopy look like:

$$(r\delta d)_{leaf} * (c\rho)_{leaf} * H_{canopy} * \frac{dt_{leaf}}{d\tau} = \psi_{rad,sol} + \psi_{rad,TIR} + \psi_{conv,leaf-air} + \psi_{trans,leaf-air} + \psi_{photo} \quad (1)$$

$$(c\rho)_{air} * H_{canopy} * \frac{dt_{air}}{d\tau} = \psi_{conv,leaf-air} + \psi_{conv,air-free} + \psi_{conv,air-SG} \quad (2)$$

where:

r	ivy covering ratio (%);
d	green density (m^2/m^3), defined as the surface area of leaves within controlled volume;
δ	average thickness of ivy leaves (m);
ρ	density (kg/m^3);
c	specific heat (J/kg.K);
t	temperature (°C);
τ	time (sec);
H_{canopy}	height of canopy (m);
leaf	leaves of the ivy;
air	air within the ivy cover;
$\psi_{rad, sol}$	the amount of absorbed solar radiation (W/m^2);
$\psi_{rad,TIR}$	the net long-wave radiation on leaves (W/m^2);
$\psi_{conv,leaf-air}$	the convective heat flux between the leaves and the surrounding air (W/m^2);
$\psi_{trans,leaf-air}$	the heat flux due to leaves transpiration (W/m^2, negative);
ψ_{photo}	the energy consumed for photosynthesis (W/m^2);
$\psi_{conv,air-free}$	the convective heat flux between the free air and the air within the canopy (W/m^2);
$\psi_{conv,air-SG}$	the convective heat flux between the air within the canopy and the air within the supporting grid (W/m^2).

The heat transfer flux, except ψ_{photo}, including $\psi_{trans,leaf-air}$, in the right side of the equations can be calculated based on the method described by E. P. Del Barrio [1]. ψ_{photo} is treated as proportional to the absorbed solar radiation [9]. The inputs of the canopy model are solar radiation flux, sky temperature, surface temperature of the external wall, and outside temperature.

The air in canopy section but not covered by leaves moves into the supporting grid. So the gaps formed by leaves act as air inlets of the SG.

Supporting Grid Model

The supporting grid basically is composed of the metal grid where the roots of ivies climb, roots, and the air within it. In this study, the impact of the thermal masses and conductivity of the metal grid and roots is ignored. So the SG model just presents the behaviors of the air within it.The SG is characterized by the height of the grid. A time averaged turbulance transport model, k-ε, is employed to model the air within a SG. The resulting mean conservation equations of momentum can be written in the 2-dimensional formula:

$$\frac{\partial(\rho \upsilon_x)}{\partial \tau} = \frac{\partial}{\partial y}(\mu \frac{\partial \upsilon_x}{\partial x} - \rho \cdot \upsilon_x \upsilon_y) + S_x \quad (3)$$

$$\frac{\partial(\rho \upsilon_y)}{\partial \tau} = \frac{\partial}{\partial x}(\mu \frac{\partial \upsilon_y}{\partial y} - \rho \cdot \upsilon_x \upsilon_y) + S_y \quad (4)$$

$$S_x = \frac{\partial P}{\partial x} + \frac{\partial}{\partial x}(\mu_e \frac{\partial \upsilon_x}{\partial x}) + \frac{\partial}{\partial y}(\mu_e \frac{\partial \upsilon_y}{\partial x}) \quad (5)$$

$$S_y = \frac{\partial P}{\partial y} + \frac{\partial}{\partial x}(\mu_e \frac{\partial \upsilon_x}{\partial y}) + \frac{\partial}{\partial y}(\mu_e \frac{\partial \upsilon_y}{\partial y}) \quad (6)$$

where:

P	pressure (Pa);
μ_e	effective molecular viscosity (Pa.S);
ν_x ν_y	air velocity in x and y direction (m/s).

The energy equation can be written in the following formula:

$$\frac{\partial(\rho t)}{\partial \tau} = \frac{\partial}{\partial y}(\frac{\mu}{\Pr}\frac{\partial t}{\partial x} - \rho * t * \upsilon_y) + q''/c \quad (7)$$

where:

Pr	Prandtl number
q"	Heat flux per unit volume (W/m^3).

The boundary conditions are two folds: inlets among the canopy, and the wall surface. The heat transfer between air within a SG and the wall can be written as:

$$Q = h_{wall} * A * (t - t_{wall}) \quad (8)$$

where:

h_{wall}	convective heat transfer coefficient on the wall surface ($W/m^2.°C$);
t_{wall}	temperature of the wall surface (°C);
A	surface area of the wall concerned (m^2).

External Wall (EW) Model

Although it is not necessary, to simplify the problem, the wall is assumed as a homogeneous layer of a solid material. This layer has constant thermophysical properties. The heat transfer equation is in two dimensions:

$$\frac{(\rho c)_{wall}}{\lambda_{wall}} * \frac{\partial t}{\partial \tau} = \frac{\partial^2 t}{\partial x^2} + \frac{\partial^2 t}{\partial y^2} \quad (9)$$

where:

λ_{wall} the thermal conductivity of the wall ($W/m^2.°C$)

The inside ambient air is assumed of a constant temperature. Therefore the boundary condition for this side is:

$$-\lambda_{wall} * \frac{\partial t}{\partial x}\Big|_{x=L} = h_{in} * [t(L,\tau) - t_{in}] \quad (10)$$

where:

L thickness of the wall (m);

h_{in} convective heat transfer coefficient on the insidewall surface ($W/m^2.°C$).

Ivy-covered Wall (ICW) Model

The ICW model is composed of the ivy canopy model, supporting grid model, and external wall model described above, together with the coupling models. Such models represent the boundary conditions at the canopy-SG and SG-EW interfaces, satisfying the physical constraints of continuity for the state variables and the flux.

Canopy-SG coupling model

Continuity of the state variables at the Canopy-SG interface implies:

$$\psi_{conv,air-SG} = h_{air-SG} * (t_{air,SG} - t_{air@canopy}) \quad (11)$$

SG-EW coupling model

Continuity of the heat transfer flux at the SG-EW interface implies:

$$-\lambda_{wall} \frac{dt_{wall}}{dx}\Big|_{x@SG-EW} = \psi_{conv,SG-EW} + \psi_{TIR,leave-EW} \quad (12\text{-}1)$$

$$-\lambda_{wall} \frac{dt_{wall}}{dx}\Big|_{x@SG-EW} = \psi_{conv,SG-EW} + \psi_{rad,TIR} \quad (12\text{-}2)$$

where:

$\psi_{TIR,leave-EW}$ the net long-wave radiative heat transfer between leaves and the external wall.

$\psi_{conv,SG-EW}$ the convective heat transfer between the air in the SG and EW.

Equation 12-1 applies to the ivy-covered section, 12-2 applies to the section directly exposed to solar radiation.

The geometric characteristics of the ICW mode include:

(1) foliage covering ration (r);
(2) green density (d);
(3) average leaf thickness (δ);
(4) and the height of SG (H).

These parameters define the thermal performance of an ICW. This study aims to obtain an understanding of how these variables impact on the function of an ICW. Such are treated as constants in a simulation case. To figure out the impacts of these parameters, a series of simulation are needed to establish a parametric sensitivity analysis.

NUMERICAL SIMULATION

As the first stage of the study, this paper concerns with steady-state cases. Numerical method is developed to calculate the thermal performance of the external wall. In this paper, for simplification of the problem, the construction of EW is a 370mm of clay brick wall. The thermal properties of the wall is listed as the following:

Density: 1200 kg/m^3
Thermal conductivity: 0.81 W/m.K
Specific heat: 800 J/kg.K

The boundary conditions of EW are:

(1) The indoor side: temperature of inside ambient air is treated as a constant, or 25°C. The convective heat transfer coefficient is 8.33 $W/m^2.K$.
(2) The outside surface essentially consists of two parts: one shaded by ivies and the other directly exposed to solar radiation. The shaded one is treated as a convective and radiative boundary. The convective heat transfer coefficient of this part is 16.6 $W/m^2.K$. Given different combinations of (r, d, H), the Ivy Canopy model and SG model are employed to calculate the environmental temperature that is used to determine radiative heat exchange. The exposed one is treated as a normal exterior surface of external wall. It is also a convective and radiative boundary. But the long-wave radiation of this part is ignored because direct solar radiation is much greater.

Numerical method is also employed to perform simulation of SG model. This step establishes the boundary conditions of EW described above. The boundary conditions of SG are listed as the following:

(1) The EW side: shaded wall and exposed wall alternatively located. The ratio of shaded one to exposed one is calculated by the following equation:

$$\frac{shaded}{\exp osed} = r * \frac{d}{d_0} \quad (13)$$

where:

d_0: reference green density.

(2) The Ivy Canopy side: ivy is treated as a solid object that exchanges heat with air within ivy

canopy and free air, as described by equations (1) and (2). The gap between ivy foliages is treated as air inlet. Similarly, covering ratio (r) is employed to size the air gap.

Experimental data is employed to determine temperature of the foliages. Under a certain solar radiation, a normally growing leaf of green color can remain much lower temperature than any building materials. Temperature of the shined surface can be as low as just 2 to 3°C higher than the ambient air. This study employs this simplified relationship to calculate temperature of leaves. All leaves are treated as homogenous thermal object, or of an identical temperature. Thus, given climatic condition, temperature of leaves can be determined.

Overall, the following three steps are involved in implementation of the ICW model:

(1) Determine climatic condition and temperature of leaves.
(2) Construct mesh grid of air within SG according to (r, d, H). Then employ numerical method to performance simulation of SG. Figure 4 presents the profile of air movement within the SG under the conditions: solar radiation intensity is 900 W/m^2, temperature of free air is 30 °C, velocity of free air is 1.5 m/s.
(3) Using the outputs of step2, assign the boundary conditions of EW model. The mesh grid is predefined according to (r, d). Figure 5 presents temperature pattern in the external wall under different covering ratios.

Given different combinations of (r, d, H), the heat flux from the external wall into indoor air can be respectively calculated. To analyze impacts of one variable on the thermal performance of an ICW, the other two variables are kept constant so that a sensitivity analysis of this variable can be established. Such analysis can answer the questions that this paper rises up in the beginning.

RESULTS and SENSITIVITY ANALYSIS

Heat flux transferred into the indoor air is selected as an indication of the thermal performance of an ICW. Under static condition, it can be calculated by the following equation:

$$HF = h_{in} * (t_{wall}\big|_{Inside} - t_{in}) \qquad (14)$$

where:

$t_{wall}|_{inside}$: temperature of an ICW's inside surface.

Given a combination of (r, d, H), HF can be calculated accordingly. The following parametric analyses are established under such common conditions:

(1) wall: 370mm clay brick;
(2) indoor temperature: 25 °C;

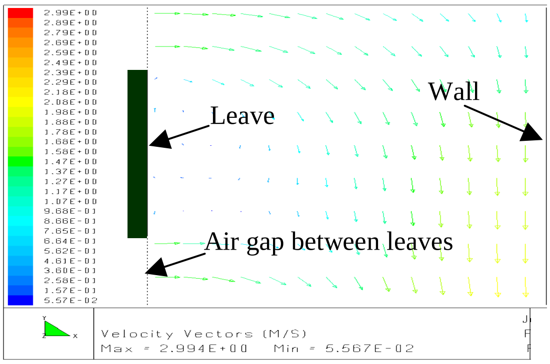
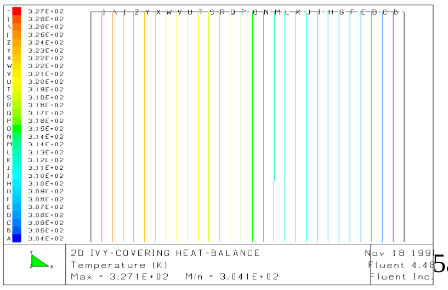
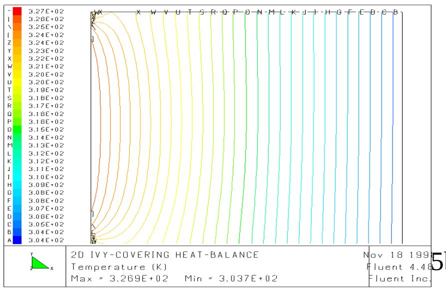


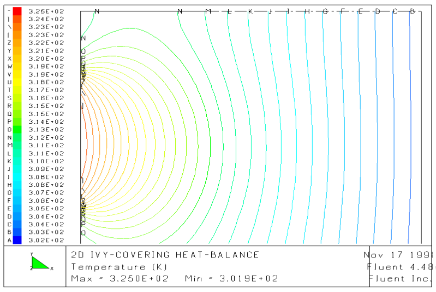
Figure 4 Air movement within SG



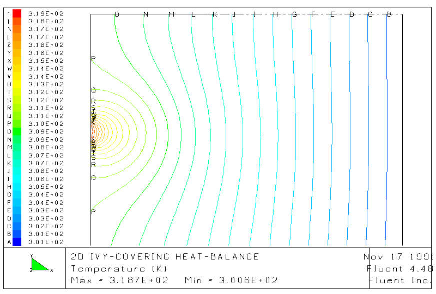
5a: r=0%, d=2



5b: r=10%, d=2



5c: r=50%, d=2



5d: r=90%, d=2

Figure 5: temperature pattern in an ivy-covered wall

(3) outdoor air temperature: 34°C;
(4) solar radiation flux: 800 W/m^2;

(5) reflectance of external surface: 0.65.

Three group of parametric sensitivity have been carried out as:

(1) HF versus Covering Ratio (r)

Case condition:
r : 0, 10%, 30%, 50%, 70%, 90%, 100%.
d : 1, 2, 3
H : 5, 10, 15 (mm)

Case	d=1	d=2	D=3
H=5mm	*	*	*
H=10mm	*	*	*
H=15mm	*	*	*

Simulation result is presented in Figure 6.

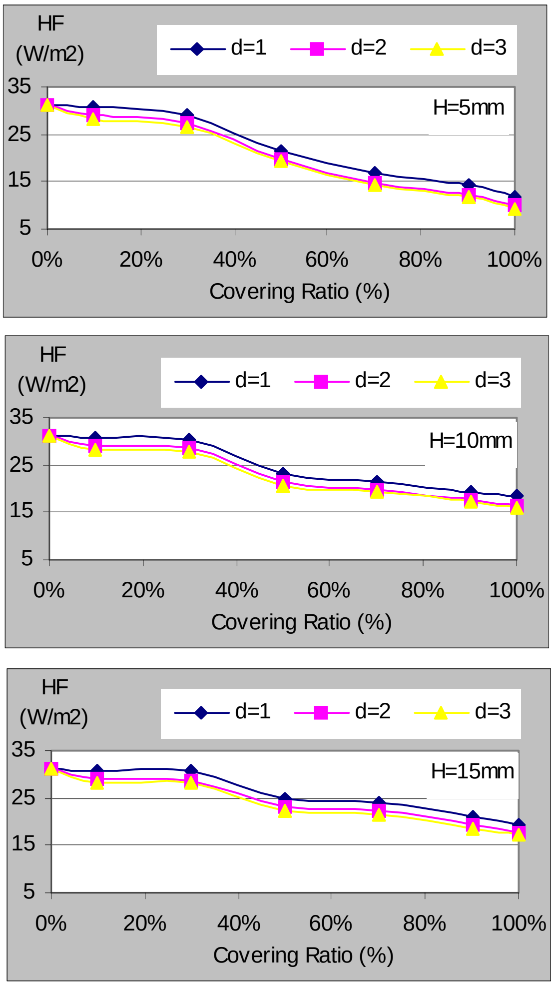


Figure 6 Relationship between HF and Covering Ratio (r)

The figure shows that for a certain height of SG, HF decreases considerably as covering ratio (r) increases. It can be explained because an increment of r results in a bigger portion of wall surface that can benefit from shading of ivies. However, it is also found that when r is less than 30%, HF is very closed to the situation of a bare wall. This is because sectional heat conduction in the wall will thus omit the benefit benefits of ivies. This criteria value, 30% for brick wall, varies with the thermal properties of walls. Between 40% to 90%, HF has strongest inverse correlation with covering ratio.

The three figures together also show that an increment of d value can slightly reduce HF. This is because for a certain value of r, bigger the value of d is, bigger portion of the external wall's surface will be actually shaded. Green Density is determined by the growing condition of ivies. A better planting results in a higher green density.

Therefore, to obtain the best performance of ICWs, It is needed to grow ivies above a certain level of covering ratio, for brick wall, the covering ratio should not be less than 30%.

(2) HF versus Green Density (d)

Case condition:
d : 1, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0
r : 30%, 60%, 90%
H : 5, 10, 15 (mm)

Case	r=30%	r=60%	r=90%
H=5mm	*	*	*
H=10mm	*	*	*
H=15mm	*	*	*

Figure 7 presents the simulation result.

The figures show that for a certain level of covering ratio, Green Density has considerable impacts on HF while d is less than 2.5. Once d becomes greater than 2.5, HF has very small dependency on d value. It can be explained because once d is greater than 2.5, shading coefficient can no longer be improved considerably by enlarged area of leaves. Therefore, in case green density reaches a certain level, for instance 2.5 for brick wall, it is important to give higher priority to achieve bigger covering ration rather than to increase green density.

(3) HF versus Height of SG (H)

Case condition:
H :5, 10, 15, 20 (mm)
d : 1, 2, 3
r : 30%, 60%, 90%

Case	d=1	d=2	D=3
r=30%	*	*	*
r=60%	*	*	*
r=90%	*	*	*

Figure 8 presents the simulation result.

The figure shows that for a certain level of green density, HF has a considerable dependency on H value. Bigger H value is, higher HF is. This is because a bigger H results in more freedom for outside free air, that is hotter in cooling season, to enter SG, which in turn increases heat convection from air to the wall. Therefore, it is important to always minimize the height of SG. The figure also shows that higher covering ratio is, bigger this dependency will be. While designing an ICW, SG should be configured as small as possible.

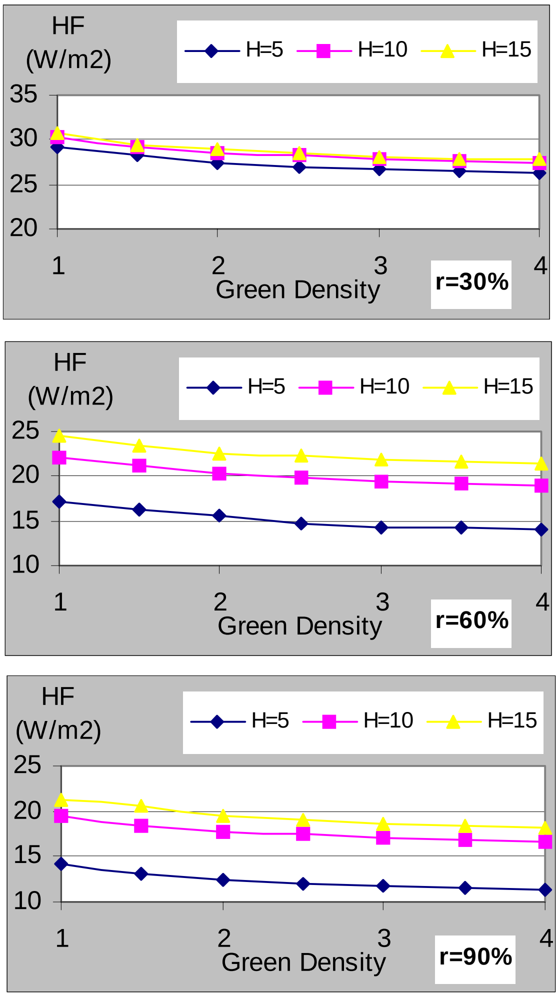


Figure 7 Relationship between HF and Green Density (d)

CONCLUSION and FUTURE WORKS

This paper introduces a model framework for simulating the thermal behaviors of ivy-covered walls. The model is then simplified and the numerical method has been employed to implement simulations. A series of parametric sensitivity analyses have been carried out to identify the key factors as relevant for technical ivy treatment with an aim of optimizing the climatological effects of ivy-covered walls in buildings. The key finding are highlighted as:

(1) An ICW is essentially consisted of three key components: ivy canopy, supporting grid, and external wall.

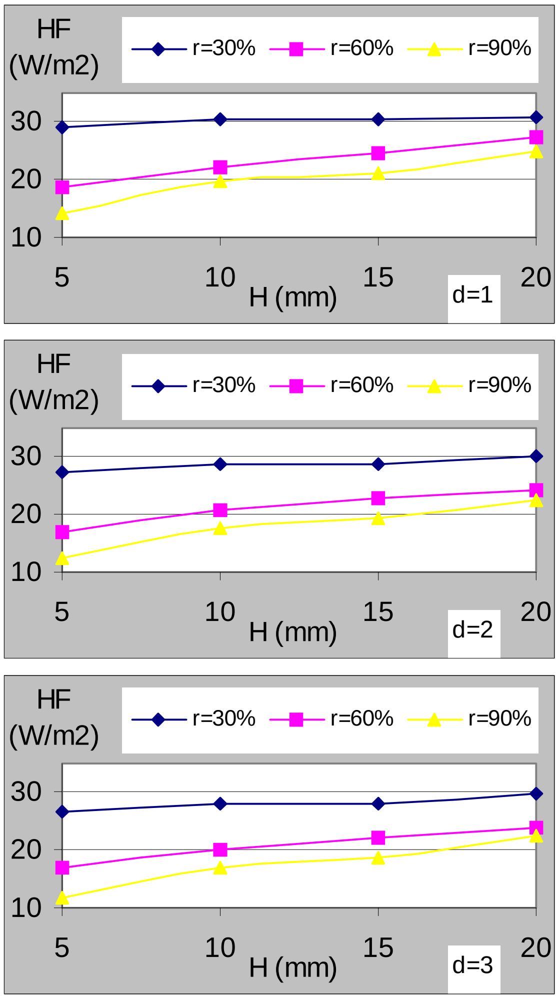


Figure 8 Relationship between HF and H

(2) The key factors that significantly affect the thermal function of an ICW include: green density (d), covering ratio (r), and geometrical characteristics of the supporting grid (H).

(3) Given certain d and r, heat flux transferred into indoor (HF) increases as H becomes bigger while H remains within the critical point.

(4) Given H and d, HF increases as r becomes smaller. It can be explained because a smaller r means less percentage of the external wall is shaded from direct solar radiation. The covering ratio (r) has most significant effect on the thermal function of an ICW.

(5) Given H and r, HF slightly increases as d becomes smaller. The percentage of the external wall surface that is shaded actually is determined not only by covering ratio, but also the green density. While the density is 1, this percentage equals to covering ratio. While d increases, this percentage slightly becomes bigger.

(6) Therefore, in case that construction requirement can be satisfied, the height of the supporting grid should be as small as possible. And covering ratio should be as big as possible. HF becomes significantly higher while r is less than 30%. An ICW of r value lower than that has similar thermal performance of a bare wall. Therefore, to take advantage of ivy-coverings, the covering ratio must greater that this value. Compared with a bare wall, a 100% covered wall could reduce solar gain by up to 37%.

To simplify implementation of simulation, a steady-state model has been employed. To study the thermal performance of ICWs in more detailed, it is necessary to simulate the time-dependent cases in the future study. An experimental system will also be built up to produce essential data that can verify the accuracy of the simulations.
Since a complete rigorous numerical simulation is too complicated, this paper presents the mathematical model and the framework for such a would-be simulation. In this paper, simplification is made to preliminarily investigate the key parameters of ICWs. Due to the simplification, the effect of some parameters, such as H, could not be well established. A conjunct heat-transfer simulation will be performed further to re-evaluate the effect of this design parameter.

REFERENCES

1. *Elena Palomo Del Barrio*. Analysis of the green roofs cooling potential in buildings. *Energy and Buildings Volume 27 (1998) P. 179-193.*

2. *V.Thanh C., T, Asaeda, E. M. Abu.* Reductions in air conditioning energy caused by a nearby park. *Energy and Buildings, Volume 29, Number 1 (1998), P. 83-92.*

3. *A. Hoyano.* Climatological Uses of Plants for Solar Control and the Effects on the Thermal Environment of a Building. *Energy and Buildings, Volume 11 (1988), P. 181-199.*

4. *S.H. Raza, M.S.R. Murthy, O. Bhagya, and G. Shylaja.* Effect of Vegetation on Urban Climate and Healthy Urban Colonies. *Energy and Buildings, Volume 15-16 (1990/91) P. 487-491.*

5. *Y. Harazono.* Effects of Rooftop Vegetation using Artificial Substrates on the Urban Climate and the Thermal Load of Buildings. *Energy and Buildings, Volume 15-16 (1990/91), P. 435-442.*

6. *Y. J. Huang, H. Akbari, and H. Taha.* The Wind-Shielding and Shading Effects of Trees on Residential Heating and Cooling Requirements. *1990 Winter ASHRAE Meeting, Atlanta, GA, February 10-14, 1990. Lbl-24131.*

7. *Y.J. Huang, H.Akbari.* The Potential of Vegetation in Reducing Summer Cooling Loads in Residential Buildings. *Lbl-21291.*

8. *Liao Zaiyi, Tsou Jinyeu.* Impacts of Greenbelts on the Thermal Environment of Residential Communities. *The First Conference on Architectural Design and Technology for Sub-Tropical Climates. Guangzhou, China, 1998.*

9. *Liu Qia.* Heat Transfer in Vegetated Rooftop of Urban Residential Buildings. *The First Conference on Architectural Design and Technology for Sub-Tropical Climates. Guangzhou, China, 1998.*

10. *Alan K. Meier.* Strategic Landscape and Air-conditioning Savings: A Literature Review. *Energy and Buildings, Volume 15-16 (1990/91), P. 479-486.*