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Cool and Green Roofs as Techniques to Overcome Heating in Building and its Surroundings under Warm Climate

Hodo-Abalo Samah*,#,1, G.N. Tiwari+, and Yawovi Nougbléga#

Abstract – *In this work, cool and green roofs have been simulated as passive cooling techniques. The model considered for heat transfer modelling is a structure representing normal room. The mathematical model developed is governed by the energy balance on each isothermal layer. Heat transfer equations are solved using a finite difference scheme and the Thomas algorithm. The investigation is carried out under New Delhi climate conditions. Concepts of solair temperature, solar heat gain factor, decrement factor and thermal load leveling are used to investigate each technique. When considering cool and green roofs, the most important parameters considered for this study are solar reflectance and Leaf-Area-Index (LAI) respectively. Depending on cool or green roof, the peak value of solair temperature is reduced by 35 °C or 20 °C respectively. In best case, maximum solar heat gain factor is less than 30% for cool roof against 14% for green roof. Thermal load leveling decreases as the solar reflectance or the LAI increases. It's clearer that, a larger solar reflectance or a great value of LAI reduces not only the heating in the building but also in it surrounding. The model has been validated with a previous experimental study, so it can be useful for engineer in optimization of such passive systems in practical buildings.*

Keywords – *cool roof; green roof; heat island mitigation; passive cooling.*

1. INTRODUCTION

Due to the climatic change and the heat island phenomenon, the temperature in cities increases continuously. These high ambient temperatures intensify the energy problem of cities and deteriorate comfort conditions in buildings. The houses and building sector account for 40% of total primary energy consumption [1]. Therefore, the reduction of energetic demand in this area is a priority in energy efficiency. The energy performance of buildings directive forces us to rethink our processes and constructive systems in the quest for higher energy efficiency and better integration of renewable energy. It is well known that the thermal performance of a building is a key aspect to consider during its design phase. A priori, it is more rational to reduce a cause of heating than to offset the heat load by increasing the cooling efficiency. On the other hand, a good thermal protection can greatly reduce the high thermal loads thereby improving thermal comfort in a hot-humid tropical building. The gains through the fabrics of the building can be minimized by the use of shading to reduce the amount of radiation falling on the building, the reduction of the absorbed radiation through the use of highly reflective finishes, the increase of the insulation value of the roof and walls. For years, many researchers have shown the role of building materials, the lens hoods or fixed overhanging roofs and building orientation on the improvement of thermal comfort in buildings. Some studies show that about 30-50% of the heat gains inside buildings are brought about by elements of the roof [2]. To counterbalance the phenomenon, important mitigation technologies have been developed and proposed. Various experimental studies proved that the heat gain through the roof can be reduced by white paint, layers of wetted gunny bags, a water pond with moveable insulation and water spreading equipment [3], [4], the use of cool coating and the roof top garden [5] – [9]. Among them, cool and green roofs technologies appear to be very promising when applied in the building and city scale. Some studies have been carried out to demonstrate cool roof efficiency in different climatological contexts [10], [11] and for different construction and occupancy typologies. In particular, Kolokotsa *et al.* [12] analyzed the performance of a cool roof applied on a laboratory building in Crete, Greece. The dynamic simulation results showed a year-round energy conservation of 19.8 % due to the cool coating application. Anna Laura *et al.* [13] performed the possibility of applying an innovative "cool roof" solution, consisting of a prototyped cool clay tile, on a traditional residential building in central Italy to improve the thermal conditions of the indoor environment. The year-round analysis shows that the proposed cool roof solution produces a maximum effect of decreasing summer peak indoor overheating of the attic by up to 4.7°C. Several studies focused on the potential decrease of the ambient temperature because of the increase of roof reflectivity. Savio *et al.* [14] and Synnefa *et al.* [15] have examined the local impact of cool roofs in New York, US and Athens Greece respectively. In [14], the impact of cool roofs on the potential ambient temperature decrease at 2 m height above ground has been evaluated for New York City, US, using simulations performed with the

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Penn State/ NCAR MM5 regional climate model [16]. An average solar reflectivity equal to 0.5 was used and it was found that the daily average temperature decrease in the various parts of the city ranges between 0.18 K and 0.36 K. In parallel, the average reduction of peak ambient temperature ranged between 0.31 K and 0.62 K as a function of the characteristics of the considered areas.

For many years, planted roofs have been a familiar construction in some countries. During the last few decades, due to climatic changes and especially the heat island effect in urban areas and the continuous destruction of green areas, planted roofs have been frequently referred to because of their ecological character and their contribution to energy conservation in the building sector. Nichaou *et al.* [17] determined how a green roof could save energy in buildings with different degrees of existing insulation. They recorded the internal temperatures for two buildings in Athens, both with similar insulation properties but one with a green roof. Without a green roof the internal air temperature exceeded 30℃ for 68% of the period, but with a green roof this was only for 15% of the period. Daily mean, maximum and minimum temperatures were found to be 2, 3 and 1 ℃ lower, respectively. Other analysis regarding the energy contribution of green roof in buildings is given in [18]. The paper describes the results of an experimental study carried out in an office building in New York, where a white, a black and a green roof were installed and monitored in parallel for about a year. Monitoring has shown that during the peak daily period the surface temperature of the green roof was almost 1-8 K lower than the temperature of the white membrane. Calculations of the contribution of the various roofing systems to the energy consumption of the building have shown that the installation of a green roof instead of a reflective one results in energy savings ranging between 40% and 110%.

Despite research that has been carried out so far, planted roofs are still a solution, which is proposed mainly for qualitative rather than quantitative reasons, since as a passive cooling technique they still cannot be a part of a building simulation study. Modelling cool and green roof should be useful for engineer in optimization of such passive systems in practical buildings. The present study aims mainly to model cool and green roofs and analyze the effect of vegetation cover and solar reflectance on the heat gains in respective buildings. Useful parameters such as solar heat gains factor, thermal load leveling, decrement factor and the solair temperature are the main control variables evaluated.

2. PHYSICAL MODEL

The physical models considered for heat transfer modeling are patios or test structures representing classic rooms. The models presented have taken into account different parts of the building: the roof, the indoor air zone and the underground assumed to be at underground water temperature (27°C). The patio with no opening has an internal height of 0.985 m (floor-ceiling). Figures 1 and 2 schematize the physical models chosen for cool and green roofs respectively.The studied zone is divided into N isothermal elements with different thickness and physical properties. The outside surfaces of the both roof are exposed to incident solar radiation, but convection heat transfer and radiation exchange with the sky also take place. The inside surfaces are subject to combine convection, radiation and conduction heat transfers. Generally, transfers into a room are much more complex because of being carried out in three dimensions space and time. The mathematical model is formulated by using the main following assumptions:

- The moisture of the air is nearly constant inside the room,
- The air is perfectly transparent in the infra-red radiation,
- The side walls of the structure are adiabatic,
- The growing medium is well drained.

Based on the above assumptions, the thermal network models are drawn up and the equations of transfers are written.

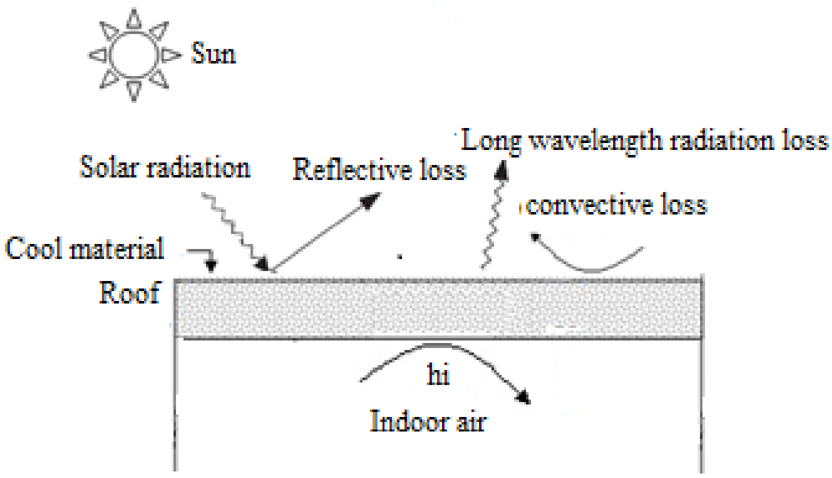

Fig. 1. Schematic representation of cool roof.

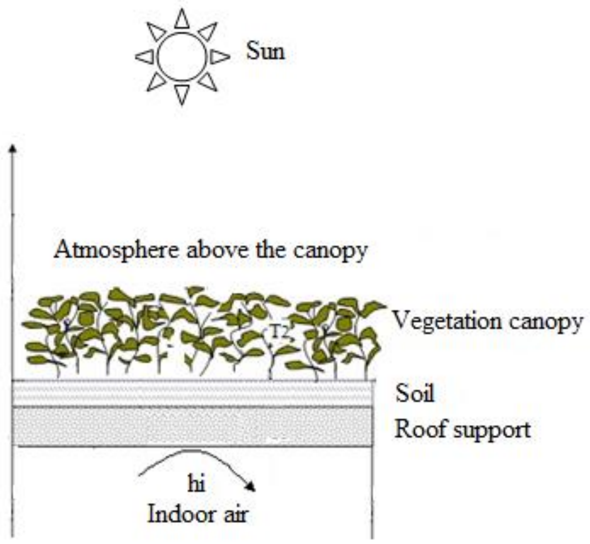

Fig. 2. Sketch of a green roof.

3. MATHEMATICAL FORMULATION

3.1 Cool Roof Model

The cool roof consist of cement flagstone covered with a reflective material or a cool coating and is discretized in four isothermal sublayers (N0=4). Energy balance equations of elements are:

$$e_1(\rho cp)_1\frac{\partial T_1}{\partial t}=\alpha I(t)-h_c(T_1-T_a) -h_r(T_1-T_{sky})-G_1(T_1-T_2) \tag{1}$$

$$e_j(\rho cp)_j\frac{\partial T_j}{\partial t}=G_{j-1}(T_{j-1}-T_j) -G_j(T_j-T_{j+1}) \tag{2}$$

for j=2,3

$$e_{N0}(\rho cp)_{N0}\frac{\partial T_{N0}}{\partial t}=G_{N0-1}(T_{N0-1}-T_{N0}) - h_{N0}(T_{N0}-T_{N0+1}) - h_{rN}(T_{N0}-T_N) - G_{N0}(T_{N0}-T_{N0+1}) \tag{3}$$

Indoor air zone is discretized in 10 identical and isothermal sublayers for which heat transfer equations are written:

$$e_j(\rho cp)_j\frac{\partial T_j}{\partial t}=h_{j-1}(T_{j-1}-T_j)+G_{j-1}(T_{j-1} - T_j)-h_j(T_j-T_{j+1}) - G_j(T_j-T_{j+1}) \tag{4}$$

for $j = N0+1, N-1$

Floor interacts with the roof and indoor air; its energy balance equation is:

$$e_N(\rho cp)_N\frac{\partial T_N}{\partial t}=h_{N-1}(T_{N-1}-T_N) +G_{N-1}(T_{N-1}-T_N)+h_{rN}(T_{N0}-T_N) -G_N(T_N-T_{soil}) \tag{5}$$

3.2 Green Roof Model

Effects of foliage density variation on the thermal performance of green roof are taken into account with the Leaf Area Index (LAI). Vegetable cover interacts with the ambient air and the growing medium placed on a water proofing membrane covering the concrete flagstone. Solar radiation falling on green roof is partially reflected and absorbed by leaves to provide the biological functions of the plants. The remainder is absorbed by the growing medium where evaporation of water takes place. Planted roof is discretized in seven isothermal sublayers (N0=7) and transfer equations are written:

$$e_1(\rho cp)_1\frac{\partial T_1}{\partial t} =\alpha_1\phi_{net}(e_1/2)+\frac{LAI}{1-\varepsilon_p}\frac{\rho cp}{\gamma(r_i+r_e)}(P_{vs}-P_v) - h_c(T_1-T_a)-h_r(T_1-T_{sky})-G_1(T_1-T_2) + L_v\Delta\dot{m} \tag{6}$$

$$e_2(\rho cp)_2\frac{\partial T_2}{\partial t}=\alpha_2\phi_{net}(e_1)+G_1(T_1-T_2) - G_2(T_2-T_3) - L_v\Delta\dot{m} \tag{7}$$

$$e_j(\rho cp)_j\frac{\partial T_j}{\partial t}=G_{j-1}(T_{j-1}-T_j) - G_j(T_j-T_{j+1}) \tag{8}$$

for j=3,..., 6

$$e_{N0}(\rho cp)_{N0}\frac{\partial T_{N0}}{\partial t} = G_{N0-1}(T_{N0-1} - T_{N0}) - h_{N0}(T_{N0} - T_{N0+1}) - h_{rN}(T_{N0} - T_{N}) - G_{N0}(T_{N0} - T_{N0+1}) \quad (9)$$

Transfer equations for indoor air are identical to the preceding ones.

4. NUMERICAL SOLUTION PROCEDURE AND CONTROL PARAMETERS

Transfer equations are discretized by using the full implicit finite-differences method. The results are presented in linear matrix systems form: $[A]\{T\} = \{B\}$. The resolution of the systems is made by using Gauss-Seidel iterative method after the triangulation process of the linear equations. Natural convective and radiative heat transfer coefficients used in the equations are deduced from the classic relation. The conductances are calculated as the ratio of the thermal conductivity to conduction layer thickness. The saturation vapour pressure is related to the layer surface temperature. The determination of temperature variations has allowed deducing useful parameters such as: solair temperature, decrement factor, heat flux transferred inside the room, room temperature and the thermal load leveling.

- Solair temperature is the temperature of the surroundings that will produce the same heating effect as the incident radiation in conjunction with the actual external air temperature.
- The room temperature Tr is the indoor average temperature calculated by using Simpson numerical method.
- The heat flux transferred inside the room $(kJ.m^{-2}.h^{-1})$ is calculated by:

$$\dot{Q} = 3.600\ h_i(T_{N0} - T_r) \quad (10)$$

h_i is the internal convective heat transfer coefficient

- The decrement factor is defined as reduction ratio in amplitude of the temperature wave at the indoor surface compared to the outside surface. The decrement factor can be calculated using the following relations:

$$f = \frac{T_{max}|_{in} - T_{min}|_{in}}{T_{max}|_{out} - T_{min}|_{out}} \quad (11)$$

$T_{max}|_{in}$, $T_{min}|_{in}$ and $T_{max}|_{out}$, and $T_{min}|_{out}$ are maximum and minimum temperatures on the indoor and outdoor surfaces of the roof, respectively.

- The thermal load leveling is defined as:

$$TLL = \frac{T_{rmax} - T_{rmin}}{T_{rmax} + T_{rmin}} \quad (12)$$

T_{rmax} and T_{rmin} are maximum and minimum temperatures in the room respectively. In best case the thermal load leveling should be close to zero and the heat flux through the roof should be minimal as possible.

5. CODE VALIDATION

To ensure the convergence of the numerical solution to the exact solution, time step has been optimized to 10 seconds, so results are independent of time step. Furthermore, in order to verify the accuracy of our numerical procedure, we tested our algorithm based on optimized time step on a patio with flagstone roof and insulated side walls. The metrological dada of a typical day in Lomé (West Africa) is used as input in our simulation code. This computation was validated with a previous experimental study [19] and found to agree quite well. Similar evolution of temperature inside the patio is obtained. Figure 3 shows the comparison of result of the present model with that obtained experimentally for the typical day. As shown in Figure 4, deviation does not exceed 1.5°C.

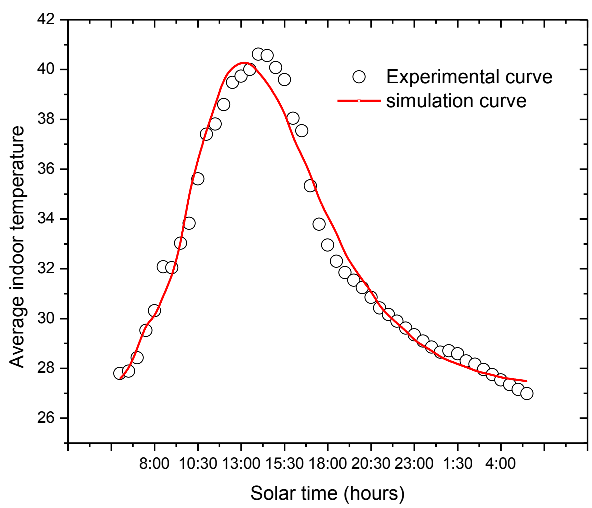

Fig. 3. Code validation.

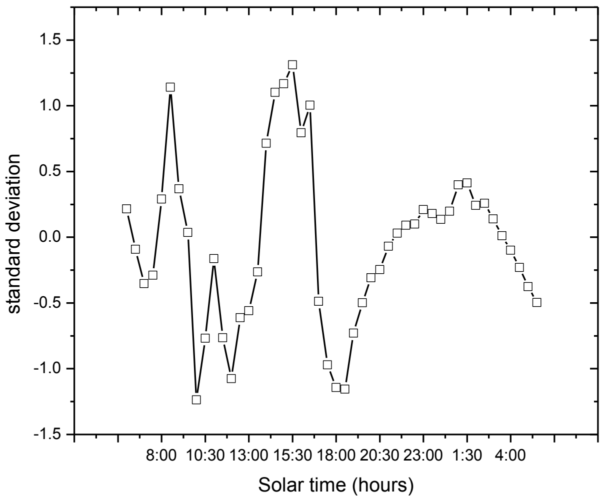

Fig. 4. Deviation.

6. RESULTS AND DISCUSSIONS

Numerical calculations have been performed corresponding to the hourly variation of global solar radiation and ambient air temperature on a typical day of September in New Delhi (India). These meteorological data are used as inputs in simulation code. Solar radiation flux reaches a maximum value of $880\ W.m^{-2}$ at 12 noon whereas the ambient air temperature reaches a maximum of 34°C at 3 p.m., with three hours delay time as it can be seen in Figure 5 which shows the hourly solar intensity and ambient air temperature.

Values of input parameters used in computation have been given in Table 1. The wind speed and air humidity are supposed remain nearly stable with average values respectively of 3 $m.s^{-1}$ and 68%.

Table 1. Input parameters used for computation.

Parameters	Values
Conductivity of concrete flagstone [20]	1.5 Wm^{-}°C^{-1}
Conductivity of soil [21]	0.52 Wm^{-}°C^{-1}
Conductivity of water proofing membrane	0.03 Wm^{-}°C^{-1}
Conductivity of the floor [20]	0.72 Wm^{-}°C^{-1}
Specific heat of concrete Flagstone [20]	1.84 $10^6\ J.m^{-3}.K^{-1}$
Specific heat of soil [21]	3.77 $10^6\ J.m^{-3}.K^{-1}$
Specific heat of the canopy [21]	1.41 $10^6\ J.m^{-3}.K^{-1}$
Specific heat of water proofing membrane	3.04 $10^4\ J.m^{-3}.K^{-1}$
Specific heat of the floor [20]	1.56 $10^6\ J.m^{-3}.K^{-1}$
Solar reflectance of cool roof	0.2 - 0.9
Mean stomatal resistance r_i [21]	160 $s.m^{-1}$
Mean canopy resistance to sensible heat transfer r_e [21]	1300 $s.m^{-1}$
Wind velocity	3.00 $m.s^{-1}$
Thickness of concrete flagstone	0.25 m
Thickness of growing medium	0.25 m
Patio height	0.985 m
Canopy height	0.5 m
Canopy absorptivity coefficient [21]	0.88
Soil absorptivity coefficient [21]	0.93

6.1 Cool Roof Thermal Response

The simulation has allowed showing clearly the effect of roof solar reflectance on heat transfer and indoor air temperature as well as on the solair temperature. The hourly variation of roof and inside temperatures was computed by using the hourly solair temperature for the reflecting surface. The simulation was performed, varying roof solar reflectance from 0.2 to 0.9. Figures 6 to 11 show the variation of the different temperatures, the heat flux transferred inside the room by cool roof, the decrement factor as well as the thermal load leveling. Hourly variation of roof, room and solair temperatures is presented in Figure 6. This variation shows that, the reflecting surface leads to decrease the different peak values of temperatures. Indeed, for solar reflectance equal to 0.4, the peak values of solair and room temperatures are respectively 60°C and 36°C.

The solair temperature combines the effect of solar radiation, ambient air temperature and the long wave radiant heat exchange with the environment. In Figure 7, is shown the hourly variation of the solair temperature for different values of solar reflectance. The peak value is reduced from 70°C for solar reflectance equal to 0.2 to 35°C for solar reflectance equal to 0.9. When varying solar reflectance from 0.4 to 0.7, the peak value of solair temperature is reduced by 15°C. This result shows that, the use of cool roof allowed reducing the surrounding air temperature and leading to mitigate the local heat island effect. The dampening of the thermal wave when passing from the outside the cool roof to the room is described by the decrement factor in this model. For a given thickness of the roof, the decrement factor is a constant.

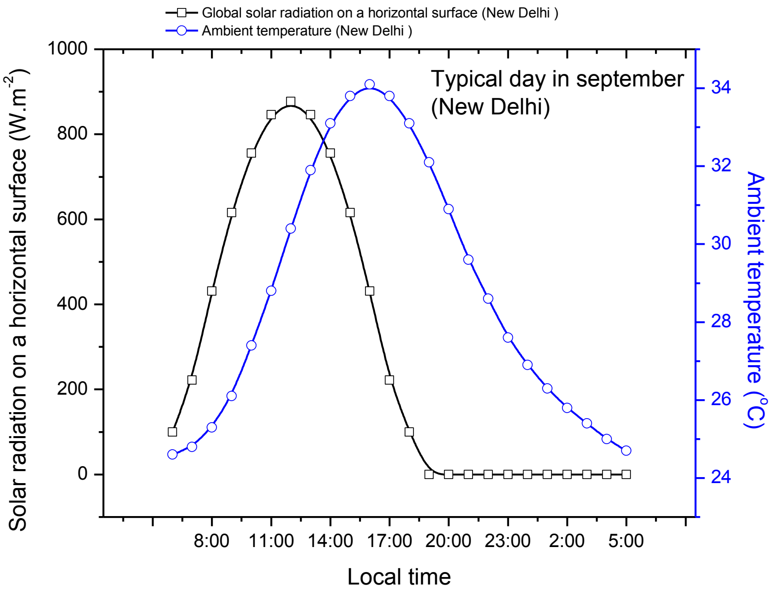

Fig. 5. Evolution of global solar radiation and ambient air temperature.

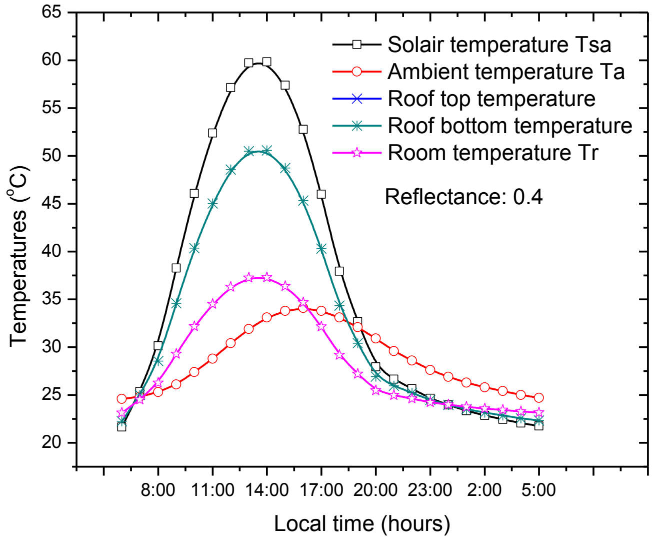

Fig. 6. Hourly variation of the different temperatures for cool roof.

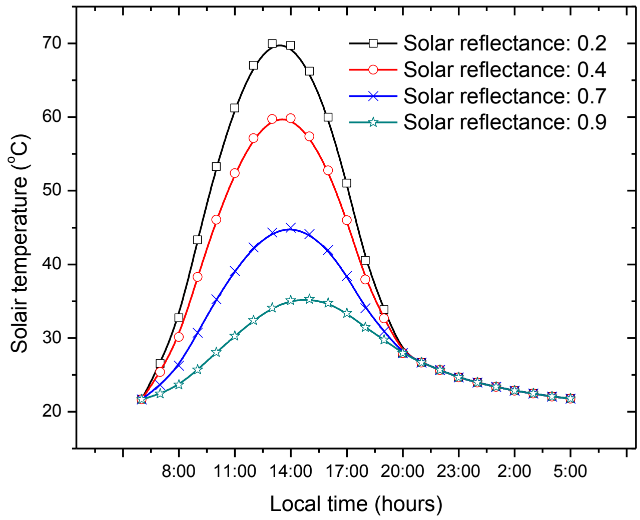

Fig. 7. Hourly variation of solair temperature for different values of solar reflectance.

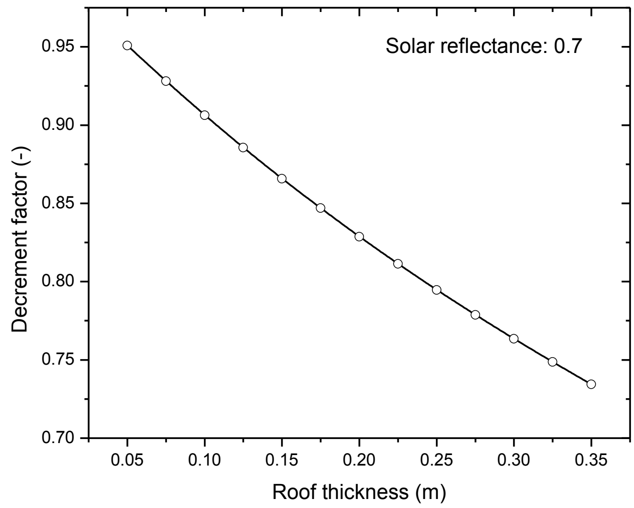

Fig. 8. Variation of decrement factor as a function of cool roof thickness.

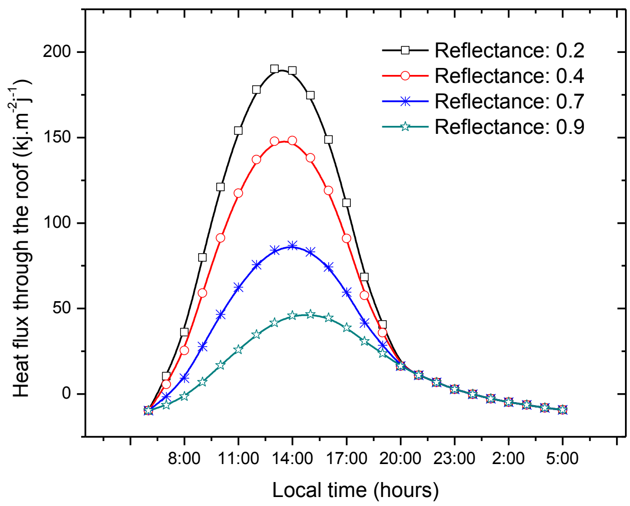

Fig. 9. Hourly variation of heat flux transferred inside the room by cool roof for different values of solar reflectance.

As shown in Figure 8, it decreases from 0.95 to 0.73 when the thickness of the cool roof increases from 0.05 m to 0.35 m. In general, for thin structures of low thermal capacitance, the decrement factor tends to unity. In this simulation the thermal capacitance is not taken in to account and the decrement factor is closed to 0.8 for 0.25 m of cool roof thickness. The effect of solar reflectance on the heat gain inside the room by the elements of the roof is also discussed. Increasing in solar reflectance of the roof, leads to a reduction of the heat flux through the roof as shown in Figure 9. The peak values are reduced from 190 $kjJm^{-2}$ for solar reflectance equal to 0.2 to 47 $kJh^{-1}m^{-2}$ for solar reflectance equal 0.9. Then, the energy saved from cooling loads can reach 143 $kJh^{-1}m^{-2}$.

Consequently, the peak value of room temperature is also reduced from 41°C to 28°C as shown in Figure 10. When varying solar reflectance from 0.4 to 0.7, this peak value of room temperature is reduced by 6°C.

There for, the indoor thermal quality should be improved for non air conditioned buildings, and for air conditioned ones, cooling loads should be reduced. Indeed, as it's shown in Figure 11, the thermal load leveling decreases from 0.28 to 0.10 when the solar reflectance increases from 0.2 to 0.9. This decrease in the thermal load leveling generates a stabilization of indoor temperatures fluctuation. In warm climate, the reduction of cooling loads should be very important with interesting economic aspects.

6.2 *Green Roof Thermal Response*

Numerical calculations have been performed thanks to the hourly variation of solar radiation and ambient air temperature as shown in Figure 5. We analysed mainly the effects of vegetation structure viz. the leaf area index (defined as the ratio of area of leaves to the area of the base occupied) on solair temperature (Tsa), the heat gain inside the room by elements of the roof and the thermal

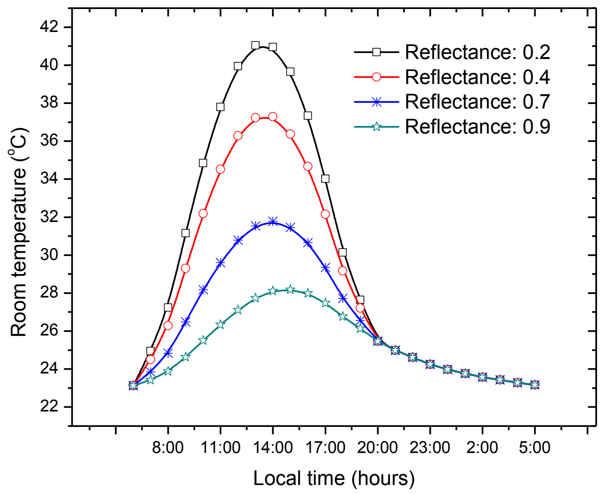

Fig. 10. Hourly variation of room temperature for different values of solar reflectance.

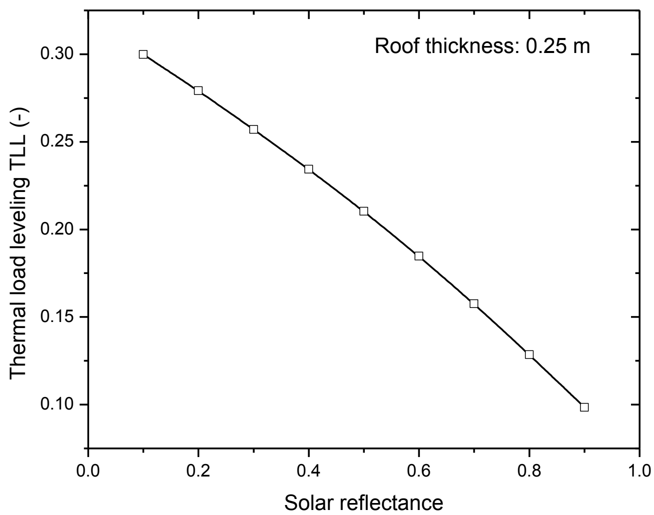

Fig. 11. Variation of the thermal load leveling as a function of solar reflectance.

load levelling (TLL). The hourly variation of green roof and inside temperatures are computed by using the hourly solair temperature for vegetalized surface. The aim of this simulation is to investigate the influence of vegetation cover on thermal performance of the green roof. Indeed, the simulation was performed, by varying the leaf area index from one (01) for low foliage material density to seven (07) for a dense canopy.

The results shown in Figures 12 to 17 summarize effects of LAI on different temperatures as well as on the heat gain inside by elements of green roof. Hourly variation of roof, room and solair temperatures is presented in Figure 12. This variation shows that, the planted roof leads to decrease the different peak temperatures. Indeed, for LAI equal to 3, peak values of solair and room temperatures are respectively 59°C and 31°C. Solair temperature for green roof combines not only the effect of solar radiation, ambient air temperature and the long wave radiant heat exchange with the environment but also the transpiration of the canopy. In Figure 13 is shown the hourly variation of solair temperature for different values of the leaf area index. The peak value is reduced from 66°C for LAI equal to 2 to 44°C for LAI equal to 7. When varying LAI from 2 to 7, the peak value of solair temperature is reduced by 22°C. The slight inversion observed in this figure after 6 p.m. can be explained by the transpiration of the canopy. This result shows that, the use of green roof allowed reducing the surrounding air temperature and leads to mitigate locally the heat island effect.

A green roof system can provide shading and protection from solar radiation, establish microclimate in urban area and minimize the building's energy consumption in hot climate areas. The decrement factor is used to describe the dampening of the thermal wave when passing from the outside of the green roof to inside the room. The thickness of flagstone has been fixed to 0.25 m. The decrement factor is obtained with increment in growing medium's thickness from 0.25 m to 0.55 m. As shown in Figure 14, it decreases when the thickness of the green roof increases. In this simulation the thermal capacitance of the green roof is taken in to account, so the decrement factor is closed to 0.66 for 0.50 m of the complex roof thickness. This thickness consists of 0.25 m of flagstone's thickness and 0.25 m for growing medium. The effect of canopy structure on the heat gain inside the room by the complex roof is also discussed. For their biological functions, such as photosynthesis, respiration, transpiration and evaporation, the foliage materials absorb a significant proportion of solar radiation and contribute to reduce heat gain in building. Indeed, increasing in LAI, leads to a reduction of the heat gain inside the room as shown in Figure 15. The peak values are reduced from 63 $kJ.h^{-1}.m^{-2}$ for LAI equal to 1 to 13 $kJ.h^{-1}.m^{-2}$ for LAI equal 7. It is clear that, an important energy could be saved from the cooling loads. Consequently, the peak value of room temperature is also reduced from 33°C for LAI equal to 2 to 29°C for LAI equal to 7 as shown in Figure 16. When varying Leaf Area Index from 2 to 7, the peak value of room temperature is reduced by 4°C.

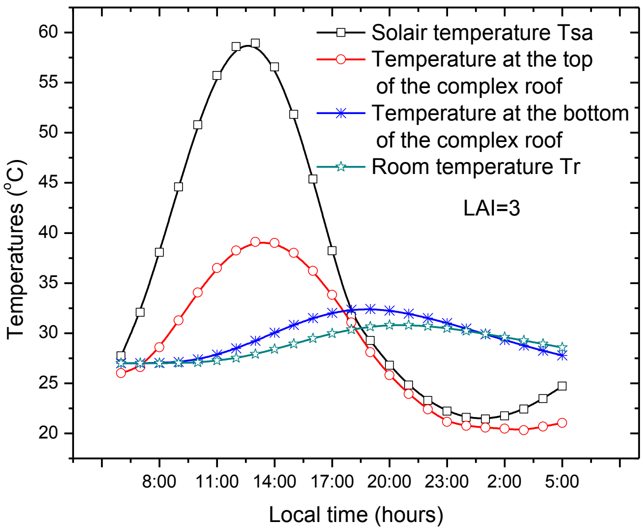

Fig. 12. Hourly variation of the different temperatures for planted roof.

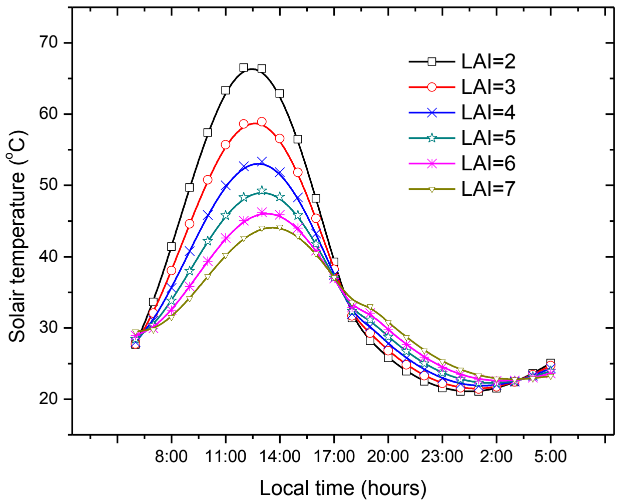

Fig. 13. Hourly variation of solair temperature for different values of LAI.

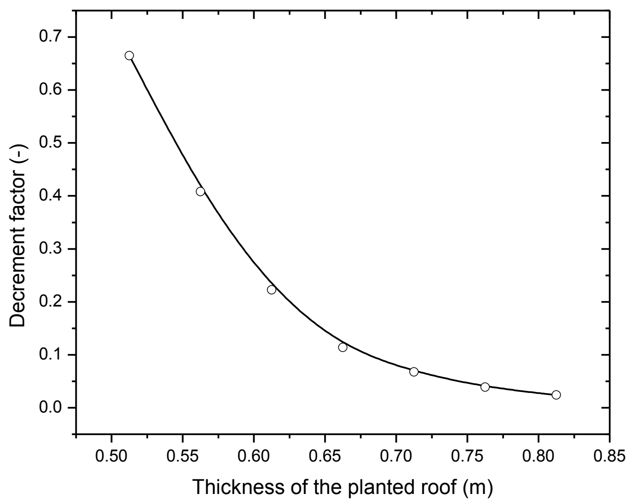

Fig. 14. Variation of decrement factor as a function of green roof thickness.

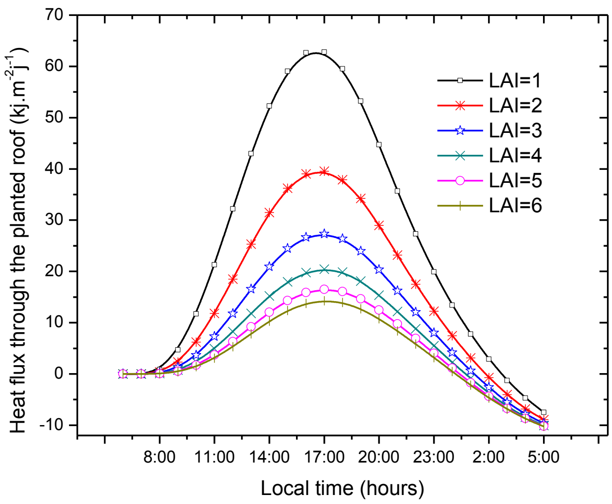

Fig. 15. Hourly variation of heat flux transferred inside the room by the planted roof for different values of LAI.

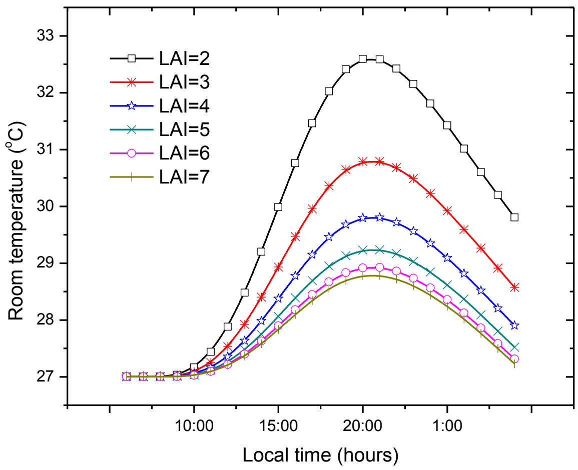

Fig. 16. Hourly variation of room temperature for different values of LAI.

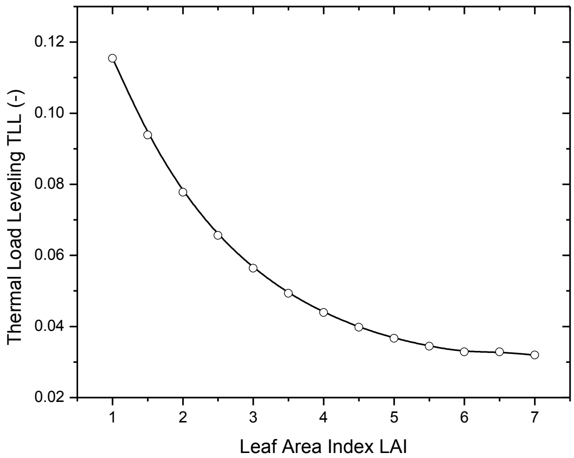

Fig. 17. Variation of the Thermal Load Leveling as a function of LAI values of LAI.

It is clear that the foliage density greatly influences the thermal efficiency of the green roof. A larger Leaf Area Index reduces the solar flux penetration, stabilizes the fluctuating values, and reduces the indoor air temperature. As shown in Figure 17 the thermal load leveling decreases from 0.08 for LAI equal 2 to 0.03 for LAI equal 6. The decreasing of the thermal load leveling towards zero stabilizes the indoor air temperature. There for, the indoor thermal quality should be improved for non air conditioned buildings, and for air conditioned ones, cooling loads should be reduced.

7. COMPARISON OF THE BOTH TWO TECHNOLOGIES

When considering the degree to which solar gain is transmitted by the fabric of the building, it is helpful to use the concept of solar heat gain factor. This is a useful parameter defined by Koenigsberger [22] as the heat flow rate through the construction due to solar radiation expressed as a fraction of the incident solar radiation. In the present study, the solar heat gains factor of the roof is defined as the ratio of transmitted solar energy into the interior of the building to incident solar energy. This factor has been calculated for the two technologies. Figures. 18 and 19 indicate that cool and green roofs can significantly reduce the solar heat gains of a building. Indeed, on a long period of the day until 4 p.m., the solar heat gain factor is less than 10% for the green roof when considering LAI equal 2 (Figure 18) against 35% for the cool roof when considering solar reflectance equal 0.2 (Figure 19).

The comparison of the both two technologies is summarized in Table 2. Cool and green roofs present a very effective and positive impact on the urban climate and microclimate as well as on the indoor climate of building beneath them. Results from this study show clearly that both technologies can allowed reducing cooling loads and mitigating the urban heat island effect. The both strategies reduce the sensible heat available for transmission to the ambient air or to building envelopes but with different mechanisms. Indeed, the green roof increases the evapotranspiration in urban areas by redirecting available energy to latent heat, while a cool roof increases the reflection of incoming solar radiation in urban areas by increasing the albedo of roof surfaces. Taken together, it seems green roof thermal performances better than cool roof ones according to the foliage density (Table. 2).

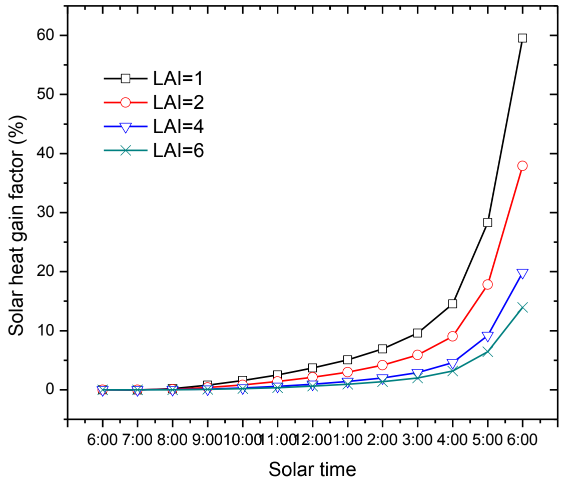

Fig. 18. Evolution of solar heat gain factor for green roof.

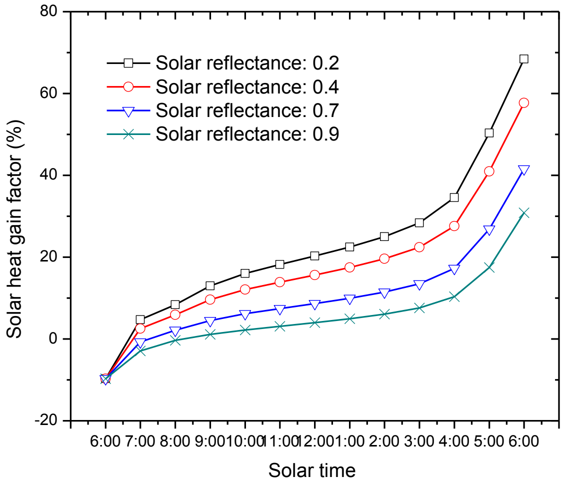

Fig. 19. Evolution of solar heat gain factor for cool roof.

Table 2. Comparison: cool and green roofs.

Parameters	Cool roof	Green roof
Solair temperature	When varying solar reflectance from 0.2 to 0.9, peak value is reduced about 35 °C	When varying LAI from 2 to 6, the peak value is reduced by 20 °C
Decrement factor	Closed to 0.8 for 0.25 m thickness	Closed to 0.66 for 0.5 m thickness Closed to 0.02 for 0.8 m thickness
Thermal load leveling DLL	DLL = 0.28 while solar reflectance equal 0.2 DLL = 0.10 while solar reflectance equal 0.9	DLL = 0.08 for LAI=2 DLL = 0.03 for LAI=6
Maximum solar heat gain factor	68% for solar reflectance equal 0.2 30% for solar reflectance equal 0.9	38% for LAI=2 14% for LAI=6

However, several studies present a compelling argument for reflective cooling strategies over the vegetative. In spite of these findings in favor of reflective roofs, this does not mean that vegetation-based strategies should be disregarded. It's also reported that, green roofs should be more effective for the buildings that are not heavily insulated [23-25]. However, green roof contributes to carbon sequestration and provides oxygen. Green roof strategy is supported by the additional benefits that vegetation brings over reflective surfaces, such as reduced storm water runoff and a number of other ecosystem services.

8. CONCLUSION

This work presented cool and green roofs as two techniques to overcome heating in building and it surrounding. Physical models considered for heat transfer are structures representing classic room. The studied zone is divided into isothermal elements with different thickness and physical properties. Energy balance on each isothermal element is used to write heat transfer equations. The Thomas algorithm and the Gauss-Seidel iterative method were used to solve the algebraic equations. The model was applied in the simulation of the cool and green roofs in warm climate. The meteorological data from New Delhi is used as inputs to the simulation code. Results show that, when varying solar reflectance of the cool roof from 0.4 to 0.7, peak values of indoor and solair temperatures are reduced by 6°C and 15°C respectively and show that the use of cool materials on the roof improved thermal efficiency of the building. In green roof model, the peak of solair temperature is reduced from 66°C for leaf area index (LAI) equal to 2 to 44°C for LAI equal to 7. The use of green roof allowed reducing the surrounding air temperature and leads to mitigate locally the heat island effect. It's found that, when varying LAI from 2 to 7, not only, the peak value of room temperature is reduced by 4°C but also the thermal load leveling is reduced. A larger LAI reduces the solar flux penetration, stabilizes the fluctuating values, and reduces the indoor air temperature. Solar heat gain factor is less than 10% for green roof when considering LAI equal 2 against 35% for cool roof when considering solar reflectance equal 0.2 until 4 p.m. Fighting urban heat island phenomenon and unbearable environment inside buildings asks for the development and application of highly effective mitigation technologies. With the current research presented, it's clear that cool and green roofs technologies have achieved a certain degree of maturity and give an important option to save energy in building and to reduce urban heat island effects

For the both two technologies, studies may continue to better improve the efficiency. Cool roofs for some typical region require maintenance to get rid of dust which affects its efficiency. For each region, suitable cool materials should be found according to their chemical proprieties.

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NOMENCLATURE

Letters

e_j	Thickness of the j-th layer (m)
G_j	j-th layer thermal conductance $(W.m^{-2})$.
h_j	Convective heat transfer coefficient on j-th layer of air $(W.m^{-2}.K^{-1})$
h_c	Convective heat transfer coefficient on j-th layer on the roof $(W.m^{-2}.K^{-1})$
h_r	Radiative heat transfer coefficient between the roof and the sky $(W.m^{-2}.K^{-1})$
h_{rN}	Radiative heat transfer coefficient between the roof and the floor $(W.m^{-2}.K^{-1})$
LAI	Leaf Area Index (-).
L_v	Latent heat of evaporation $(J.kg^{-1})$
$\dot{m}$	Air flow rate Débit massique de l'air $(kg.s^{-1})$.
$N0$	Number of sub layers of complex roof (-).
P_v	Partial vapour pression (P_a)
P_{vs}	Saturation vapour pression (P_a)
r_i	Mean stomatal resistance ($s.m^{-1}$)
r_e	Mean canopy resistance to sensible heat transfer $(s.m^{-1})$
t	Time (s)
T_j	j-th node temperature (°C)
T_a	Ambient temperature (°C)
T_{sky}	Sky temperature (°C)
T_r	Room température (°C)

Greek letters

$(\rho cp)_j$	j-th layer specific heat ($J.m^{-3}.K^{-1}$)
α	Absorptivity coefficient (-)
ε_p	Vegetation canopy porosity (-)
λ	Thermal conductivity $(W.m^{-1}.K^{-1})$
σ	Boltzmann-Stefan constant ($\sigma = 5.67\ 10^{-8}\ W.m^{-2}.K^{-4}$).
ϕ_{net}	Net flux $(W.m^{-2})$

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