Extensive Green Roofs: Potential for Thermal and Energy benefits in buildings in central India

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ABSTRACT

Any building essentially contains walls and roof which are directly exposed to external environment. Undoubtedly the most critical part of the whole building surface is the roof as it receives the maximum solar radiation particularly in summer months thereby increasing the heat load in buildings. Many studies have been conducted over the years to consider the potential building energy benefits of Extensive Green Roofs. There is a sharp increase in the number of countries that conduct green roof research in the last two decades realizing its importance globally. A green roof offers a building and its surrounding environment many benefits, which include: storm water management, improved water runoff quality, improved urban air quality, extension of roof life and a reduction of the urban heat island effect; other benefits also include enhanced architectural interest and biodiversity.

Green roofs cool through latent heat loss and improved reflectivity of incident solar radiation. This suggests that green roofs are predominately seen as a passive cooling technique. Intensive literature review shows that barely any research is done in Indian context for usage of green roof. Green roofs are hardly visible in Indian context: probable reasons are lack of awareness, socio-cultural backgrounds and cost factors. Also it has not been given importance in local building bylaws. Moreover, an in-depth research is needed on green roof in Indian climatic conditions as we have longer sunny days with higher solar intensity (thereby increasing load on air conditioning). It may prove to be important ‘investment’ in longer terms considering the huge energy requirements in the future.

The paper also highlights study in composite climate of central India with high global horizontal irradiation. It highlights thermal simulation modelling using Autodesk Simulation CFD (Computational Fluid Dynamics) software, used as a tool to validate the summer cooling potential of extensive green roofs.

Key words: Extensive Green Roofs, Passive and Low Energy Architecture, Energy consumption in Buildings, Simulation Modelling

INTRODUCTION

Walls only receive about two-thirds of the maximum solar radiation that falls on the roof, and considerably less than this on the wall which faces away from the equator. The period of reception of direct solar radiation on walls is shorter than on roofs: east and west walls will only receive direct sunlight for half of the day. Undoubtedly the most critical part of the whole building surface is the roof.
In any location near the equator this receives the greatest amount of solar radiation, thus the highest heat load. The horizontal roof receives maximum solar radiation during the summer and generally is the main path of heat flux entering the living space.

City surfaces are prone to absorb and release large quantities of heat thereby creating urban heat-island effect. Urban heat-island (UHI) is a common phenomenon where urban temperatures are significantly higher than those of its surrounding suburban and rural areas in summertime. UHIs can affect communities by increasing summertime surface temperature of building envelopes and infrastructures; intensifying thermal discomfort; elevating cooling energy use and peak energy demand; adding air pollution; and raising risks in heat-related illness or mortality. A higher air temperature tends to increase cooling needs and reduce working efficiency of cooling systems for built environments, resulting in higher power demand and energy use.

The roof of a building can be fully or part covered with a layer of vegetation known as a Green Roof. A green roof is a layered system comprising of a waterproofing membrane, growing medium and the vegetation layer itself. There are two main classifications of green roofs; extensive and intensive. Extensive green roofs have a thin substrate layer with low level planting, typically sedum or lawn, and can be very lightweight in structure. Intensive green roofs have a deeper substrate layer to allow deeper rooting plants such as shrubs and trees to survive. Extensive systems offer the most cost effective solution over intensive types. Extensive roofs are the preferred option for retrofitting onto existing buildings as the structural capacity of the roof will often not have to be increased. Green roofs greatly reduce the proportion of solar radiation that reaches the roof structure beneath as well as offering additional insulation value.

India is experiencing an unprecedented construction boom. The country doubled its floorspace between 2001 and 2005 and is expected to add 35 billion m$^2$ of new buildings by 2050. Buildings account for 35% of total final energy consumption in India today, and building energy use is growing at 8% annually. Studies have shown that carbon policies will have little effect on reducing building energy demand. Various researchers have predicted that, if there are no specific sectoral policies to curb building energy use, final energy demand of the Indian building sector will grow over five times by the end of this century, driven by rapid income and population growth. The growing energy demand in buildings is accompanied particularly by an increase in electricity use. This also leads to a rapid increase in carbon emissions and aggravates power shortages in India. Growth in building energy use poses a challenge for the Indian government.

It becomes very important for architects, designers, builders and owners to focus on building designed with Passive measures, design tools and methods thereby reducing/kerbing energy consumption in buildings thereby moving in the direction of sustainability.

This paper addresses the potential building energy reduction benefits arising from the enhanced thermal properties of a Green Roof making it essential part of passive design and low energy architecture.

THE STUDY CASE

Variation of the solar thermal gain in a typical room with green roof using Autodesk Simulation CFD (Computational Fluid Dynamics) software as an analysis tool is investigated in this study as compared to that of a conventional bare roof situated in the state capital of Chhattisgarh state, Raipur having composite climate. Simulation is performed for one typical solar day corresponding to the peak summer season and generally peak temperature of the day in a given time so as to understand the difference between conventional and green roof outcomes. Because this scenario simulates a design day, the simulation of air movement is done with natural convection only.

Geometry

The room admeasuring 6.0 M X 3.5 M consisted of two windows on the southern side and a door on the northern side, east-west being the longer axis of the room, which is naturally ventilated had been taken as a case for the study. The construction of the room is of RCC framed structure having conventional RCC beams, columns, floor and roof along with brick work (0.23 M thick) covered with cement plaster as infill. Total height of the room taken including parapet is 4.05 M and interior room...
height is 3.0 M.

The green roof consists of a water proofing membrane (thickness taken as: 0.01 M), growing media: soil (thickness taken as: 0.15 M) and green cover: grass (thickness taken as: 0.10 M)

Material Properties

Table 1. Material Properties for Simulation Modeling

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity (W/m-K)</th>
<th>Resistivity (K-m/W)</th>
<th>DENSITY (kg/m3)</th>
<th>SPECIFIC HEAT (J/kg-K)</th>
<th>EMISSIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air (variable) (void)</td>
<td>0.02563</td>
<td>-</td>
<td>Equation of state</td>
<td>1004</td>
<td>1</td>
</tr>
<tr>
<td>Brick with plaster: walls</td>
<td>1.44</td>
<td>0.69</td>
<td>2100</td>
<td>875</td>
<td>0.94</td>
</tr>
<tr>
<td>Glass (window)</td>
<td>0.78</td>
<td>1.28</td>
<td>2700</td>
<td>840</td>
<td>0.92</td>
</tr>
<tr>
<td>Hardwood (door)</td>
<td>0.16</td>
<td>6.25</td>
<td>720</td>
<td>1255</td>
<td>0.8</td>
</tr>
<tr>
<td>Steel concrete cement</td>
<td>1.75</td>
<td>0.57</td>
<td>2400</td>
<td>840</td>
<td>0.92</td>
</tr>
<tr>
<td>(floor, roof slab, columns &amp; beams)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water proofing membrane</td>
<td>1</td>
<td>1</td>
<td>950</td>
<td>837</td>
<td>0.8</td>
</tr>
<tr>
<td>Growing media: Soil</td>
<td>1</td>
<td>1</td>
<td>766</td>
<td>1000</td>
<td>0.92</td>
</tr>
<tr>
<td>Grass</td>
<td>0.115</td>
<td>8.69</td>
<td>500</td>
<td>1380</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Simulations

The simulations are performed for peak summer hours of 2:30 PM on 30th of May (Figure 1 to Figure 5). Considering the fact that because of time lag, temperatures in late hours than afternoon peak temperatures may give varied results; simulations are also done with the same parameters on the same day changing the time only to 6:00 PM in the evening (Figure 6 to Figure 10).

Figure 1 (a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 2:30 PM, outside temperature: 44°C, humidity-13%, highlighting external surface temperatures around the room and roof)
Figure 2 (a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 2:30 PM, outside temperature: 44°C, humidity-13%, highlighting external surface temperatures around the room and roof)

Figure 3 (a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 2:30 PM, outside temperature: 44°C, humidity-13%, highlighting external surface temperatures around the roof)

Figure 4 (a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 2:30 PM, outside temperature: 44°C, humidity-13%, highlighting internal and external surface temperatures)
Figure 5 (a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 2:30 PM, outside temperature: 44°C, humidity-13%, highlighting internal surface temperatures)

Figure 6 (a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 6:00 PM, outside temperature: 40°C, humidity-12%, highlighting external surface temperatures around the room and roof)

Figure 7 (a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 6:00 PM, outside temperature: 40°C, humidity-12%, highlighting external surface temperatures around the room and roof)
Figure 8 (a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 6:00 PM, outside temperature: 40°C, humidity-12%, highlighting external surface temperatures around the roof)

Figure 9 (a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 6:00 PM, outside temperature: 40°C, humidity-12%, highlighting internal and external surface temperatures)

Figure 10 (a) Temperature distribution without green roof and (b) Temperature distribution with green roof (both simulations at 6:00 PM, outside temperature: 40°C, humidity-12%, highlighting internal surface temperatures)
RESULTS

As shown in Figure 1 to Figure 5, upto 4°C reduction in temperature difference is visible in simulation modeling above the green roof as well as inside the room in given location and environmental conditions as compared to that of bare conventional roof.

And in the same model changing timings of the simulation to 6:00 PM (shown in Figure 6 to Figure 10), shows difference more than 4°C temperature i.e interior of the room will be more than 4°C cooler because of the presence of a green roof and similarly temperatures above the green roof also show similar differences.

CONCLUSION

Review of various scientific research works shows the importance and potential of green roof in numerous ways. Energy required for conditioning of spaces is aggravated in urban areas through the exhaustion of natural resources spent for electricity production (electricity production in the state of Chhattisgarh, India is by coal fired thermal power plants). Harnessing conventional fossil fuels and heat emissions by AC systems further add to the temperature increment in the environment. Planting a green roof will reduce a. exterior temperatures: thereby controlling micro climate because of plant’s presence and will reduce the urban heat island effect and b. inside temperatures: thereby reducing cooling loads inside the buildings.

The analysis of the simulations done with the help of computational fluid dynamics (CFD), clearly highlight the importance of a green roof as a passive design measure to be incorporated in buildings which would decrease the cooling requirements or the burden on the Air Conditioning systems for Raipur city in geographical location of the state of Chhattisgarh in central India.

An extensive review of the computational fluid dynamics (CFD) simulation results have exposed the following key factors when assessing their energy saving potential in the context of building use:
1. Observations of simulations providing green roofs in the buildings in the city of Raipur showed that green roofs are effective in reducing heat flow through the roof, thus lowering the energy demand for space conditioning in the building.
2. The green roof was effective in reducing high temperature and temperature fluctuations experienced by the roof membrane in conventional roofing system in the summer.
3. Since the average mean temperature was greater then comfort level temperature therefore, thermal comfort cannot be achieved only by providing green roof but it can reduce the load on air conditioning systems to considerable levels.
4. Results proved highly satisfactory and provided enough confidence for the study to be extended further for a larger solution space in real life measurements.

Reduced indoor temperature
Providing Green Roofs
Reduced outdoor temperature
Reduction of Air Conditioning usage
Reduction of Urban Heat Island effect
Reduced CO₂, VOC and Ozone levels
Reduced building energy consumption
Cost savings
Reduced power demands from thermal power plants
Sustainable Environment

Figure 11 Benefits of Providing Green Roofs
Enormous use of ground for various purposes has lead to disappearance of green planted surfaces. In order to prevent dangerous and uncomfortable urban heat island effects the indispensable need of planted surfaces is quiet inevitable as is confirmed by many researchers. For example, a study estimated that an increase of 1°C in air temperature would require the addition of about 500 megawatts (MW) for air-conditioning of buildings in the Los Angeles Basin. Similar air temperature increases in urban areas are taxing the ability of developing countries to meet urban electricity demand while raising global greenhouse gas (GHG) emissions associated with energy use and power generation. Space constraints have further reduced the applicability of green surfaces in various areas surrounding the building envelope. Consequently, planting green roofs become very promising and stabilizing choice in the present scenario.

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