

Mitigating Heat Gain Using Greenery of an Eco-House in Abu Dhabi

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Abstract: Two fundamental design strategies should be taken into consideration when designing a residential building in desert climates, they are as follows: minimizing solar heat gain through shading and proper building envelope and maximizing passive cooling through natural ventilation. By introducing extensive vegetation yet carefully distributed, shading of building's facades or roofs will directly mitigate heat gain through building envelope. An eco-house was designed in Abu Dhabi with special attention to greenery. In this study, landscape elements were intensively analyzed with the aim of reducing heat gain and improving overall building energy performance. Landscape elements such as green roofs, grass ground cover and greenery next to external walls were simulated in order to achieve optimum energy performance. The use of outdoor landscape (grass ground cover and shade trees) has made a 9% improvement of performance over the reference case regarding the electrical energy use and greenhouse gas emissions. The energy use of the house dropped down by 16% for cooling and 18% for fan operation. With regards to the green roof scenario, a performance improvement of 19% over the base case has been achieved. The energy use of the house dropped down by 24% for cooling and 27% for fan operation.

Keywords: Heat gain, Green roof, Grass ground cover, Energy performance

1. Introduction

Cooling and air conditioning of buildings in Abu Dhabi accounts for 75% of electricity consumption in the summer months and are considered the major consumer of electricity [1]. This leads to very high levels of CO₂ and other greenhouse emissions. Landscape effect on heat gain mitigation on buildings has not been studied in the UAE. With the new policies in the UAE calling for green building such as Estidama guidelines and other codes, the consideration of landscape strategies to improve building environmental performance has become significant. Landscaping is considered as a challenging part due to its high water consumption and the scarcity of water resources especially in arid regions such as Abu Dhabi. In this study, the focus is on how landscape design contributes directly in enhancing the building energy performance; and thus lowering the overall energy consumption. Landscape elements such as green roofs, grass ground cover and greenery next to external walls were simulated to evaluate how it will integrate with other passive systems for an Eco-house design in order to achieve optimum energy performance. Where plants normally take a huge amount of water resources, the suitable plants type was carefully selected to consume least amount of water.

2. Background

Vegetation can reduce the heat reaching the building and penetrating its envelope by increasing the reflection of solar radiation and by providing shading. They can achieve evaporative cooling and taking the heat away through the process of transpiration. In this study, the effect of conventional landscape elements (i.e.; grass cover with shade trees) combined with green roof was investigated in terms of their thermal behavior.

2.1. Green roof

The term “green roof” generally represents vegetation and growing medium planted on the building rooftop. There are several environmental benefits associated with green roofs such as energy savings through building envelope thermal regulation, roof membrane protection and

thus prolonged building's life cycle, sound insulation as green roofs act as an acoustic barrier and finally other benefits at the urban level such as mitigating urban heat island effect and storm water retention. With introducing circular no. 171, green roofs and vertical landscaping by Dubai Municipality (DM) that became effective since July 2009 [2], both buildings consultants and contractors have to integrate green roofs into their new buildings design taking into consideration the selection of proper vegetation type, irrigation system, insulation materials and roof structural membrane system. Estidama also encourages applying the concept of green roofs and external landscaping in order to mitigate heat island effects [1]. NRC-IRC constructed a field roofing facility at its Ottawa campus to study the performance of garden roofs [3]. This energy demand was reduced from 6.5–7.0 to less than 1.0 kWh/day in the garden roof, a reduction of over 75%. The garden roof was more effective in controlling heat gain than in reducing heat loss because of the various thermal mechanisms involved, shading, insulation, evapotranspiration and thermal mass. It reduced heat gain by 95% and heat loss by 26%. The study also predicted that in warmer regions where cooling rather than heating is the main concern, the results could be more significant. The study also showed how garden roofs can lower the temperature and modify the temperature fluctuations experienced by the roofing membrane, which results in greater durability and an extended service life for the roof membrane. Another study [4] evaluated the life cycle environmental impacts of an eight story residential building, including the addition of a green roof (only 16% of the building's exposed surface area) located in downtown Madrid, Spain using computer simulation. Due to a lower absorption of solar radiation and lower thermal conductance, the addition of a green roof was estimated to reduce annual energy consumption by 1.2%. This was primarily due to summer cooling load reductions of over 6%. For the upper floors, the peak hour cooling load was reduced by as much as 25% relative to the common flat roof.

2.2. *Shade Trees*

Akbari et al. [5] quantified the effect of shade trees on the cooling costs of two similar houses in Sacramento, California and the results showed that the trees reduced seasonal cooling costs by between 26% and 47%. The same study modeled the effect of the trees on both houses using the DOE-2.1E3 simulation program and found that the model underestimated the energy savings of the trees by as much as twofold. Another study by Akbari and Taha [6], used simulation to study the effect of trees on energy use in four Canadian cities, concluded that increasing the vegetative cover of a neighborhood by 30% and increasing the albedo of houses by 20% would decrease heating costs by 10–20% and decrease cooling costs 30–100%. A simulation study by Simpson and McPherson [7] found that trees shading the west side of houses in California had the biggest effect on cooling costs and that adding shade trees to a house on the west side and east sides reduced annual cooling costs by 10–50%. Another study by McPherson and Simpson [8] used simulation modeling and aerial photography to estimate the energy savings of existing urban trees and new plantings in California indicated that existing trees could reduce peak energy load by 10% resulting in annual savings of \$779 million. They estimated that planting an additional 50 million trees on the east and west sides of houses would further reduce peak load by an average of 4.5% over the next 15 years, which would result in total savings for consumers of \$3.6 billion or \$71 per tree. In a recent study Donovan and Butry [9] estimated the effect of shade trees on the summertime electricity use of 460 single-family homes in Sacramento, California. Results showed that trees on the west and south sides of a house reduced summertime electricity use by 185 kWh (5.2%), whereas trees on the north side of a house increased summertime electricity use by 55 kWh (1.5%). Results also showed that a London plane tree, planted on the west side of a house, can reduce carbon emissions from summertime electricity use by an average of 31% over 100 years.

2.3. Grass ground cover

Vegetation surfaces and pavement materials heavily influence outdoor thermal environments. Field measurements performed in Singapore revealed there were clear effects of hard versus vegetation surfaces on globe temperature and mean radiant temperature (MRT) [10]. The characteristics of heat and water transfer processes in porous block pavement, asphalt, grass and ceramic porous pavement was analyzed using numerical modeling. The model revealed that the surface temperature of permeable pavement is appreciably lower than that of impermeable pavement [11]. A field experiment conducted in Eastern Saudi Arabia found a good correlation between pavement temperature and air temperature [12]. Other experiments in Singapore showed that granite slab, terracotta bricks and concrete interlocking blocks provide lower surface temperatures and heat output than conventional asphalt concrete pavements [13]. An empirical study was performed on five pavements in three areas of Taiwan to study the seasonal influence of pavement on outdoor thermal environments [14]. The study found that asphalt concrete and concrete have higher temperature than interlocking blocks or interlocking blocks with grass infilling, and grass always has the lowest air temperature. The surface temperature of artificial pavements was 10°C higher than that of vegetation surface at noon in the summer, but the difference among the various pavement types were not significant in winter.

3. Methodology

One of the most important and challenging architectural targets in this design exercise was the proper landscaping. Landscape design went hand in hand with other passive and active design components of the eco-house. Grass ground cover and greenery next to external walls (LS case) was simulated and considered as the first scenario. The effect of the green roof element was simulated in a separate scenario (GR case) and the results of both cases were compared against the reference house (REF case). All three cases were simulated using Enerwin-EC software [15]. The window to wall ratio (WWR) as 0.20, 0.15, 0.20, and 0.10 for North, East, South, and West facades, respectively, was used in all three cases.

Landscape design and location (whether horizontally or vertically) tend to maximize shading around the house especially near the windows, and minimize the load due to ground reflected solar radiation by using appropriate ground cover such as grass. The impact of the grass ground cover along with the shade trees on energy was evaluated in this eco-house. The exterior shade trees were set to provide only 50% shading on walls and windows. Where plants normally take a huge amount of water resources, the suitable plants type was carefully selected. Palm trees, ornamental trees and aqueous plants such as *Yucca Filamentosa* and *Yucca Aloifolia* were recommended [2]. These desert plants are suitable for intensive greening, yet consume least water. They are normally watered by drip irrigation and consume from 50-60 liters/day for palm and ornamental trees, and as little as 15-20 liters/m²/day for the aqueous plants. According to Estidama credit (PW-2.1: Exterior Water Use Reduction: Landscaping) in areas with low rainfall or seasonal droughts, up to 60% of total seasonal water usage can be attributed to irrigation [16]. As mentioned earlier, the main system used of plants irrigation is drip irrigation (mainly for roof gardens) besides a bioswale for the house central courtyard. A bioswale is a densely vegetated open channel designed to attenuate and treat storm water runoff. It has gentle slopes to allow runoff to be filtered by vegetation planted on the bottom and sides of the swale (see Fig.1).

As for the green roof structure [17, 18], the whole roof area was 150 mm solid concrete slab, lined with a waterproof membrane insulated with Polyfoam Roofboard 200 mm thick

(2x100mm), covered with Polyfoam Slimline membrane. The Slimline membrane was overlaid with a root barrier/ moisture reservoir as specified ensuring there were no gaps and edges were overlapped. That was covered with a filtration layer, and growing matter as specified by Estidama [16] in order to match desert plants. That typical green roof section (see Fig. 2) has a U-value of 0.15 W/m²K without considering the insulation value of the soil which varies with the water content.



Fig. 1. Landscape elements distribution in the Eco-House

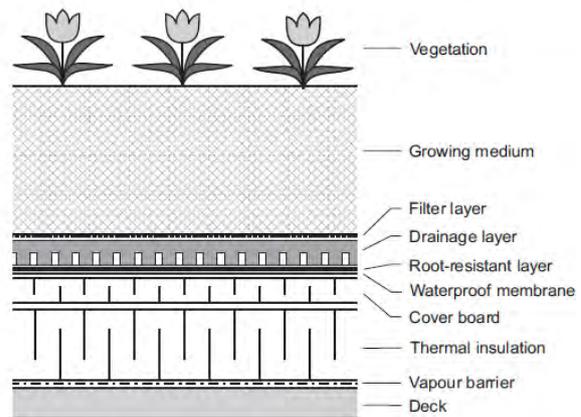


Fig. 2. Green roof structural elements, adapted from [17].

4. Results and Discussion

Typically at the UAE latitude (24° N), the heat gain through the roof component is usually the highest; then comes heat gain through the windows and walls; other building components have usually smaller effect compared to these main components. Thus, before improving the house performance by proper design of the greenery, it was necessary to optimize its form design so that distribution of load becomes a bit more uniform with smaller magnitude at each component, and thus easier to solve. That was done in a previous stage in which the courtyard form was tested and evaluated against a typical Emirati house [19]. The typical house yielded load distribution as follows: 25% for roof, 23.5% windows solar, walls 20%, and 30% for other components. The courtyard configuration (referred to as the reference house or REF case in this study) helped to distribute the cooling loads as follows: 24.3% for roof, 18.1% for windows solar, 27.4% for walls, and 30% for other components; this helped to decrease the windows solar and roof loads' contributions.

4.1. Landscaping results

The first decision was to minimize direct and reflected solar heat gain by maximizing shading on walls and windows and improve ground cover. This would help to reduce the walls and windows-solar loads. Landscaping has great potential to provide these benefits and in the meantime attain other Estidama credits such as LV-R1: Urban Systems Assessment, LV-R2: Outdoor Thermal Comfort, RE-1: Improved Energy Performance [16]. This resulted in great reduction of the windows-solar (63.7%), windows transmission (22.1%), walls loads (20.7%), and mass effect (16.9%); and 21.5% reduction in the total annual cooling load, compared to the base case. The energy use of the house (compared to the REF case) dropped down by 16% for cooling and 18% for fan operation. It also helped to reduce the greenhouse gas emissions and the electrical energy use by 9%.

4.2. Green Roof

The second decision scenario was to improve thermal resistance for the roof heat gain. This resulted in great reduction of the heat gain through roof (99.6%), compared to the reference case. The energy use of the house (compared to the reference case) dropped down by 24% for cooling and 27% for fan operation. It also helped to reduce the greenhouse gas emissions and the electrical energy use by 19%. See figures 3, 4, and 5.

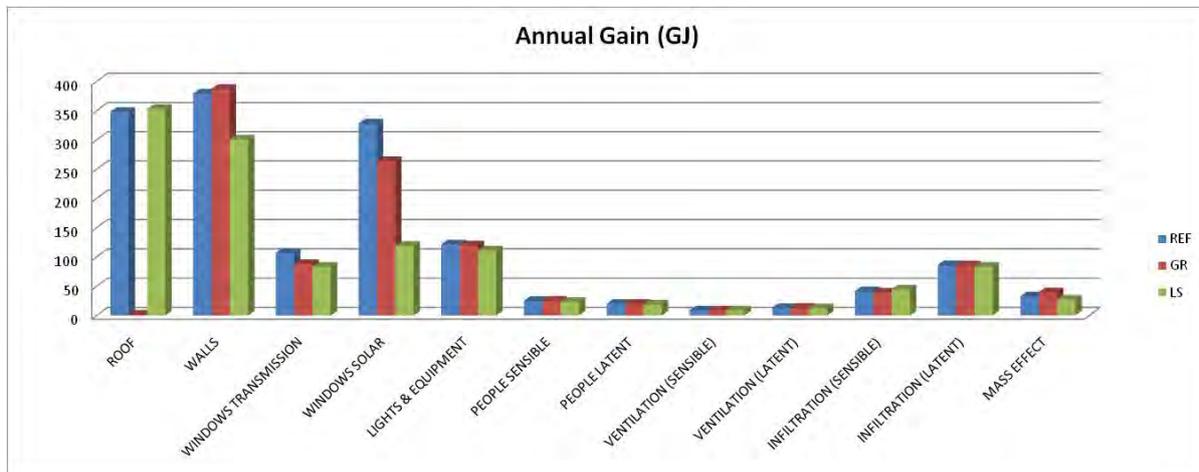


Fig. 3. Annual heat gain by component for the tested cases.

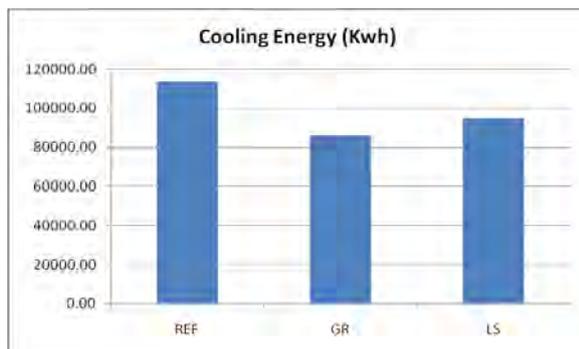


Fig. 4. Cooling energy of the tested cases.

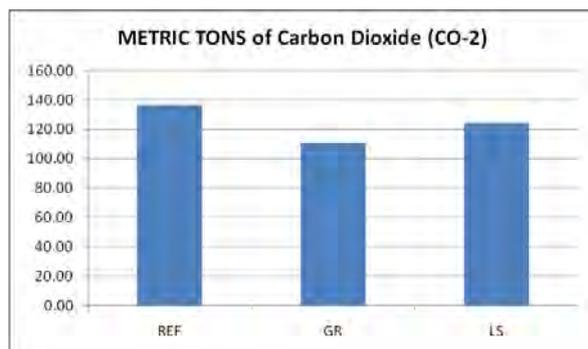


Fig. 5. CO₂ emissions of the tested cases..

5. Conclusion

In a hot climate such as Abu Dhabi for an envelope dominated building, most of the heat gain comes through the roof, the windows and the walls (approximately 70%). This indicated the critical need to minimize solar gain and improve the thermal conservation level of the building envelope. Using greenery to improve the building thermal performance can also result in other benefits such as improved air quality, visual comfort via daylight uniform distribution, noise reduction, prolonged building structure (as green roof), outdoor and indoor thermal comfort, and aesthetics. The use of outdoor landscape (grass ground cover and shade trees) has made a 9% improvement of performance over the base case regarding the electrical energy use and greenhouse gas emissions. The energy use of the house (compared to the reference case) dropped down by 16% for cooling and 18% for fan operation. With regards to the green roof scenario, a performance improvement of 19% over the base case has been achieved. The energy use of the house dropped down by 24% for cooling and 27% for fan operation. Such strategies and improvement of performance would eventually help to earn several points in Estidama Pearl Rating System for Villas such as: LV-R1: Urban systems assessment, LV-R2: Outdoor thermal comfort, LV-9: Indoor noise, IP-1: Innovative cultural

& regional practices, IP-2: Innovating Practice, IDP-R1: Integrated Development Strategy, IDP-1: Life Cycle Costing, NS-R1: Natural systems assessment & protection, NS-1: Landscape design & management plan, NS-2: Landscape enhancement, PW-2.1: Exterior water use reduction: Landscaping, PW-3: Stormwater management, and RE-1: Improved Energy Performance.

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