Affordable Green Roof System for Middle Income Households

L. Jawahar Nesan, Ph.D.[1], Abdul Hakim Mohammed, Ph.D.[2]

[1] *Department of Civil & Construction Engineering,*
College of Engineering & Applied Sciences,
Western Michigan University,
Kalamazoo, Michigan 49008-5316, USA
jawahar55@hotmail.com

[2] *Department of Property Management*
Faculty of Geoinformation Science and Engineering
Universiti Technologi Malaysia
81310 Skudai, Johor, Malaysia
hakim@fksg.utm.my

Abstract

This paper presents a green roof system suitable for middle-income households in Pakistan. While the west has successfully implemented green building systems, the developing countries did not realise it mainly due to the lack of affordable systems and technical know how and the presence of social barriers. Especially, in these countries, the energy efficient building envelope is beyond the reach of the middle-income households, as they cannot afford the current systems. A new system has been developed with respect to the specific needs of the middle class dwellings in the city of Lahore. A detailed survey was conducted among the middle-income households in the Wahdat Colony (Lahore, Pakistan) to assess both the specific constraints and needs of the green roof system. Several aspects including the building envelope, roofing system, local materials, use of air conditioners, local weather, thermal comfortability, thermal response of the existing residential buildings, health problems, and sleeping patterns influenced by the solar radiations were studied and properly addressed in the model development. The new system was designed by using locally available materials and to meet the specific demands of the middle-income residents including affordability and less maintenance. Cost efficiency of the new system has been analysed and found more advantageous than the use of present insulated roof systems and air conditioners.

Keywords: *green roof, energy efficiency, green building, sustainable building, affordable green system.*

1. Introduction

Issues such as global warming, pollution and depletion of energy resources seek a radical change in the way in which buildings are designed and constructed so that new materials are identified and deployed, used building materials are recycled, and energy is conserved. All of the matters, considered in conjunction with one another, are today called green building or sustainable design (Bobenhausen and Lahiri, 1999). At present, one third of the energy used in the world is consumed by buildings (Aveni, 2001). Most of this energy is absorbed by lighting, heating and cooling. Thus, it seems reasonable that inter-alia architectural aspects and principles, building envelops and systems are treated with green technologies to save energy in buildings. A growing body of research indicates that green building is a powerful tool for designing future buildings considering both human and environmental needs (USGBC, 2003).

To achieve energy efficiency in buildings, basic factors need to be considered such as local climate, building envelope, and the building system (Hui, 2003). Of which, climate has the major effect on building performance and energy consumption. The most important aspect of a building envelope is the roof, as it plays a great role in the energy transfer. CNN (Cable News Network, 2001) noted that a 3 to 7 degree Fahrenheit drop through green roof could reduce the need for air-conditioning by 10 percent and reduce the cooling cost by 30 percent. A traditional dark roof absorbs more than 70 percent of the energy radiating down from the sun (California Energy Commission, 2002). Hence, a 10° F reduction in the outside air temperature achieved through the green roof can reduce energy consumption for air conditioning by 50-70% (Peck et al, 1999).

However, the energy efficient building envelope is yet to be realised by the economically disadvantaged communities in developing countries as the cost of the materials involved in existing systems, and technology and service available to these communities are not affordable. The challenge is incorporating cost effective indigenous materials while attaining a desirable degree of efficiency. In this pursuit, a detailed investigation was conducted within the city of Lahore in the middle-income residential area and a cost effective and durable green roof system was developed for the middle-income residential units. The data related to the middle income residential units and their households were collected from the existing middle-income Wahdat Colony located at the heart of the Lahore city (Pakistan). It included the details of the building envelope, roofing system, local materials, local weather, thermal comfortability, thermal response of the existing residential buildings, health problems, sleeping patterns influenced by the solar radiations, and use of air conditioners. The data related to the model development including the locally available materials, building codes and regulations, weather details, cost of system components, vegetations, landscape developments, and structure were obtained through interviews and document reviews with different authorities, agencies and organisations as stated below. Two case studies were also conducted on the existing green buildings located at Lahore to identify the system components and their applications.

An on-site technical support team composed of an Architect and a Building Engineer residing at Lahore collected all relevant data on behalf of the researchers through several approaches including a questionnaire survey among the residents of the Wahdat Colony, and interviews with several entities including the residents of the Colony, engineers and staff of the office of the Chief Engineer, Water And Power Development Authority (WAPDA) of Lahore, Park and Horticulture Authority of Lahore, and A.K. Pak Consultants and Contractors (Lahore).

This paper presents the development of a new green roof system suitable for the middle-income housing units in Pakistan. It was developed to serve both the retrofit works and new buildings. It was intended that the system should be practical and provide sufficient detail so that its practical value and economic feasibility are clearly and logically specified with technical clarity. However, the system was not empirically tested for its intended purpose.

2. Green Roofs in Europe and North America

In the early 1960s, terraced green roof technologies were developed and enhanced in many countries, particularly in Switzerland and Germany. In the 1970s different components of green roof technology including root-repelling agents, waterproof membranes, drainage, lightweight growing media and plants were extensively studied.

According to the English Nature (2003) 13.5 million square meters of green roofs were installed in Germany in 2001. This tremendous growth was stimulated largely by state legislation and municipal government grants of 35 to 40 Deutsch Marks per square meter of roof (Johnston and Newton (1992). Other European states and cities have adopted similar types of support and policy, with several mid to large-size cities incorporating roof and vertical greening into their bylaws and planning regulations. A key motivator for the municipal governments supporting the green roof has been the benefit associated with improved storm water quality and quantity management.

In US, the Green Building Council (USGBC) encourages the society to build safe and healthy places to live. The council contributes to this cause in several ways including the councils' Leadership in Energy and Environmental Design (LEED), Green Building Rating System, International Green Building Conference and Exposition, membership summits, information exchange, and policy advocacy (USGBC, 2002). One of the objectives of the council is its consensus-oriented approach to ensure an effective balance between state-of-the-art concepts and technologies with established green building practices. Many of the council's successes can be attributed to the work of the dedicated members who volunteer their time, experience, and expertise to committees working on issues ranging from developing guidelines and building codes (USGBC, 2002). The rapidly expanding portfolio of LEED standards offers a third-party validation and recognition of sustainable building achievements supported by training and professional accreditation programs (LEED, 2002). The last version of LEED is to check the building on the following aspects: sustainable sites; water efficiency; energy and atmosphere; materials and resources; and indoor environmental quality. As most of the energy in buildings is used for air conditioning and lighting, these two major elements need more attention from the perspective of architecture. Natural forces such as wind and flow of hot and cold air create opportunities for the architects to accommodate both passive and active energy consumption systems in their design.

A green roof is a lightweight vegetated roof system used in place of a conventional roof. Green roofs using free standing containers or planters should not be confused with the typical European green roof installation, which is applied as another layer of the roofing system. A typical green roof technology includes: the roof structure perhaps with some insulation; a waterproof membrane inserted often with root repellents; a drainage layer, sometimes with in-built water reservoirs; a landscape or filter cloth to contain the roots and the soil; a specialised growing medium; and the plants.

There are two basic types of green roof systems: extensive and intensive (Soprema Roofing Inc., 1996). Extensive green roofs are characterised by their light weight, low capital cost and minimal maintenance. The growing medium, typically made up of a mineral-based mix of sand, gravel, crushed brick, peat, organic matter and some soil, varies in depth between 5 cm to15 cm and in weight between 72.6 to169.4 kg per sq. meter. Due to the shallowness of the soil and the extreme microclimate on many roofs, plants must be low and hardy, typically alpine and indigenous. Plants are watered and fertilised only until they are established and after the first year, maintenance consists of two or three visits a year for weeding of invasive tree and shrub species, mowing, safety and membrane inspections (Thompson, 1998). As a general rule, a minimal technical expertise or practical experience is required for installation and maintenance (Johnston, 1996).

Intensive green roofs are characterised by greater weight, higher capital costs, more plantings and higher maintenance requirements. The growing medium is soil-based, with a depth ranging from 20 to 60 cm, and weight between 290 and 967.7 kg per sq. meter. Due to increased soil depth, the plant selection is more varied including trees and shrubs, which allows a more complex ecosystem to develop. Requirements for maintenance and watering are continual and more demanding than an extensive green roof. Structural and landscaping consultations and an experienced installer are required. Since these roofs are accessible by tenants, employees and/or the general public, certain safety requirements must be adhered to include exiting, occupant loads, guardrails and lighting. Accessible green roofs can provide an important social benefit to their users and increase the market value of the building.

In general a green roof is employed with either a single-ply or multi-ply waterproof roofing membrane, with a root barrier, if the membrane is organic in nature. A single or multi-layer drainage material follows, with a non-woven, non-biodegradable filter fabric on top of the drainage layer to retain the soil media. Insulation is optional although most often recommended, and may be located: above or below the roof deck; above the roofing membrane (protected membrane, common in Europe); and below the roofing membrane (conventional), as determined by the architect or contractor. Finally, the engineered substrate/soil media or planting medium is determined and placed along with appropriate green roof plants. There are several green roof systems available in the market including Xero Flor and Hydrotech.

3. Overview of the region of the study

This study is intended to focus on Pakistan. Electricity consumption in Pakistan has been growing at a fast rate at around 30 percent annually during the past 25 years (Enercon, 1990). Pakistan's previous record on dealing with environmental issues was poor and the country has not yet been able to fulfill its commitment for environmental protection. Eight months of scorching heat and three months of unbearable winter severely affect the people, as they cannot afford to have amenities like double glazed windows and central air- conditioning or heating systems. The city of Lahore has been chosen for investigation, as it is an ideal location for comparing two extreme weathers, unlike other big cities such as Karachi and Islamabad.

Lahore is very cold (1o C) in winters (December, January and February) and very hot (39o C) in summers (May, June, and July). Situated in Punjab province, it is the most fertile region in the country. Lahore is known as the "city of gardens" or "city of flowers". It is the second most populous city (about 7 million people) of Pakistan dominated by the working middle class people. The total land area of the city is 404 sq. km. Air pollution in Lahore is estimated to be twenty times higher than the standards of the World Health Organization (Energy Information Administration, 2003). As a result of the toxic carbon emissions, the temperature is steadily rising, causing a climate change in the city.

A middle-income residential colony (Wahdat Colony), situated on Wahdat Road, Lahore was chosen for data collection. Wahdat Colony was developed in 1958 by the Lahore Development Authority for its government employees. The colony was established in an area of 300 acres, comprised of 1000 residential units divided into 34 blocks. The units are single floor detached houses consist of two bedrooms, one living room, one guest room, a small kitchen with a store and two bathrooms. This colony was chosen as all units were built for the same plan with similar building envelopes. As the colony was designed for typical middle class people whose social and economic levels are the same, the results drawn out of the study was thought of undistorted by conflicting data.

4. Survey of building envelope and related problems in a middle class residential area in Lahore (Pakistan)

The objective of the survey was to investigate the need for green roof system and help solve energy efficiency and thermal problems faced by the inhabitants of the middle income residential units. It was aimed to identify the potential problems attributed to building envelopes, especially, the roofing system that influences energy efficiency in buildings. A questionnaire survey was conducted randomly within the total population of 1000 households in the Wahdat Colony. Out of the 100 questionnaires sent randomly, only 36 were received complete. Some of the respondents returned the questionnaires unanswered reporting several reasons including lack of time and lack of knowledge on the concept of green roof.

The questionnaire focused mainly on issues related to demographic details of the residents of Wahdat Colony and their building envelopes. Specifically, it included questions related to demographic data such as profession, income level, number of family members, sleeping hours in winter and summer, and building data including area of the house, facades, windows, air conditioning, floors, and seasonal energy consumptions. A team of three local professionals including one architect and two draftsmen on behalf of the researcher conducted the survey as the researchers were stationed at USA. After the postal questionnaire survey, the team also visited the respondents and informally interviewed them for further clarifications and information. Besides the dwellers, the team also interviewed the technical experts including engineers, architects, horticulturists, and floriculture experts to collect technical data required to develop the green roof system.

Analysis of the survey data indicated that 80 percent of the houses had two bedrooms, one living, and two bathrooms, whilst others were altered and extended. The average family size was approximately five, whereas, the original plan could accommodate only three per unit. The houses have large window openings on the facades in the east-west direction. The window glass allows short wave radiation to pass through but fails to pass the long wave radiation emitted by the objects or room surface. Thus the heat caused by sunlight enters the building through the window glass is trapped inside and increases the indoor temperature. Eighty percent of the windows were made of steel and have poor sealing capabilities. There were no measures taken for heat prevention. The inhabitants used heavy curtains on windows to prevent the incoming solar radiation.

The concrete roof finished with gray colored cement mortar absorbs solar heat when exposed to sun. No measures were taken to stop this heat load. Walls were built with 9 inch load bearing bricks without plastering. Most houses displayed pavements around them with negligible green spaces. This results in solar radiation and consequent heating of the houses. Table 1 summarises the details of the building envelope of the housing units at Wahdat Colony.

Table 1 : Housing Envelope in Wahdat Colony Items Data

Types of Houses	Single Storey
Plot size	42.75' x 55'
Covered area	1360 sq ft to 1444 sq ft
Houses with single glazed window	All
Altered houses (50 samples)	None
Other cladding used on walls	14 percent Clad stone-14%, Tile-4 %,Marble-2%
Average house hold per unit	4.1 per unit
Average salary per unit	10872.5 Rupees
Types of windows	80 % Steel windows, 20%
Houses with air-conditioners (50 samples)	Aluminum 19 % of the population
Average open space available	74sq ft

A part of the questionnaire assessed how people cope with the seasonal weather distress in these kinds of buildings. The results show that 19% of the homes have air-conditioning, as others could not afford it. Other means of cooling included fans and desert cooler. Seventy six percent of the households could not afford air-condition because of high electricity bill. It was also found that the sleeping pattern of the households during summer was varied with respect to their use of different cooling appliances. Figure 1 shows that the average sleeping hours during winters remain the same regardless of the use of cooling appliances while in summer it is reduced to an average of 5 hours for those without air-condition.

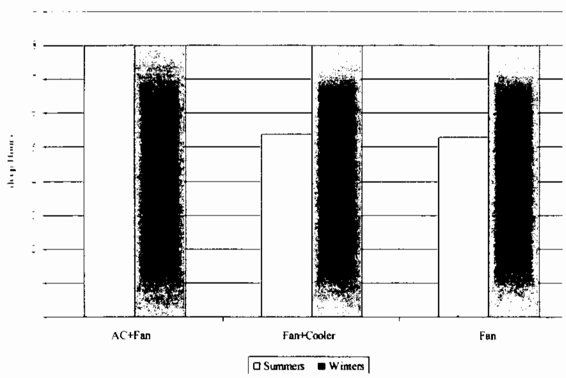

Figure 1: Sleeping patterns of the Wahdat Colony residents

The survey also focused on the health issues faced by the residents of the colony. The results show that summer diseases such as achnae, fungal infection, itching. and malaria have little effect on people that used air conditioners (see Figure 2). Malaria is a common summer disease among the households without air-conditioners as the inside temperature is not controlled resulting in hot, humid, and uncomfortable weather condition.

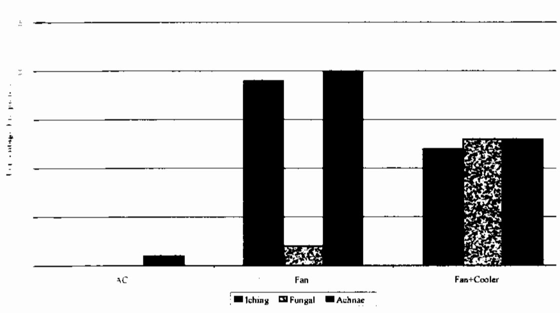

Figure 2: Health problems faced by the Wahdat Colony residents due to solar heat

The above results of the survey indicate that the current building envelopes create a great deal of problems to the people living in that area. Although several remedies including 'vertical gardening' can be considered to improve the thermal comfortability and energy efficiency of the units, this paper focuses mainly on development of a green roof system suitable to the middle-income dwellings as more than 70 percent of the heat is absorbed through the roof.

5. Current Practice of Thermal Insulated Roof Slabs in Pakistan

This section discusses different roof insulation systems currently used in the Lahore region. Both field observations and literature review show that there are four major systems currently used in Lahore including: conventional; polystyrene system (Bead Board); jumbolon system; and concrete block.

The conventional system is the most widely used system in Lahore, which comprises a six- inch concrete roof slab superimposed with a bitumen layer, 0.5 mm thick polythene sheet for insulation, a three-inch clay layer, and a three-inch layer of kiln burnt brick tile. The conventional insulation does not help much in reducing the heat entering the roof instead towards the end of the day the ceiling temperature usually exceeds the side out air temperature.

Another common practice is the use of polystyrene (Thermo pore) system. It is nothing but a conventional system with the top two layers being replaced with polystyrene and washed gravels respectively. Although it improves insulation properties of the roof, the insulation membrane is compressible and non-resistant to the damages caused by insects and ants, which leads to further water leakage in the system. Tests indicate that this damage often happens within one year (Enercon 1990).

In the Jumbolon system, two layers of Jumbolon sheets (polythene sheets) are provided on the alternate bituflex coats. The first layer Jumbolon sheet is silver coated 3 mm thick laid over the bituflex coated roof slab and it acts as a waterproof layer over which a coat of bituflex is applied again. The second layer is one inch thick Jumbolon over which a 2.5 inch concrete layer (top layer) is provided. This procedure has been found to be more effective as it lowered the temperature from 2o C to 3o C degrees. This system is the most expensive costing around Rs. 30 to Rs. 35 per square foot.

In concrete block system, a layer of inverted box-shaped concrete blocks is provided as a top layer. It is a four-legged square block (1'X1' or 2'X2') of 2 to 3 inches height providing air channels under the blocks. The intermediate layers, in the ascending order, include: two coats of bitumen over the roof slab; 5mm thick polythene layer; one inch clay layer (to provide required slope; and a 3 inch brick layer immediately below the top concrete-block layer. The cost of this system goes up to Rs. 15 per block. It reduces the internal temperature up to 4o c to 5o c. This is a much cheaper and a quick procedure compared to Jumbolon. However, during the rainy season water leakage is a main problem.

Each of the above systems currently in use is inefficient in one way or the other, while some provide simply shading to the roof and the others provide partial insulation to prevent the heat being absorbed by the roof. To effectively reduce the surface temperature of the roof, the roof must have all relevant features including thermal insulation, shading and evaporative cooling. Evaporative cooling can be achieved by either providing vegetations (green roof) or by installing a sprinkler system that intermittently sprays water over the roof surface. Every pound of water that is evaporated absorbs approximately 1000 Btu of heat, lowering the temperature of the roof considerably (Enercon, 1990). An additional advantage of evaporative roof cooling is that the humidity of inside air remains unaffected. Table 2 collectively summarizes the application and benefits of green roof systems over the current roof systems used in Pakistan.

Table 2: Comparison of the Green Roof with the Current Roofing Systems in Pakistan

Green Roof System	Concrete Block System	Insulation System	Conventional System
Provide thermal insulation in long term.	No thermal insulation is provided	Provide thermal insulation	No thermal insulation
Provides shading of roofs using plants that dramatically reduces the heat gain into the building	Provides shade	Provides no shades	Provides no shades
Green roofs provide evaporation that helps cool the roof.	No cooling effect	No cooling effect	No cooling effect
Provides improved air quality	Does not improve the air quality	Does not improve the air quality	Does not improve the air quality
Controls urban heat effect	Increases urban heat effect	Increases urban heat effect	Increases urban heat effect
The surface of green roof remains at same temperature as of the ambient temperature	The surface temperature almost doubles	The surface temperature almost doubles	The surface temperature almost doubles
Green roofs provides oxygen to environment by photosynthesis	N/A	N/A	N/A
Retains storm water Runoffs	N/A	N/A	N/A
Reduce excessive energy use	Reduce energy use only to a limit	Reduce energy use only to a limit	Does not reduce excessive energy use
Prevents water pollution caused by combined sewage overflow	N/A	N/A	N/A
Extends roofs' life	A short term system	A short term system	N/A
Creates visible/accessible green space	Roof is not accessible	Discourages access	Accessible
Visual and aesthetic benefits: green roofs offer the potential for people to enjoy the out door weather on the roof.	Not Accessible	Not Accessible	Does not provide such benefits
Green provides sound insulation. Soil, plants and the trapped layer of air between plants and the building surface works as an insulation barrier for sound.	Provides insulation to a limit	Provides insulation to a limit	No such insulation.
Proven to protect the roofing system against ultra violet rays or extreme temperature fluctuation.	N/A	N/A	N/A

6. Development of a Green Roof System for the Middle Income Households in Lahore

The results of the survey of the Wahdat Colony as discussed early in this paper clearly indicated a need for an alternative cost-effective energy efficient roof system affordable to the middle-income households in Pakistan. It not only highlighted the excessive energy consumed by the housing units but also ascertained how the residents faced problems of solar radiations affecting their sleeping hours and causing health problems. In efficiently addressing this persistent problem. the above discussion further justifies the need for developing an affordable green roof system for middle-income residents of Pakistan. This section discusses the model development and proposes a new green roof system suitable for Pakistan (Lahore), and further provides the details on cost efficiency and maintenance of the system. It should be noted that this model is not empirically tested with prototypes.

As stated earlier, the local on site technical support team collected all relevant data including the housing envelope. environmental, thermal and cultural effects through interviews with the Wahdat residents. The details about different aspects of the green system including the growing medium composed of soils, minerals and fertilizer, vegetation, and maintenance of the system all were collected through interviews with the technical experts of and document reviews at the Park and Horticulture Authority of Lahore. The cost details of different items involved in the new system were collected through interviews with the A K Pak Consultants and Contractors (Lahore) and the Chief Engineer's office of Water And Power Development Authority (WAPDA) of Lahore.

While the concept of green roof currently practiced in North America and Europe was strongly considered in developing the new system, their systems were considered as not much suitable for Pakistan due to regional variations on issues such as culture, housing envelope. weather, and locally available materials. For instance, interviews with the Wahdat residents revealed that they preferred a more integrated in-built roof system that requires less technical maintenance and less operational cost during the life cycle. Further it should be affordable to the middle-income households. Besides, the system must meet the local environmental, cultural, building, and weather conditions. However, the concept of the green roof as practiced in North America and Europe was the base on which the new system has been developed. To be cost effective, the new system has to be 'extensive'. As where else, the system was planned to include a protective and drainage layer on the top of the roof slab, a filter layer, a layer of growing medium, and vegetation. The new system has been developed to used in both retrofits and new buildings.

At the outset it was decided that the new system should be developed fully with indigenously available materials. While the materials of planting (growing) medium and vegetations were selected based on the expert opinion (Park and Horticulture Authority of Lahore) the structural aspects including the filter and drainage layers and roof protection system were designed based on the researchers own structural engineering knowledge coupled with case studies on two existing green roofs in Lahore. The case studies included the Data Darbar building and a private house. Data Darbar renovated by the Lahore Development Authority in 1998 is a shrine located in the inner city of Lahore. It has a terraced roof garden covering an area of 9000 sqft. The rooftop with a water fountain in the middle is covered with a growing medium and seasonal flowers. The second case is a four-bed house located in Lahore. The roof is completely covered by terraced garden featuring plantation, waterfalls and water channels. The planting layer composed of locally available soils is 450mm thick. These roofs provided more thermal comfortability and reduced the energy bills. However, they required greater attention, labor, time and knowledge to maintain the quality of the system. Some of the features of these roofs including the drainage system reflect the demands of the local residents. However, this system may not be affordable to the middle-income groups as the initial cost is comparatively high.

The main constraint in developing a green roof system, as per the response of the Wahdat residents, is that the system must be cost effective, integrated, thermal efficient, energy efficient, and requires less operational efforts after installation. While any green roof system will offer energy and thermal efficiency, the development of an integrated cost effective solution that requires less operational efforts in the post installation period was a challenge in this study. Considering all options currently used in both western countries and Pakistan, a system integrating all major components including the structural roof slab, drainage system, filter system, and planting (growing) medium was resolved by introducing an in-built monolithic drainage system in the structural roof slab (see Figure 3). A similar approach was adopted in the case of the private (green) house in Lahore. Further, the development of different components of the proposed green roof system including the protective layer, drainage layer, filter layer, growing (planting layer), and vegetation are discussed below.

rooftop infiltrates into the building's drainage system. Some systems simply use a layer of large –diameter expanded clay as in the case of the "Data Darbar". This is suitable for a large area. However, in this system, 4 cm diameter PVC pipes with perforations on the top surface are used. These pipes are half embedded in the PCC layer (one inch) provided on

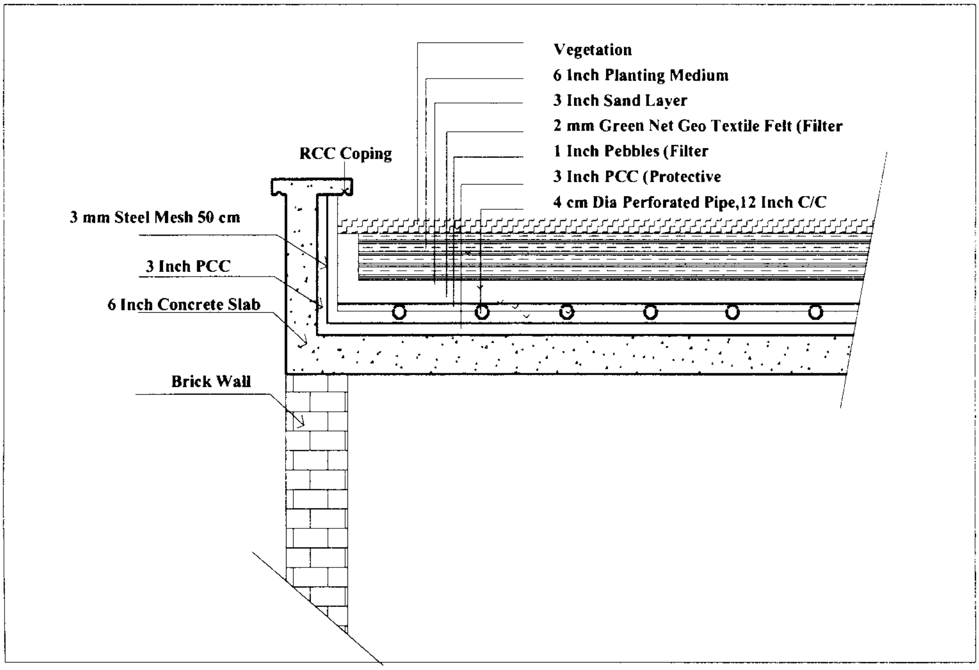

Figure 3: Section of the new green roof model

Protective Layer

To protect the structural roof slab from water leakage and other potential deteriorations caused by the green system including fertilizers and root penetrations, a 3 inch PCC (Plain Cement Concrete) layer of ratio 1:4:8 (with waterproof additives) with 3mm steel mesh added on its top is provided in between the concrete roof slab and the drainage system. The locally available waterproofing and plasticizing material (feb-proof) can be used as an additive. This entire set up is considered as a protective layer and it purports to: enhance the waterproof capacity of the roof; repel the roots of vegetation entering the roof slab; and provide a strong base to the superstructure of the green system. The iron mesh acts as reinforcement and protects the layer from the effect of expansion and contraction caused by the temperature change. The PCC is also used to provide slope to the roof at the suggested ratio of 1:10.

Drainage layer

In between the filter layer and protective layer is a drainage layer through which the water from the the top of the protective layer at 12 inch center to center. The purpose of these pipes is not only to drain water but also to retain water so that moisture is maintained under the filter layer even during the dry season.

Filter layer

In between the planting medium and drain layer lays a filter layer of one-inch pebble bed with 2mm geo textile felt on its top. Locally manufactured geo textile felt is available. The purpose of this layer is to prevent the planting medium eroded away by the infiltrating water and also to act as a root barrier.

Planting medium

The planting medium is composed of a 6 inch top layer of planting soil and a 3 inch (river) sand course underneath. According to Minke (1982) a 6 inch layer of substrate plus a thick layer of grass have a combined insulation value equivalent to 6" (15 cm) mineral wool insulation. Therefore, the traditional insulation is avoided in this system. A grass covered green roof with an 8-to16 inch (20-40 cm) thick layer of substrate can hold between 4 to 6 inch (10-15 cm) of water (Minke, 1982). In Pakistan, where the average rainfall is 1.7 inch, a green roof could certainly become a viable option for storm water management too.

According to the Park and Horticulture Authority of Lahore, the planting soil should be a mixture of 50% loamy soil, 40% canal silt and 10% locally used manures. The Park and Horticulture Authority of Lahore stated that the locally available loamy soil is good for growing grass without any addition of fertilizer. Its salt content and other properties are within the allowable limit to readily use as a plant medium. A little quantity of phosphate and potassium fertilizers can be added as per the prescription of the Authority.

Vegetation

The vegetation layer transfers solar energy to the atmosphere and acts as an insulation along with the other green roof components. Based on the data collected from the Park and Horticulture Authority of Lahore, the most suitable locally available grass vegetations are presented in Table 3. Various kinds of seasonal flowering plants as suggested by the Authority can also be used.

Table 3: Grass and Ground Covers Locally Available for Roof Garden

Botanical Name	Common Name
Grass	
Zoysia Japonica	Kori Grass
Zoysia Tenuifolia	Korean Grass
Agrostis Stolonifera	Bent Grass
Axonopus Compressus	Cow Grass
Cynodon Dactylon	Bermuda Grass
Ground Cover	
Asparagus	Foliage
Wedelia Trilobata	Foliage + Yellow Flower
Humulus Lupulus	Foliage
Tradescancia	Foliage
[illegible]	Foliage
[illegible]	Foliage
Clerodendron	Foliage + Red Flower

Source: (Pakistan Horticulture Development Authority)

The new model is flexible to retrofit the existing roofs. In the existing buildings in Wahdat Colony, the protective layer can be laid very easily without disturbing the existing roof. As the model assumed a typical thickness of 6 inch for the structural roof slab (housing), as is the case widespread in Pakistan and at the Wahdat colony, the proposed green system including the protective, drainage, filter, and planting layers and the vegetation can be added to the existing roof slabs. The strength of the existing 6 inch slab was also analyzed for the superimposed load of the green system and found that it could support those additional load.

7. Cost efficiency of the proposed system

One of the primary objectives in developing the model was to produce an affordable green roof system for the middle class households in Lahore. The model described above was estimated for the cost and compared with the costs of the existing roof systems. The costs of different work items and materials involved in the model were formulated using the data obtained from the local market, builders, architects, local contractors, and the Water And Power Development Authority of Pakistan. The cost information of different roofing systems presented in the Table 4 shows that the cost of the green roof system is only marginally higher than the conventional and concrete block systems whilst cheaper than the Jumbolon system. The cost of the vegetation, which is so little, is excluded in the original green roof system, as there are several varieties of vegetations including grasses and flowers available. This item is considered as a maintenance cost as the owners may wish to change the vegetation seasonally. Besides the vegetation, the only other maintenance costs are weekly watering and lawn mowing, which are negligible as the owner themselves can perform maintenance or a gardener can be hired for a very low monthly wage. Compared to the cost of Air-Conditioning (AC), the maintenance cost of the green system including the vegetation is far cheaper. For instance, according to the Water And Power Development Authority of Pakistan, the cost per month of AC for 1360 sq. ft. housing unit is Rs.29, 808. This was calculated based on the use of 1 ton capacity AC for nine hours per day consuming one unit of electricity per hour. The prevailing cost per unit of electricity is Rs.5.50. Therefore, the proposed green roof system is affordable to the middle income households in Lahore with respect to both installation and maintenance.

Table 4: Cost of different roofing systems in Lahore

Conventional Roof Systems	New Green Roof System
Total cost of conventional RCC slab (6") - Rs. 105/sqft	RCC slab - Rs.90.00/sqft Febflow (Waterproof) – Rs.04.00/sqft
Total cost of concrete block roof - Rs. 115/sqft	PCC (Protective layer + Drainage) – Rs.20.00/sqft
Total cost of Jumbolon roof - Rs. 125/sqft	PVC Pipe – Rs.04.00/sqft Pebbles – Rs.01.50/sqft Green geo felt – Rs.01.00/sqft Plantation medium – Rs.02.50/sqft Fertilizers – Rs.00.50/sqft Total Cost – Rs.123.50/sqft

Note: All cost items include the costs of the materials and labor.

8. Conclusion

Green roofs are proven technologies that provide building owners with opportunities to utilize often wasted roof spaces for energy efficiency, storm water management, sound insulation, and aesthetic improvements. This paper has initially justified how critical is the green roof system for the middle-income households in Pakistan for them to achieve both energy efficiency and thermal comfortability and thus to avoid sleeping disturbances and health problems caused by the solar heat.

A variety of prevailing thermal insulated roof systems including conventional, polystyrene system, Jumbolon system, and concrete block were reviewed and their drawbacks ascertained. Finally, based on the current global practice of green roof and locally available materials and green systems, a new affordable system has been proposed. The system has been developed taking into consideration some of the main constraints of the middle-income households of that region including: integration of structural roof and green system that seeks lesser maintenance and technological supports, affordable to the middle-income households, energy efficiency, and thermal comfortability. The system was logically and technologically discussed for all of these constraints except the thermal response and concluded that the proposed system satisfies all of them. As the literature suggests that there is no need for a separate insulation in the presence of a green roof as it lowers the indoor temperature reasonably than the hot outdoor, a thick growing layer composed of a 6 inch planting medium and 3 inch sand layer underneath and a thick top vegetation layer of the proposed model should suffice. However, the thermal response of the system and its durability and maintenance problems need to be studied empirically.

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