DESIGN OF A GREEN ROOF CONCRETE UNITS

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Abstract: In Urban areas, reinforced concrete roofs are often left arid, un-utilized, and are thus misused. In addition, these roofs are exposed to weathering and thereby contribute to extra consumption of heating and cooling. Recent attempts have been made to cultivate the roofs in order to make them greener and render better aesthetics to the structure.

This paper examines the green roof concept by designing concrete small units and attempting to cultivate them with small plants. The testing scheme was conducted with the aid of the German Guidelines for Green Roof Systems. Testing included materials testing, water retention and water runoff as well as thermal testing. In addition, thermal pictures were taken to demonstrate the potential impact of the green roof on the indoor temperature.

With this simplified feasibility study, it was found that implementing different types of green roofs in countries such as Egypt is achievable. The roofs demonstrated adequate structural performance, helped reduce internal heat which led to a reduction in the overall consumption of energy, and yielded simple food elements within the urban area.

Keywords: Green Roof, structural performance, sustainable development

1 INTRODUCTION

1.1 Background

Green roofs are roofs that are covered with plantation on top of buildings. Basically, there are three types of green roofing; extensive, semi-intensive and intensive green roof. These types vary in maintenance, irrigation, plant communities, system height, cost, and use (FLL, 2008) as shown in Table 1. Additionally, the major difference between the three types is the system height/soil depth (Weiler and Barth, 2009). Consequently, the weight and cost increase with the increase of the soil depth.

Table 1: Types of green roofs According to International Green Roof Association

Type/Properties	**Extensive Low Soil Depth and Plants**	**Semi-Intensive Medium soil Depth and Plants**	**Intensive High soil Depth and Plants**
Maintenance	Low	Periodically	High
Irrigation	No	Periodically	Regularly
Plant communities	Moss-Sedum-Herbs and Grasses	Grass-Herbs and Shrubs	Lawn or Perennials, Shrubs and Trees
System build-up height	60 - 200 mm	120 - 250 mm	150 - 400 mm on underground garages > 1000 mm
Weight	60 - 150 kg/m^2	120 - 200 kg/m^2	180 - 500 kg/m^2
Costs	Low	Middle	High
Use	Ecological protection layer	Designed Green Roof	Park like garden

Implementing a green roof guarantees a set of benefits. First, having a green roof would serve for fresh food supply. Second, it is used for the sake of aesthetics. Third, it reduces temperature of the building's roof. Fourth, it reduces pollution and noise (Contor, 2008).

Layers of green roof, in sequence from the structural roof deck, are: insulation, waterproof membrane, root resistant membrane, water retention mat, drainage system, filter sheet, growing media and a vegetated cover (Luckett, 2006). Root barrier layer is only used when planting trees in order to protect concrete. The materials used to construct the three types of green roof are listed in Table 2. Other economical and locally available materials were used in Egypt in order to facilitate the implementation of green roof by households are shown in Table 3. Those materials were selected and used to construct another three models for green roofing in order to evaluate the performance of each model.

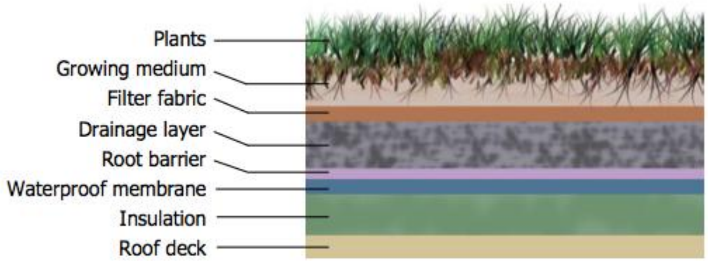

Figure 1: Layers of green roofs, (Pineo, R.& Barton, S., 2009)

Table 2: Typical models of green roofs

Materials	**Extensive Low Soil Depth and Plants**	**Semi-Intensive Medium soil Depth and Plants**	**Intensive High soil Depth and Plants**
Water proofing	Cementitious Insulation	Cold Applied Bitumen	Rubber Bitumen
Protection	1 Layer of 200g of Geotextile	-	-
Drainage	Aggregates	2 layers of 600g of Geotextile	2 layers of 600g of Geotextile
Filter	1 Layer 300g of Geotextile	1 Layer 300g of Geotextile	1 Layer 300g of Geotextile
Soil	25cm	40cm	90cm
Plants (examples)	mint, spinach	tomato, carrot, lettuce	Small trees, flowers, grass

Table 3: Innovative models of green roofs

Materials	**Extensive Low Soil Depth and Plants**	**Semi-Intensive Medium soil Depth and Plants**	**Intensive High soil Depth and Plants**
Waterproofing	Trash plastic bags	Polyethylene Sheets	Roof Tiles
Protection	1 Layer of 200g of Geotextile	-	-
Drainage	Crushed Bricks	Polystyrene Foam	Roof Tiles
Filter	1 Layer of 300g of Geotextile	1 Layer of 300g of Geotextile	1 Layer of 300g of Geotextile
Soil	25cm	40cm	90cm
Plants	mint, spinach, watercress	tomatoes, carrots, lettuce	Dodonaea trees, flowers, grass

2 Experimental work

2.1 Specimen Preparation

Construction of six models of green roofs was divided into: extensive, semi-intensive, and intensive; categorized into two: typical and innovative. The typical models consist of materials found easily in the local market as shown in Table 2. The innovative models consist of materials that are both domestic, recyclable, and can easily be obtained as a product of daily life as shown in Table 3.

The process started with designing the slab supporting the green roof considering different structural systems. It was concluded that the optimum the slab thickness is 12 cm and the slab to be reinforced with 5 Φ 8/ m'. Three forms were built to cast the concrete slab. After curing for two days, the forms were removed and the remaining three slabs were cast. The concrete mix was designed as shown in Table 4. Additionally, super plasticizer was added to the concrete so that it hardens rapidly and it was added with a rate of 8 liters per cubic meter of concrete.

Table 4: concrete mix design

Material	Weight (kg/m^3)
Cement	400
Water	160
Fine aggregate	752
Coarse aggregate	1150

Walls surrounding the growing medium are of thickness 25 cm. The models have different wall heights based on the green roofing type. Wall heights for extensive, semi intensive and intensive were specified to be 25, 45, 90 cm respectively. Additional layer of plastering was added for the interior of the walls.

In the plantation process, adding fertilizers should be taken into consideration. Table5 illustrates the various types of fertilizers that were used and the stage of application to the plants.

Table 5: Fertilizers use in green roofs

Fertilizer Name	Chemical Composition	When is it applied?
Super Phosphate	$Ca(H_2PO_4)2(s)+2CaSO_4.2H_2O(s)$	Before plantation
Urea	$(NH_2)2CO$	Before Plantation
Sulfur	S	Before Plantation
Starch	NH_4SO_4	After Plantation

2.2 Testing Procedure

The experimental work for the green roof consisted of two main types of testing; material testing and system testing. The main guidelines for the experimental work were: the "ASTM" standards and the German code for Green roof system, "FLL-Guidelines for the Planning, Construction and Maintenance of Green Roofing – Green Roofing Guideline". The ASTM standards were used for the material testing while the FLL guideline (FLL, 2008) was used for the System testing.

Material Testing:

The standards used for the material testing along with their description are illustrated in Table 6:

Table 6: Summary of material testing conducted

Standard	Objective
ASTM E 2397	Estimating the dead load and transient water live load of green roof systems
ASTM E 2399	Testing the densities for different media.
ASTM E 2400	Providing guidelines for the selection, installation, and maintenance of plants.

System Testing:

The testing conducted for the green roof systems with the aid of the FLL guideline are shown in Table 7.

Table 7: Summary of system testing conducted

Testing	Objective
Temperature	This practice was to achieve the temperature profile of the green roof system. Objective was to measure the temperature at different depths.
Water Runoff	Determining the water runoff coefficient C.
Moister Content	Investigating the moister at different layers of the green roof using a regular avometer.
Service/Durability	Observing the effects of access loading or wear and tear after the system has been loaded.

Once the material testing and the system testing were performed, a better understanding of the different materials used was formed. Then, it was concluded which materials would be suitable for applying in a green roof system.

3 RESULTS AND DISCUSSION

3.1 Material Testing

Media Density: The media density was tested using the proctor apparatus with a total of 6 blows to simulate the soil conditions on a green roof system. A density of 19.5 KN/m^3 and a live load of 3.13 KN/m^3 were calculated. As shown in Table 8, this density was used to calculate the weight of soil in terms of square meter for the different types of green roof systems; extensive, semi-intensive, and intensive.

Material dead load/live load and water retention analysis: each layer of the systems consisted of different type of materials. The dead load and live load as shown in Table 8 were calculated by weighing the materials at a dry state and at a saturated state. The dead load is concluded from the dry state, and the difference between the dry state and the saturated state was the live load. Also, the water retention was calculated from the saturated state as shown in Table 8.

From the results, it was concluded that all the waterproofing materials had no water retention and no live load. The highest water retention was in the soil layer and in the geo-textile materials. However, the major contributing layer in terms of loading was the soil layer and the geo-textile material had a higher capability of retaining water. Furthermore, a loading analysis was conducted as shown in Table 9. The total loading is gathered for the typical and innovative green roof systems.

Sieve Analysis of growing media: a sieve analysis of the growing media was conducted to see if the soil used is suitable for the system. Furthermore, these calculations were compared with the FLL guideline to check if it abides by the standard. The objective was to examine if the soil has granules 20% by mass passing through sieve with a diameter less than 0.063mm. As shown in Figure 2 and Table 10, the desert sand used, was in accordance to the standard.

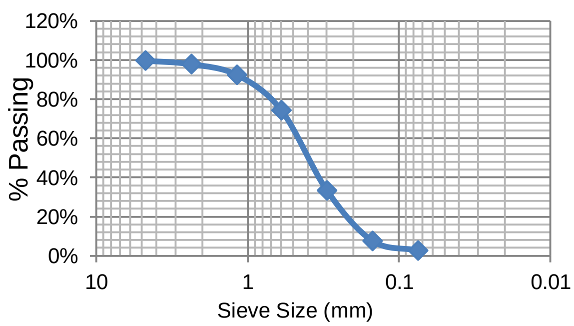

Figure 2: Graph of sieve size vs % passing

Table 8: Dead load/live load and water retention analysis

No	Material	Description	Dead Load (N/m²)	Live Load (N/m²)	Water Retention
1	**Water Proofing layers**				
	Bitumen	Cold apply bitumen	29.4	N/A	N/A
	Cemantatious Insulation	Water proof cement	58	N/A	N/A
	Cerouplast bitumen	Rubber Bitumen	29.4	N/A	N/A
	Garbage Bags	Black	1.3	N/A	N/A
	Plastic Sheets	Transparent	1.72	N/A	N/A
2	**Drainage layers**				
	Course Aggregates	Gravel	180	N/A	N/A
	Smashed Bricks	Light weight bricks	90	N/A	N/A
	Polystyrene Foam	Thermal insulation board	24	17.6	N/A
	Roofing tiles	Clay roofing tiles	194	N/A	N/A
	Geo-textile	non-woven 600g/m²	44.12	19.31	38.83 N/m²
3	**Protection layers**				
	Geo-textile	non-woven 200g/m²	13.94	11.9	9.94 N/m²
4	**Filter Layer**				
	Geo-textile	non-woven 300g/m²	34.29	13.21	30.47 N/m²
5	**Soil**				
	Extensive 25cm	Saturated-Drained	4875	783	36%
	Semi-Intensive 40 cm	Saturated-Drained	7800	1252	36%
	Intensive 90 cm	Saturated-Drained	17550	2817	36%
6	**Plants**				
	Extensive Greening	Corchorus (molokhia),mint, spinach	100	N/A	N/A
	Semi-Intensive Greening	Tomato, carrots, lettuce	200	N/A	N/A
	Intensive Greening	Dondonaea trees, flowers, Okra	400	N/A	N/A

Table 9: Dead load/live load for typical systems

Typical	Extensive		Semi-Intensive		Intensive	
	Dead Load (N/m^2)	Live Load (N/m^2)	Dead Load (N/m^2)	Live Load (N/m^2)	Dead Load (N/m^2)	Live Load (N/m^2)
Water Proofing	58	N/A	29.4	N/A	29.4	N/A
Drainage	180	N/A	44.12	19.31	44.12	19.31
Protection Layer	13.94	11.9	N/A	N/A	N/A	N/A
Filter Layer	34.29	13.21	34.29	13.21	34.29	13.21
Soil	4875	783	7800	1252	17550	2817
Plants	100	N/A	200	N/A	400	N/A
Total (KN/m^2)	5.26	0.81	8.1	1.3	18.05	2.84

Table 10: Sieve Analysis of growing Media

Sieve no.	Sieve Size (mm)	Weight Retained (Gm)	Weight Retained %	Cumulative Weight Retained	Cumulative Weight Retained %	% Passing
#4	4.75	1.5	0.3%	1.5	0.3%	99.7%
#8	2.36	9	2.1%	10.5	2.1%	97.9%
#16	1.18	27.5	7.6%	38	7.6%	92.4%
#30	0.6	90.5	25.7%	128.5	25.7%	74.3%
#50	0.3	205	66.7%	333.5	66.7%	33.3%
#100	0.15	129	92.5%	462.5	92.5%	7.5%
#200	0.075	24.5	97.4%	487	97.4%	2.6%
Pan		13	100.0%	500	100.0%	0.0%

3.2 System Testing

Temperature testing: temperature was measured at 3 cm below the surface, at the center, and at the bottom of the green roof system, in order to establish a temperature profile. From the profile obtained, it was noticed that the deeper the planting soil, the lower the temperature. Accordingly, this demonstrates that the measured green roof systems are effective at reducing the temperature within the soil, as compared to atmospheric pressure or the presumed surface temperature of an arid concrete roof.

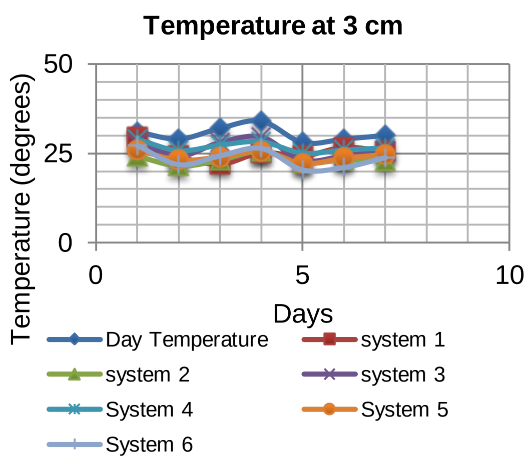

Figure 3: Temperature at 3 cm below surface

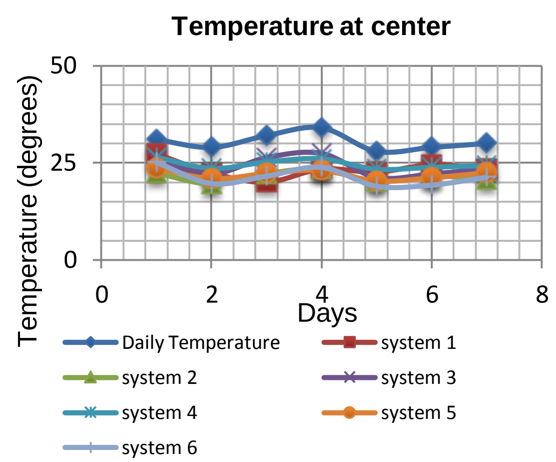

Figure 4: Temperature at the center of the systems

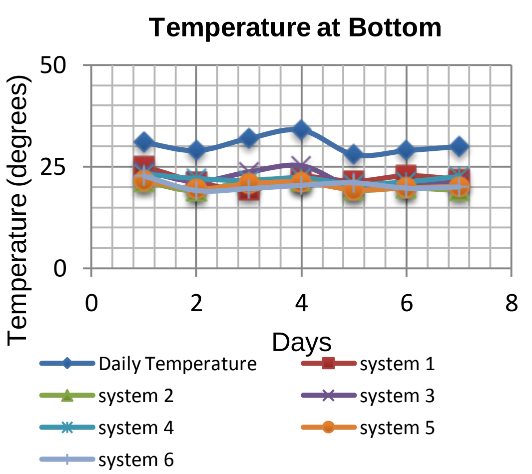

Figure 5: Temperature at the bottom of the systems

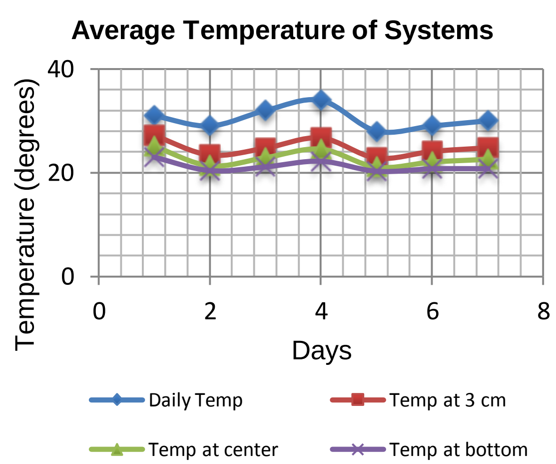

Figure 6: Average temperature of all systems at different depths

Figure 3, Figure 4 and Figure 5 show the temperature of the 6 systems at noon for the three different depths respectively. In all the charts a reference, which is the daily temperature, has been shown to show that the system temperatures are much lower than the daily temperature. The temperature profile is more evident in Figure 6, showing the temperature at different depths in one chart.

Thermal Photography: The thermal photography was qualitative test to show the variation in temperature in the green roof system and the variation between the green roof and the surrounding structures. From the thermal images, it was obvious that the green roof systems contributed to temperature reduction. The thermal image captured temperature variations of 4 to 5 degrees. As illustrated in Figure 7, it is evident that the green area is showing lower temperatures compared to the wall surface. In Figure 8, it is shown that the green roof lowers the surrounding temperature compared to the surrounding surfaces, which in this case is the pavement. The thermal photography added to the strength on the claim that green roof systems reduce internal and external temperatures.

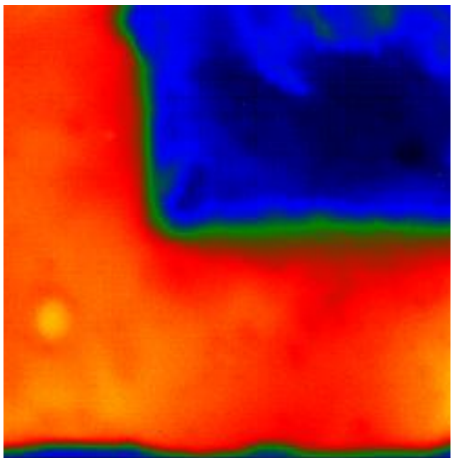

Figure 7: Thermal image comparison between temperature of green area vs wall

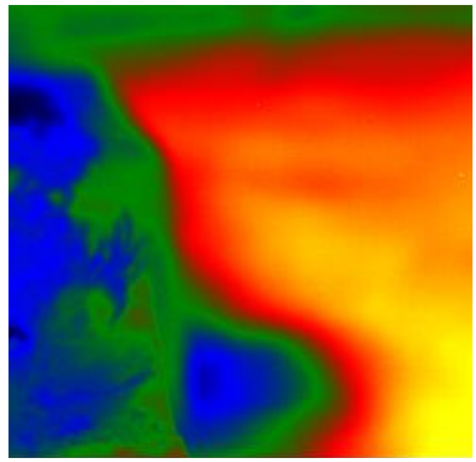

Figure 8: Temperature around green roof systems compared to pavement temperature

Water runoff testing: The objective of this test was to establish whether the green roof systems reduced water runoff and, if so, the relative performance of each system. The testing method involved simulating rain and excess irrigation and then examining the relationship between water drainage and intake. For the typical and innovative systems, as per Table 11 and 12 respectively, system 1 and system 4 exhibited higher relative drainage performance.

The maximum water flow rates for drainage are calculated using equations 1 and 2. The water runoff coefficient is calculated from equation 1 and substituted in equation 2. Values shown in Table 13 would help in determining which drainage system may be better for a certain size of green roof area. It is illustrated that for an area of 25m x 35m, the drainage of system 1 is above 160 (l/s), which is too high. This means that the drainage material used in system 1; aggregates, would not be suitable to be used for large green roof areas (Nicholaus et.al, 2005).

[1] $$C = \frac{\text{Outlet water volume in liters in 15 minutes}}{\text{Rain volume in liters in 15 minutes}}$$

[2] $$Q = A * C * I$$

Where:
Q= the volume in (l/s) cleared via the drainage course
A= the surface area to be drained in m^2
C= the runoff reference of discharge
I = Maximum rainfall in $l/(s \times m^2)$

Table 11: Results of water runoff test and water runoff coefficient for typical systems

System 1: Extensive-Typical	
input (ltrs)	110
Output (ltrs)	68.4
Water Runoff Coefficient C	0.62
System 3: Semi intensive-Typical	
input (ltrs)	150
Output (ltrs)	28.8
Water Runoff Coefficient C	0.192
System 5: Intensive-Typical	
input (ltrs)	150
Output (ltrs)	1.2
Water Runoff Coefficient C	0.01

Table 12: Results of water runoff test and water runoff coefficient for innovative systems

System 2: Extensive-Innovative	
input (ltrs)	150
Output (ltrs)	19.2
Water Runoff Coefficient C	0.13
System 4: Semi intensive-Innovative	
input (ltrs)	120
Output (ltrs)	22.8
Water Runoff Coefficient C	0.19
System 6: Intensive-Innovative	
input (ltrs)	130
Output (ltrs)	2.4
Water Runoff Coefficient C	0.02

Table 13: Maximum draining flow rate for standard roof sizes

Length (m)	Width (m)	Area (m^2)	Max flow Q (l/S)					
			System 1	System 2	System 3	System 4	System 5	System 6
1.3	1.3	1.69	0.3	0.1	0.1	0.1	0.0	0.0
5	5	25	4.7	1.0	1.4	1.4	0.1	0.2
10	10	100	18.6	3.9	5.7	5.7	0.3	0.6
15	15	225	41.9	8.8	12.8	12.8	0.7	1.4
25	35	875	162.8	34.1	49.9	49.9	2.6	5.3

Service/Durability testing: In this testing, the same methodology of water runoff test was followed to investigate the effect of over loading on the systems. The innovative systems were loaded with 500 kg for 72 hours and then water runoff test was conducted. A total settlement in the systems was observed due to compaction. Furthermore, calculations listed in Table 14 showed a reduction in the water runoff coefficient. This may have been due to the compaction and or clogging of the layers in the systems. (Stewart, 2010) However, no definite justification can be claimed until the systems are dismantled and effects on the layers are studied. Thus, the excessive loading does affect the system drainage but does not result in failure.

Moister content testing: This test was carried out similar to the procedure one would use to monitor the moister content in wood. During construction, two electrical wires were inserted on the drainage layers and concrete slab surfaces in each model. The concept behind this test was to observe moister content inside each layer, and to try to find the best system that provided lower moister contents on the water proofing layer. Regular avometer was used along with a 9-volt battery. The 9-volt battery was used to connect the avometer and the electrical wires in series with each other in order to eliminate the internal resistance of the avometer. Thus, the voltage drop across the meter and wires will be equal to the 9 volts from the battery, and the voltage drops across the meter and the wires will be in the same proportion as their resistances. By using equation 3 and from Figure 9, moister content obtained as a percentage on each layer (Moisture Meter, 2011).

[3] $$R = \mathrm{Rmeter}\left(\frac{\mathrm{Vbattery}}{\mathrm{Vmeter}} - 1\right)$$

Table 14: Results of water runoff test and water runoff coefficient for innovative systems for service/durability testing

System 2: Extensive-Innovative	
input (ltrs)	150
Output (ltrs)	48
Settlement (cm)	2
Water Runoff Coefficient C	0.32
System 4: Semi intensive-Innovative	
input (ltrs)	150
Output (ltrs)	20
settlement (cm)	3
Water Runoff Coefficient C	0.13
System 6: Intensive-Innovative	
input (ltrs)	150
Output (ltrs)	0
settlement (cm)	3
Water Runoff Coefficient C	0.00

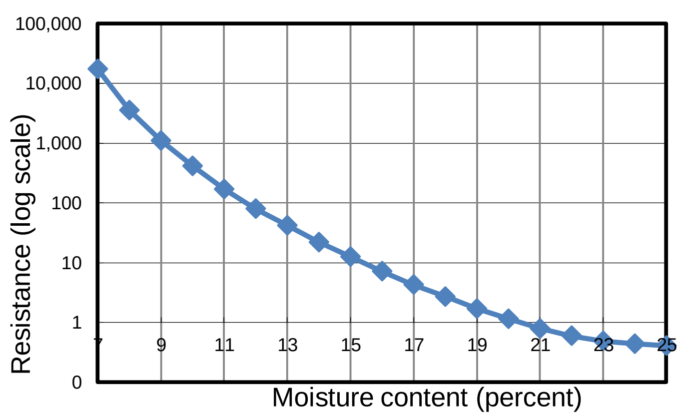

Figure 9: Chart used to obtain moisture content from resistance (Moisture Meter, 2011)

4 Conclusion

In order to summarize the requirements to construct a green roof system, the following diagram is established, Figure 10. It is concluded that in order to design a green roof system, there isn't a specific material or a specific combination of materials that is the best. However, it depends on the application and on the engineer's judgment to select the best suitable material and combination of layers to create the green roof system. However, the requirements that an engineer should have at hand are all combined together in order to make the best decision. The designer should be aware of the system testing data, material testing data, economics data, and other tests which are highlighted in red should be conducted. These set of data, would result in an economical and good performance green roof system.

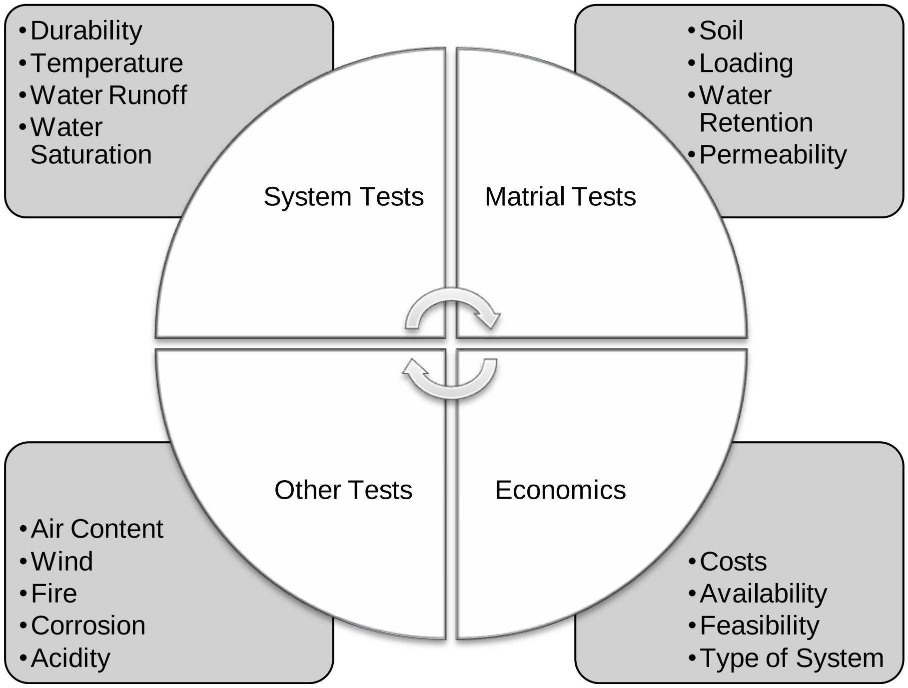

Figure 10: Requirements for designing a green roof system

Adopting green roof in Egypt, as an example, would assist in supplying of some small plantations whether for nutrition or decorative purposes, both of which has environmental merits and can assist in reducing energy cost for cooling in such an overall hot climate.

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