Thermal Comfort Assessment of Green Roofs on Container Shelters in Hot Arid Climates in Zaatari Camp in Jordan

Abstract:

Green roofs strategy is a major area of interest within the field of passive design strategy due to its environmental benefits. This paper discusses the definition of extensive green roofs and their typical constructional details and how this strategy can contribute to enhance the thermal comfort of container shelters in displaced shelters. It also critically examines the thermal performance of extensive green roofs in hot arid climates. Its purpose is to test the thermal comfort parameters.

Therefore, simulating the air temperature and humidity is required. For achieving the purpose of this investigation, a real case study was used by selecting a container shelter in the Zaatari camp in Jordan. Simulations are conducted using DesignBuilder software.

The first section of this paper overviews the climate of Jordan and the parameters discussed in this research paper are air temperature and humidity. Then, a description of the building's location and the constructional details are presented.

To demonstrate the effect of the green roof system, thermal insulation layer and LAI value are varied in order to obtain thermal comfort and find out the correlation between these and the thermal comfort. Setting all these parameters and data together, DesignBuilder simulations of air temperature and humidity are explained in the next section, results of these simulations and findings are also discussed. Finally, a comparison between conventional and green roofs has been done in terms of thermal comfort. The study concludes that green roofs are partially effective in hot climates and some further suggestions were proposed.

1. Introduction:

1.1. Green Roof Strategy

Green roofs, also named "eco-roofs", "living roofs" or "roof gardens", are defined as roofs with a top layer of plants (La Roche and Berardi, 2014). Basically, Green roofs can be intensive roofs or extensive roofs (Zhou et al., 2018) and (Anwar et al., 2013). Extensive roofs require less maintenance than intensive green roof. In addition, they are lighter due to the 20-60 cm soil layer depth. (Jaffal et al., 2012). (Figure 1)

Figure 1 Difference Between Extensive and Intensive Green Roofs (Anwar et al., 2013)

TABLE I
DIFFERENCE BETWEEN EXTENSIVE AND INTENSIVE GREEN ROOFS

Topics	Extensive green roof	Intensive green roof
Substrate	100-200 mm	>200 mm
Weight	50-150 Kg/m^2	>150 Kg/m^2
Plant option	Sedums, Succulents, Herbs with shallow rooting	Perennial, Lawn, Trees and shrubs with deeper rooting
Maintenance	Low	High
Irrigation	Low	High
Fertilization	Low	High
Energy efficiency	Low	High
Installation	Easy to retrofit in existing structure.	Difficult to retrofit.
Storm water retention	Low capacity	High capacity
Cost	Low	High
Technical expertise	Minimum	Higher
Structural support	Lower	Greater

Generally, the green roof system consists of three main parts: canopy, soil and roof slab (Jaffal et al., 2012). While (Anwar et al., 2013) and (Zhou et al., 2018) classify the green roof layers to vegetation layer, substrates, drainage system and water proofing membrane.

Green roofs reflect between 20% and 30% of solar radiation and absorb up to 60% of it through photosynthesis. This means that a percentage below 20% of the heat is transmitted to the growing medium (Berardi et al., 2014).

1.2. Occupant Details

The Zaatari camp provides one caravan for every family of up to six members, and two caravans for families of 6-12 members (Albadra et al., 2018). Therefore, in this paper a family of four is assumed to occupy this shelter (Parents and two children). The shelter is occupied all day, it is a bedroom living space, since kitchen and bathroom are separated outdoors.

Mainly, activity has been considered as quite seated. For the clothing insulation, the traditional women clothes are taken into consideration. While men wear western style outfits in summer, and in winter multi layered clothes with heavy coats. The values of clothing insulation for both winter and summer are derived from the table shown in Figure 2. (Albadra et al., 2017)

Figure 2 Refugee Clothing Insulation (Albadra et al.,2017)

Table 1: Examples of refugee clothing insulation.

	Al Ajami et al., 2008 'islamic dress'		Calculated refugee clothing (minimum values)	
	ensemble	I_{cl} (clo)	ensemble	I_{cl} (clo)
Women Summer	Bra, pants, sandals, long dress, hijab	0.8	Bra, pants, long bottoms, long dress, hijab, barefoot	0.93
Women Winter	Bra, pants, shoes, socks, thicker dress, hijab	1.15	Bra, pants, long bottoms, long sleeve blouse, thicker dress	1.43
Men Summer	T-shirt, short bottoms, long dress, sandals, headwear	0.69	Men western style clothing: Men briefs, t-shirt, short sleeve blouse, trousers	0.43
Men Winter	T-shirt, short bottoms, long serwal (bottoms), long dress, socks, shoes, headwear	0.79	Men western style clothing: Men briefs, t-shirt, long sleeve sweater, thick trousers, socks	0.75

1.3. Climate:

Jordan is situated between 29° 45' N and 32° 32' N, and it is characterized by an arid desert climate according to the Köppen-Geiger climate classification. (Albadra et al., 2018). Al Za'atari refugee camp, (32.29° N, 36.33° E) 12km south of the Jordan-Syria border, and the mean maximum outdoor temperature in Zaatari is 32.7°C and the mean minimum is 1.9°C.

Figure 3 and 4 show the dry bulb temperature and relative humidity for a nearby camp in Jordan (blue: daily average, grey: daily min-max range) (Fosas et al., 2018).

Figure 3 Annual Dry Bulb Temperature (Fosas et al., 2018)

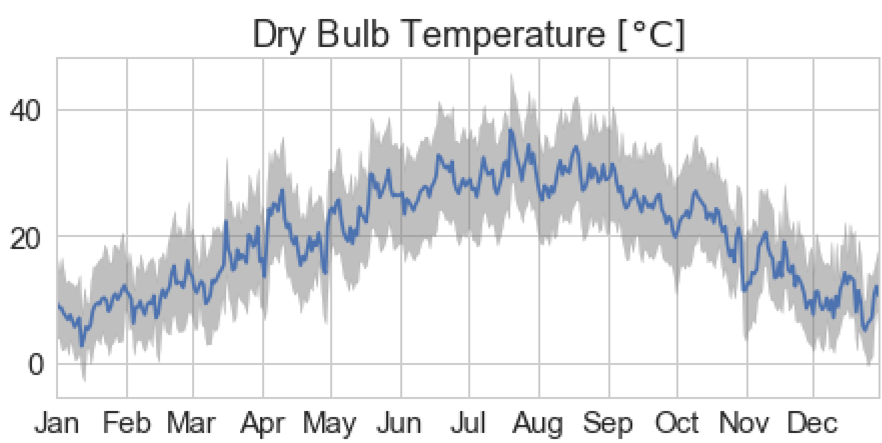
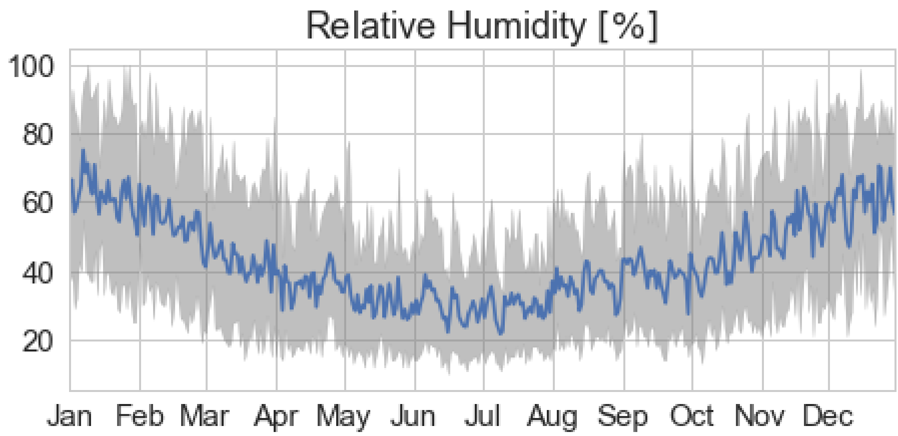


Figure 4 Annual Relative Humidity (Fosas et al., 2018)



1.4. Shelter Description:

A container refugee's shelter located in Jordan is selected as a case study. The total occupied area is 14 m² area. Ventilation is through one door and two $1m^2$ windows, one facing to the south and the other to the east (Figure 5). The shelter's roof and walls are made up of 40mm polyurethane insulated sandwich panels with inner and outer surfaces of 0.35mm steel sheet, while floors are of suspended timber (Albadra et al., 2018). Based on (Elrayies, 2017) the size standard of this container shelter is 6m*2.4m and 2.89m high.

Figure 5 Container Shelter Case Study- Source https://archnet.org/sites/15817/media_contents/114895

The occupancy details of the space are given in Table 1. In addition, the thermal characteristics of the building envelope are presented in Table 2.

Generally, according to (Fosas et al., 2017) Refugees do not have access to electricity and the main cooling strategy at building level is natural ventilation. Minimum ventilation is at $8ls^{-1}\,p^{-1}$ (Fosas et al., 2018) and the Infiltration rate is 2.0 ach.

Table 1 Occupancy Details

Parameter	Value
Occupied floor area (m^2)	14.0
Occupied volume (m^3)	39.2
Number of people	4.00
Activity	Seated quiet
Metabolic factor	0.84
Winter clothing (clo)	1.09
Summer clothing (clo)	0.68
Fresh air (l/s-person)	8.00
Infiltration rate (ach)	2.0

2. Literature

Literature about green roofs is available and extensive, and the efficiency of these green roof systems has been monitored and evaluated by many researchers with different methodologies. This section discusses some of the methodologies and findings of these studies, in which different analyses on the thermal comfort and heat balance topics have been used.

Several studies have performed comparative studies to investigate the green roof efficiency. For example, in France, a temperate oceanic climate, (Jaffal et al., 2012) performed a comparative study between conventional and green roofs of a single-family house. The author assessed the values of the temperature of the exterior surface of the roof slab, the heat flux through the roof to the inside of the building, the indoor air temperature and the heating and cooling demand. One interesting finding is green roofs are more suitable for retrofitting non- or poorly insulated old buildings than for use in well-insulated new buildings. Another important finding was that green roofs increase the longevity of roofing membranes. Because solar shading, evapotranspiration, and thermal resistance caused by green roofs protect the roof slab from extreme temperatures and high temperature fluctuations.

A related study in Athens, (Niachou et al., 2001) conducted experimental and mathematical approaches to evaluate the green roof's thermal performance of a hotel in Athens. The experimental approach recorded the indoor air temperature using an infrared thermograph camera, infrared thermometer, and an infrared psychrometer.

Similarly, in humid-subtropical Hong Kong, (Jim, 2014) installed outdoor sensors for air temperature and material temperature, green roof and indoor sensors to record the ceiling temperature and air temperature. The authors could work out the heat flux through the roof slab using the equation $V=k(Tt-Tc)\,\Delta d$

In a recent study in Shanghai, China (Zhou et al., 2018) are much more concerned with the Leaf Area Index (LAI) and proposed an equation to calculate the LAI value for seasonally variable vegetation. The study concluded that LAI parameter can significantly influence the evapotranspiration effect of a green roof.

In a detailed study In Phoenix, Los Angeles, and Chicago, (La Roche and Berardi, 2014) assessed four plots with an insulated traditional roof, a non-insulated green roof, an insulated green roof, and a green roof in a hot dry climate with mild winter, by studying the effect of LAI, soil depth and insulation thickness on EnergyPlus.

Generally, in non-insulated buildings, the impact of green roofs is much higher than in insulated ones, whereas the better the insulation of the roof, the lower their contribution.

The only study that was found in the literature review which examined green roofs on container shelters is by (Anwar et al., 2013). The study carried out an experimental method in Australia and recorded indoor temperature and humidity every 30 minutes for 10 months long. The author concluded that green roofs act as insulation rather than a cooling strategy and a bare roof receives 100% direct exposure, whereas green roofs can shelter buildings from 87% of solar radiation.

In all the studies reviewed here, LAI, soil depth and heat flux appear to be the most significant parameters examined.

3. Methodology

3.1. Methodology Selection

Based on the literature review, the section below describes the methodology performed. This paper aims at developing a passive design strategy to obtain thermal comfort in hot desert climates. In order to achieve the objectives of this study, a base case approach was adopted, and examined the implementation of a green roof on a container shelter in the Zaatari refugee camp in Jordan, to find the value of the air temperature and humidity.

The developed methodology is based on building simulation, a 3D computational model of a base case scenario for the container shelter (6m*2.4m) was developed on DesignBuilder and for comparison purposes the same shelter with a green roof system was modelled (Figure 6 and 7). The system consists of five layers from bottom to top Polyvinylchloride PVC layer (2.50 mm), EPS thermal insulation (50 mm), Polyvinylchloride PVC layer (2.50 mm), Gravel (38.1 mm), Soil (200 mm) and Plants layer (200 mm) (Figure 8).

Figure 6 Base Case Scenario Model of The Shelter

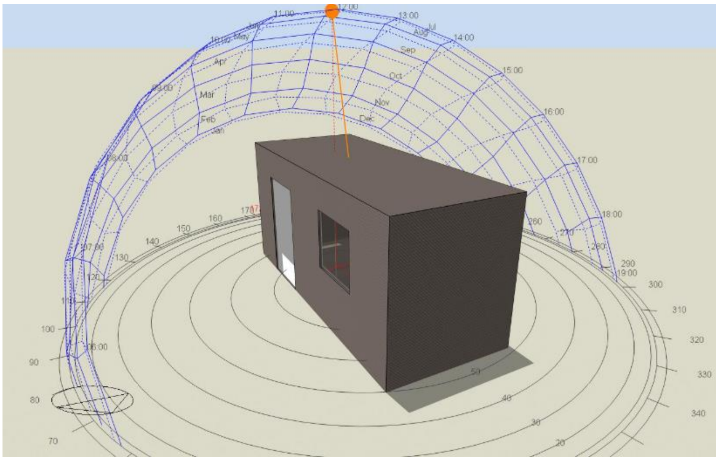
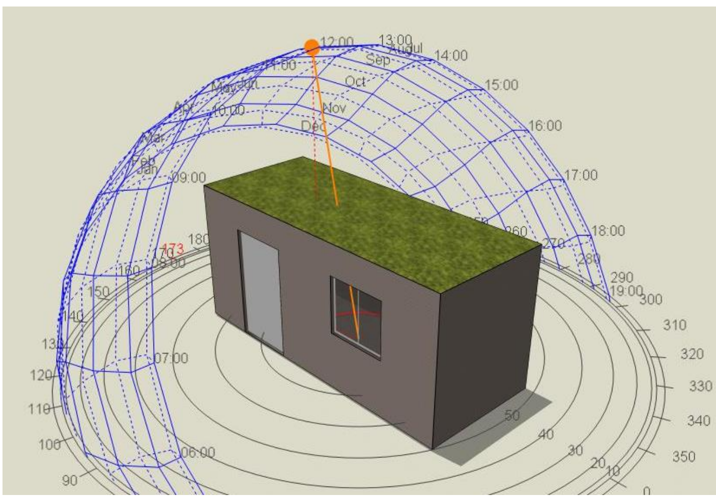


Figure 7 Green Roof Model on DesignBuilder



The evaluation of the comfort parameters is performed by DesignBuilder. This simulation tool is based on Energy Plus calculation engine. DesignBuilder develops accurate thermal analyses and detailed inputs, that include climatic data and construction materials and components. Energy Plus has a green roof feature which takes the evapotranspiration of the vegetation layer, the time dependent soil thermal properties (conduction and inertia), the radiative and convective heat exchanges into account (Zinzi and Agnoli, 2012).

Figure 8 Green Roof Structure Modelled on DesignBuilder

3.2. Methodology Implementation

This study uses the weather file of Israel, Jerusalem due to the limited options available of weather data in EnergyPlus near to Jordan. Considering the shelter is a free running unit and naturally ventilated.

3.3. Base Case Scenario

The base case scenario is a bare roof for a steel panel sandwich container shelter, with a U-value of 0.638 W/m^2.K

Table 2 Structural Details of the Container Shelter

Sandwich Panel Container Structure				
Layer name	Thickness [mm]	Density [kg/m³]	Specific heat capacity [J/kg/K]	Thermal conductivity [W/m/K]
steel	0.35	7800	450	50.00
EPS	40	30	1400	0.03
steel	0.35	7800	450	50.00

Basically, all simulated data are examined and compared to the baseline data of the DesignBuilder simulated results of the conventional roof. Data comparison and evaluation can help in detecting the green roof system efficacy.

3.4. Investigated Parameters

The performance parameters are thermal insulation thickness of the green roof system and the Leaf Area Index (LAI) value. It is necessary here to clarify exactly what is meant by LAI. (Berardi et al., 2014) refer to LAI as a representation of the plan-form area coverage of the leave. Values of LAI depend on plant type and are typically in the range of 0.5–5.0. While (Zhou et al., 2018) define it as "the ratio of the entire one-sided area of the leaf divided by one unit of ground soil surface area. It is a non- dimensional quantity that is determined by the vegetation canopy". This value is reliable on the behavior of the plant and its structure. Additionally, it is a pivotal parameter for the energy performance of a green roof when the influence of the evaporation rate is considered (Zhou et al., 2018). Therefore, the variables of LAI in this study are 0.5 and 5.

The second investigated parameter is the thickness of the thermal insulation of the roof. Hence, this paper proposes three scenarios for the green roof shown in Table 3.

The main measures generated in this study to assess the thermal comfort of the occupants are the indoor air temperature and relative humidity.

Table 3 Examined Scenarios of The Roofs

Case	Description
Base Case	Bare Roof
Scenario 1	Green Roof: LAI= 0.5 Thermal Insulation Thickness=0.2m
Scenario 2	Green Roof: LAI= 5.0 Thermal Insulation Thickness=0.2m
Scenario 3	Green Roof: LAI= 5.0 No Thermal Insulation

4. Results

On typical winter day, the diurnal air temperature profile is presented in Figure 9, the line chart below compares the air temperature profile obtained from the DesignBuilder simulation of the conventional roof and three different green roofs for typical two days in winter (March).

What stands out in the graph is that the air temperature of the green roof is slightly higher than the conventional roof from 1:00 am to 6:00 am approximately by 0.5ºC. Remarkably, when the sun is up both the conventional and the green roofs gets warmer and green roofs are warmer than conventional roofs by 2ºC. The peak temperature of 18.59ºC is recorded in the green roof at 11:00 am while it is 16.67ºC in the bare roof. After that, the warming effect of the green roofs starts to slow down at night around 1:00 am

Turning now to the relative humidity in winter (Figure 10). On average, the relative humidity of conventional roofs is slightly higher than in the all scenarios of the green roofs.

Surprisingly, in a typical day in summer (Figure 11), no significant differences of thermal performance were found between the roofs. From 8:00 am to 10:00 pm all roofs are higher in temperature than the dry bulb temperature. Relative Humidity for all examined roofs follows the same pattern and is approximately the same.

The variable insulation thickness of the green roof and the variable LAI performs similarly in all seasons. The three scenarios of the green roofs are labelled in the legend of each graph.

Figure 9 Air Temperature Profile Comparison Between Bare Roof and Variable Green Roofs

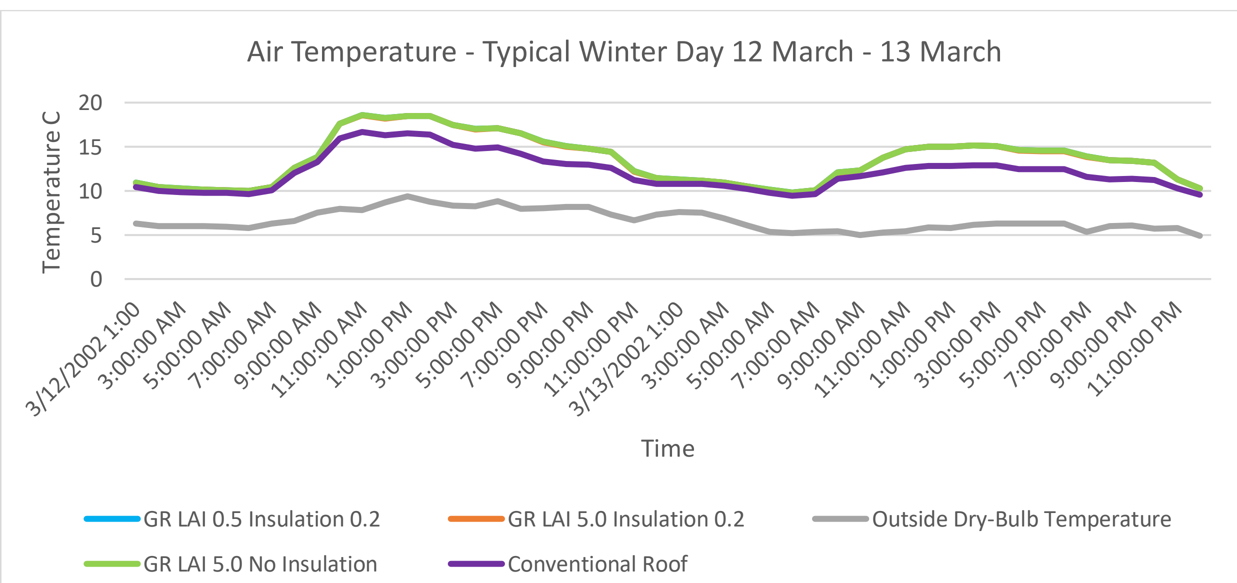


Figure 10 Relative Humidity Comparison Between the Examined Roofs

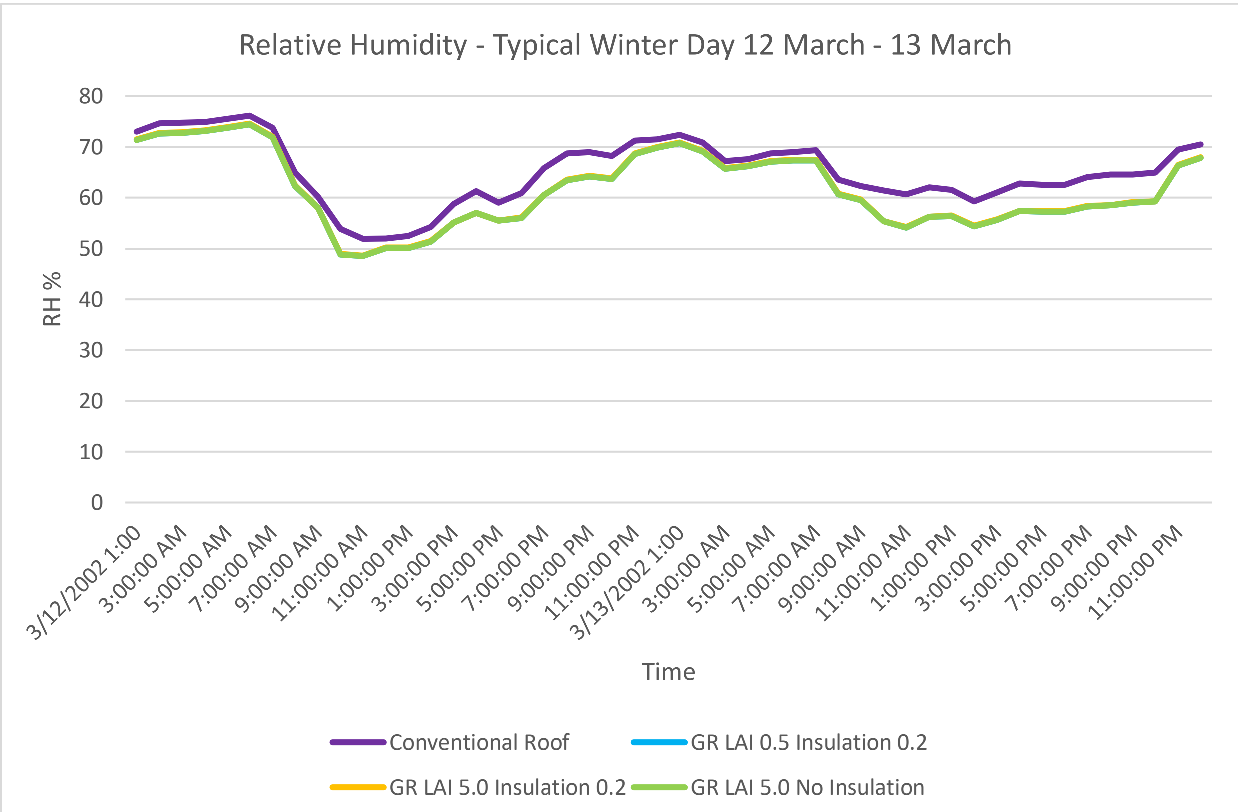


Figure 11 Air Temperature Profile Comparison of the Examined Roof in A Typical day In Summer

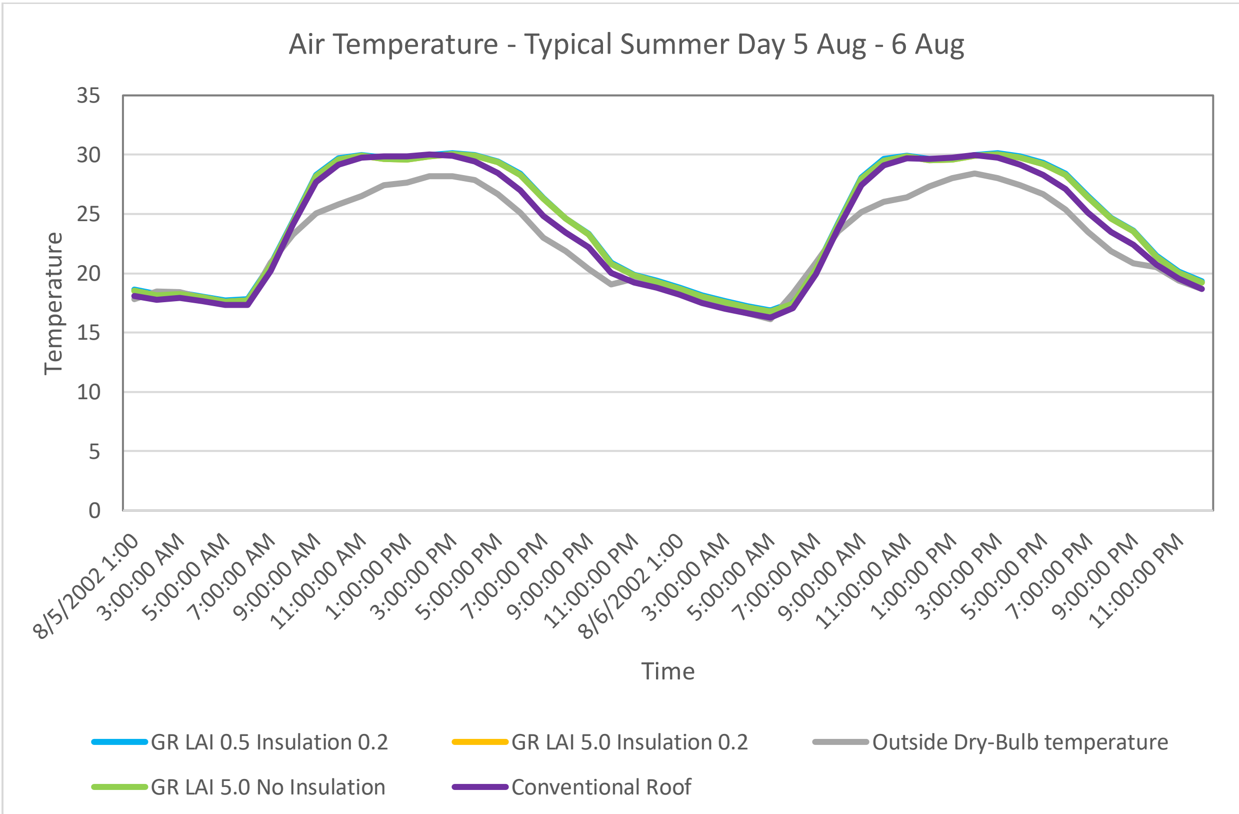
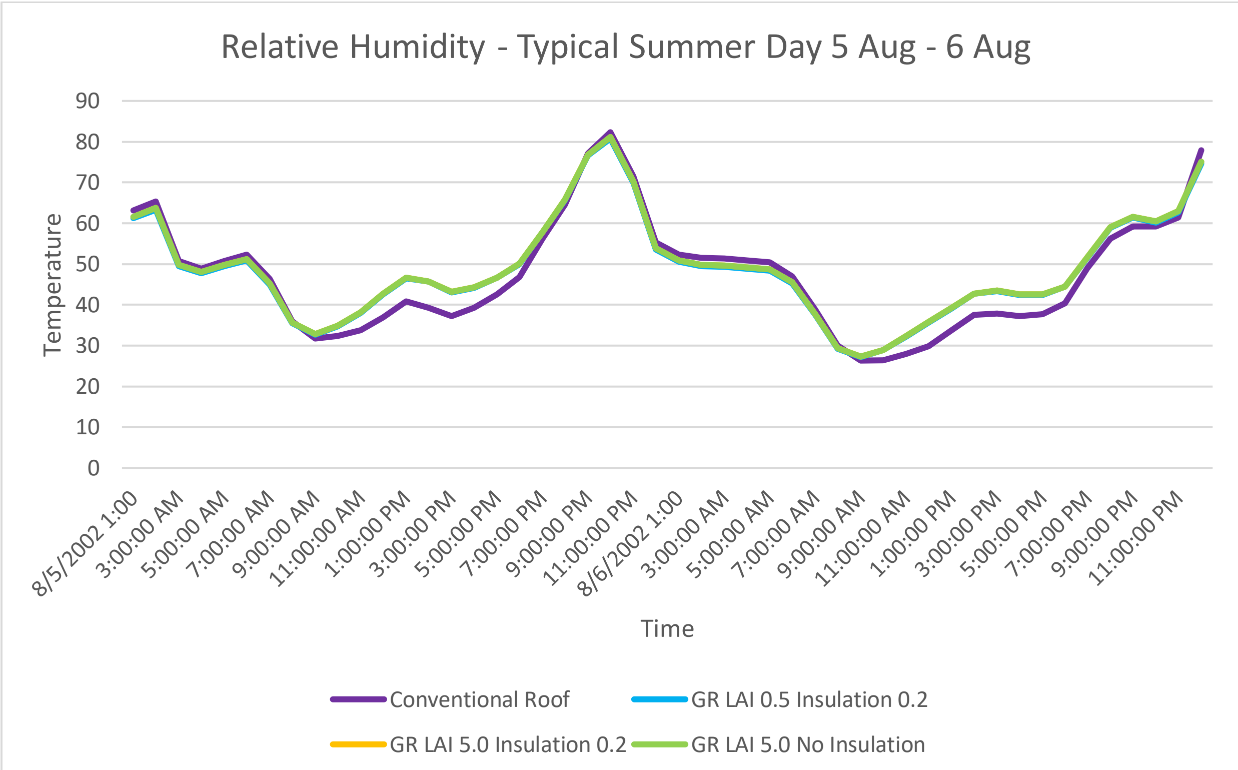


Figure 12 Relative Humidity of A Typical Day In Summer For all Examined Roofs



5. Discussion

Based on the literature review, green roofs systems have three main phenomena, that can be summarized as below (Berardi et al., 2014)

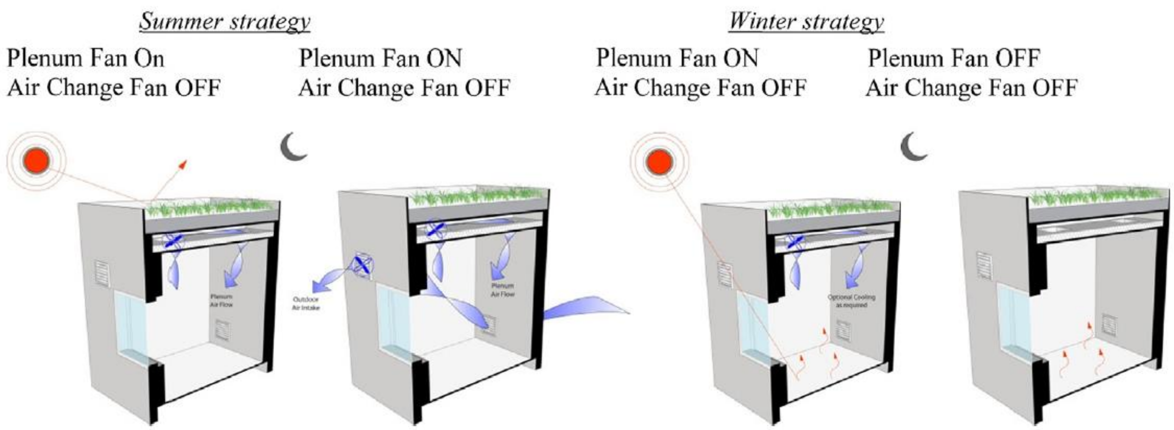
- 'Soil works as an inertial mass with a high heat thermal capacity, high time lag effect and low dynamic thermal transmittance."
- "Foliage behaves as a shading device under which convection provokes heat thermal exchange, but foliage absorbs part of the thermal energy for its vital process of photosynthesis."
- "Soil and plants contribute in evaporative and evapotranspiration cooling."

Contrary to expectations, this study did not find a significant difference between green roofs and conventional roofs in summer. However, the observed difference between green roofs scenarios in this study was not significant.

A possible explanation for the overheating in green roofs in summer might be that the soil layer in extensive roofs is very thin, therefore it dries quickly in hot regions.

Another possible explanation for this is that variable insulated green roofs act as a thermal mass and trap heat. This can be improved by combining a plenum fan that circulates the air and air change fan as shown in Figure (La Roche and Berardi, 2014)

Figure 13 A Possible Solution To the Overheating Occurs In Summer (La Roche and Berardi, 2014)



6. Limitations

A limitation of this study is that using the weather data file of Israel instead of Jordan. In addition, the study should be repeated taking the heat transfer through the green roof layers into consideration and all the biological processes of the plants. For example, irrigation must be considered, since arid climates affect the evapotranspiration processes.

7. Conclusion

The aim of the present research was to examine the thermal performance of extensive green roofs on container shelters in hot arid climates. The performance of green roofs was compared to bare roofs using DesignBuilder. The simulated results have shown that green roofs are warmer in winter, but in summer the graphs present overheating. This might be due to several factors, like ventilation and climate.

References

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Appendix

Typical Winter Day 12 March - 13 March												
	Conventional Roof			Green Roof LAI 0.5 Insulation 0.2			Green Roof LAI 5.0 Insulation 0.2			Green Roof LAI5.0 No insulation		
	Air Temperatur	Outside Dry-Bu	Relative Humid	Air Temperatur	Outside Dry-Bu	Relative Humid	Air Temperatur	Outside Dry-Bu	Relative Humidit	Air Tempe	Outside D	Relative H
3/12/2002 1:00	10.44	6.32	73.01	10.91	6.32	71.34	10.88	6.32	71.46	10.91	6.32	71.34
2:00:00 AM	9.98	5.97	74.62	10.44	5.97	72.64	10.42	5.97	72.77	10.44	5.97	72.64
3:00:00 AM	9.84	6	74.77	10.26	6	72.75	10.23	6	72.89	10.26	6	72.75
4:00:00 AM	9.79	6	74.92	10.16	6	73.1	10.13	6	73.23	10.16	6	73.1
5:00:00 AM	9.75	5.93	75.51	10.09	5.93	73.8	10.07	5.93	73.93	10.09	5.93	73.8
6:00:00 AM	9.66	5.75	76.15	10	5.75	74.44	9.97	5.75	74.58	10	5.75	74.44
7:00:00 AM	10.03	6.3	73.76	10.42	6.3	71.87	10.39	6.3	72	10.42	6.3	71.87
8:00:00 AM	11.99	6.57	64.9	12.61	6.57	62.3	12.58	6.57	62.41	12.61	6.57	62.3
9:00:00 AM	13.25	7.5	60.13	13.81	7.5	57.96	13.79	7.5	58.07	13.81	7.5	57.96
10:00:00 AM	15.94	7.95	53.82	17.63	7.95	48.83	17.6	7.95	48.89	17.63	7.95	48.83
11:00:00 AM	16.67	7.85	51.91	18.59	7.85	48.52	18.56	7.85	48.58	18.59	7.85	48.52
12:00:00 PM	16.29	8.7	51.99	18.23	8.7	50.12	18.2	8.7	50.18	18.23	8.7	50.12
1:00:00 PM	16.51	9.38	52.46	18.48	9.38	50.13	18.45	9.38	50.19	18.48	9.38	50.13
2:00:00 PM	16.38	8.75	54.27	18.48	8.75	51.38	18.45	8.75	51.44	18.48	8.75	51.38
3:00:00 PM	15.23	8.35	58.77	17.46	8.35	55.08	17.43	8.35	55.14	17.46	8.35	55.08
4:00:00 PM	14.78	8.23	61.34	17.01	8.23	56.96	16.98	8.23	57.03	17.01	8.23	56.96
5:00:00 PM	14.92	8.8	59.02	17.1	8.8	55.47	17.08	8.8	55.53	17.1	8.8	55.47
6:00:00 PM	14.17	7.95	60.88	16.52	7.95	56.01	16.5	7.95	56.08	16.52	7.95	56.01
7:00:00 PM	13.32	8.05	65.88	15.57	8.05	60.49	15.54	8.05	60.57	15.57	8.05	60.49
8:00:00 PM	13.04	8.2	68.7	15.04	8.2	63.48	15.01	8.2	63.56	15.04	8.2	63.48
9:00:00 PM	12.96	8.2	69.01	14.8	8.2	64.23	14.77	8.2	64.31	14.8	8.2	64.23
10:00:00 PM	12.6	7.3	68.21	14.44	7.3	63.65	14.41	7.3	63.74	14.44	7.3	63.65
11:00:00 PM	11.23	6.63	71.19	12.21	6.63	68.56	12.18	6.63	68.68	12.21	6.63	68.56
12:00:00 AM	10.78	7.32	71.46	11.46	7.32	69.83	11.43	7.32	69.97	11.46	7.32	69.83
3/13/2002 1:00	10.81	7.6	72.39	11.26	7.6	70.71	11.23	7.6	70.85	11.26	7.6	70.71
2:00:00 AM	10.8	7.53	70.87	11.17	7.53	69.12	11.14	7.53	69.26	11.17	7.53	69.12
3:00:00 AM	10.6	6.9	67.19	10.93	6.9	65.71	10.9	6.9	65.85	10.93	6.9	65.71
4:00:00 AM	10.2	6.1	67.61	10.53	6.1	66.17	10.49	6.1	66.31	10.53	6.1	66.17
5:00:00 AM	9.75	5.38	68.67	10.1	5.38	67.08	10.07	5.38	67.23	10.1	5.38	67.08
6:00:00 AM	9.44	5.2	69.03	9.81	5.2	67.31	9.78	5.2	67.46	9.81	5.2	67.31
7:00:00 AM	9.65	5.35	69.35	10.09	5.35	67.36	10.06	5.35	67.5	10.09	5.35	67.36
8:00:00 AM	11.34	5.4	63.59	12.06	5.4	60.68	12.02	5.4	60.8	12.06	5.4	60.68
9:00:00 AM	11.63	4.95	62.28	12.32	4.95	59.5	12.29	4.95	59.63	12.32	4.95	59.5
10:00:00 AM	12.06	5.25	61.36	13.78	5.25	55.31	13.75	5.25	55.41	13.78	5.25	55.31
11:00:00 AM	12.61	5.4	60.6	14.73	5.4	54.16	14.7	5.4	54.24	14.73	5.4	54.16
12:00:00 PM	12.8	5.85	62.1	15.01	5.85	56.22	14.99	5.85	56.29	15.01	5.85	56.22
1:00:00 PM	12.79	5.78	61.52	15.03	5.78	56.42	15	5.78	56.5	15.03	5.78	56.42
2:00:00 PM	12.91	6.15	59.21	15.15	6.15	54.35	15.13	6.15	54.43	15.15	6.15	54.35
3:00:00 PM	12.86	6.3	61.04	15.09	6.3	55.61	15.06	6.3	55.68	15.09	6.3	55.61
4:00:00 PM	12.44	6.3	62.78	14.61	6.3	57.34	14.59	6.3	57.41	14.61	6.3	57.34
5:00:00 PM	12.44	6.3	62.53	14.55	6.3	57.28	14.52	6.3	57.35	14.55	6.3	57.28
6:00:00 PM	12.46	6.3	62.52	14.55	6.3	57.29	14.52	6.3	57.36	14.55	6.3	57.29
7:00:00 PM	11.57	5.32	64	13.88	5.32	58.3	13.85	5.32	58.38	13.88	5.32	58.3
8:00:00 PM	11.32	5.97	64.52	13.49	5.97	58.49	13.46	5.97	58.57	13.49	5.97	58.49
9:00:00 PM	11.39	6.07	64.61	13.4	6.07	59.01	13.37	6.07	59.09	13.4	6.07	59.01
10:00:00 PM	11.24	5.7	64.9	13.21	5.7	59.23	13.19	5.7	59.32	13.21	5.7	59.23
11:00:00 PM	10.31	5.75	69.48	11.32	5.75	66.31	11.29	5.75	66.44	11.32	5.75	66.31
12:00:00 AM	9.56	4.9	70.52	10.28	4.9	67.88	10.25	4.9	68.02	10.28	4.9	67.88

	Typical Summer Day 5 Aug - 6 Aug												
	Conventional Roof			GR LAI 0.5 Insulation 0.2			GR LAI 5.0 Insulation 0.2			GR LAI 5.0 No Insulation			
	Air Tempe	Outside D	Relative H	Air Tempe	Outside D	Relative H	Air Tempe	Outside D	Relative Humidity (%		Outside D	Relative Humidity (%	
8/5/2002 1:00	18.07	17.83	63.18	18.61	17.83	61.19	18.52	17.83	61.55	18.52	17.83	61.55	
2:00:00 AM	17.76	18.45	65.38	18.27	18.45	63.31	18.17	18.45	63.71	18.17	18.45	63.71	
3:00:00 AM	17.92	18.42	50.81	18.34	18.42	49.47	18.25	18.42	49.76	18.25	18.42	49.76	
4:00:00 AM	17.66	17.92	48.93	18.06	17.92	47.72	17.97	17.92	48	17.97	17.92	48	
5:00:00 AM	17.31	17.42	50.8	17.72	17.42	49.49	17.63	17.42	49.78	17.63	17.42	49.78	
6:00:00 AM	17.36	17.52	52.38	17.82	17.52	50.89	17.73	17.52	51.18	17.73	17.52	51.18	
7:00:00 AM	20.22	20.9	46.41	20.73	20.9	44.97	20.64	20.9	45.2	20.64	20.9	45.2	
8:00:00 AM	24.13	23.27	36.04	24.4	23.27	35.52	24.32	23.27	35.7	24.32	23.27	35.7	
9:00:00 AM	27.69	25.05	31.81	28.28	25.05	32.67	28.17	25.05	32.83	28.17	25.05	32.83	
10:00:00 AM	29.17	25.8	32.36	29.68	25.8	34.75	29.58	25.8	34.87	29.58	25.8	34.87	
11:00:00 AM	29.78	26.5	33.81	29.97	26.5	38.04	29.89	26.5	38.14	29.89	26.5	38.14	
12:00:00 PM	29.86	27.45	36.99	29.74	27.45	42.59	29.66	27.45	42.7	29.66	27.45	42.7	
1:00:00 PM	29.87	27.63	40.87	29.68	27.63	46.57	29.6	27.63	46.7	29.6	27.63	46.7	
2:00:00 PM	30.02	28.2	39.25	29.95	28.2	45.65	29.87	28.2	45.79	29.87	28.2	45.79	
3:00:00 PM	29.91	28.17	37.16	30.13	28.17	43.1	30.05	28.17	43.22	30.05	28.17	43.22	
4:00:00 PM	29.43	27.88	39.23	29.99	27.88	44.16	29.91	27.88	44.29	29.91	27.88	44.29	
5:00:00 PM	28.46	26.67	42.61	29.45	26.67	46.61	29.37	26.67	46.73	29.37	26.67	46.73	
6:00:00 PM	27.02	25.1	46.84	28.38	25.1	49.98	28.31	25.1	50.12	28.31	25.1	50.12	
7:00:00 PM	24.86	22.98	56.31	26.35	22.98	57.74	26.29	22.98	57.87	26.29	22.98	57.87	
8:00:00 PM	23.42	21.88	64.6	24.65	21.88	65.71	24.6	21.88	65.86	24.6	21.88	65.86	
9:00:00 PM	22.2	20.35	77.08	23.35	20.35	76.59	23.29	20.35	76.83	23.29	20.35	76.83	
10:00:00 PM	20.06	19.08	82.33	20.89	19.08	80.78	20.79	19.08	81.15	20.79	19.08	81.15	
11:00:00 PM	19.24	19.55	71.48	19.9	19.55	69.86	19.81	19.55	70.18	19.81	19.55	70.18	
12:00:00 AM	18.82	19.27	55.22	19.38	19.27	53.55	19.29	19.27	53.88	19.29	19.27	53.88	
8/6/2002 1:00	18.21	18.27	52.37	18.78	18.27	50.64	18.68	18.27	50.96	18.68	18.27	50.96	
2:00:00 AM	17.51	17.63	51.45	18.13	17.63	49.49	18.03	17.63	49.82	18.03	17.63	49.82	
3:00:00 AM	17.01	17.13	51.29	17.64	17.13	49.29	17.54	17.13	49.6	17.54	17.13	49.6	
4:00:00 AM	16.62	16.63	50.86	17.24	16.63	48.89	17.14	16.63	49.2	17.14	16.63	49.2	
5:00:00 AM	16.27	16.13	50.35	16.87	16.13	48.44	16.77	16.13	48.75	16.77	16.13	48.75	
6:00:00 AM	17.07	18.33	46.96	17.56	18.33	45.23	17.47	18.33	45.51	17.47	18.33	45.51	
7:00:00 AM	19.91	20.9	38.87	20.44	20.9	37.53	20.36	20.9	37.73	20.36	20.9	37.73	
8:00:00 AM	23.79	23.52	30	24.24	23.52	29.18	24.16	23.52	29.31	24.16	23.52	29.31	
9:00:00 AM	27.41	25.17	26.33	28.1	25.17	27.18	27.98	25.17	27.32	27.98	25.17	27.32	
10:00:00 AM	29.13	26.02	26.37	29.62	26.02	28.86	29.51	26.02	28.95	29.51	26.02	28.95	
11:00:00 AM	29.71	26.42	27.94	29.94	26.42	32.22	29.85	26.42	32.3	29.85	26.42	32.3	
12:00:00 PM	29.65	27.33	29.83	29.63	27.33	35.7	29.54	27.33	35.79	29.54	27.33	35.79	
1:00:00 PM	29.77	28.05	33.83	29.66	28.05	39.18	29.57	28.05	39.29	29.57	28.05	39.29	
2:00:00 PM	29.97	28.42	37.57	29.99	28.42	42.66	29.9	28.42	42.8	29.9	28.42	42.8	
3:00:00 PM	29.75	28.05	37.93	30.11	28.05	43.32	30.02	28.05	43.45	30.02	28.05	43.45	
4:00:00 PM	29.14	27.45	37.23	29.85	27.45	42.39	29.76	27.45	42.51	29.76	27.45	42.51	
5:00:00 PM	28.28	26.7	37.71	29.32	26.7	42.47	29.23	26.7	42.58	29.23	26.7	42.58	
6:00:00 PM	27.11	25.38	40.33	28.38	25.38	44.41	28.3	25.38	44.52	28.3	25.38	44.52	
7:00:00 PM	25.12	23.5	48.96	26.5	23.5	51.52	26.43	23.5	51.63	26.43	23.5	51.63	
8:00:00 PM	23.47	21.88	56.3	24.7	21.88	58.95	24.65	21.88	59.08	24.65	21.88	59.08	
9:00:00 PM	22.4	20.83	59.27	23.59	20.83	61.43	23.52	20.83	61.6	23.52	20.83	61.6	
10:00:00 PM	20.74	20.52	59.28	21.47	20.52	60.21	21.37	20.52	60.53	21.37	20.52	60.53	
11:00:00 PM	19.55	19.38	61.37	20.15	19.38	62.62	20.05	19.38	62.99	20.05	19.38	62.99	
8/6/2002 0:00	18.69	18.7	77.97	19.31	18.7	74.65	19.2	18.7	75.13	19.2	18.7	75.13	

	Conventional Roof			GR LAI 5.0 Insulation 0.2		GR LAI 0.5 Insulation 0.2		GR Lai 5.0 No Insulation	
	Air Tempe	Outside Dry-Bul	Relative Humidit	Air Temperature	Relative Humidity (%)	Air Temperature	Relative Humidit	Air Temperature	Relative Humidit
January	13.29	8.37	59.83	14.52	57.62	14.57	57.45	14.52	57.62
February	12.78	7.34	55.18	14.08	53.01	14.14	52.84	14.08	53.01
March	15.16	10.47	58.03	16.3	56.52	16.39	56.25	16.3	56.52
April	18.26	14.85	50.37	19.13	50.34	19.26	50.02	19.13	50.34
May	20.88	18.74	50.36	21.54	51.15	21.7	50.74	21.54	51.15
June	22.45	20.91	57.56	22.98	58.74	23.13	58.27	22.98	58.74
July	23.34	22.33	60.42	23.81	61.74	23.98	61.2	23.81	61.74
August	23.93	23.08	64.15	24.34	65.48	24.51	64.92	24.34	65.48
September	22.36	20.73	66	22.96	66.81	23.11	66.28	22.96	66.81
October	21.64	19.87	58.85	22.28	59.48	22.41	59.06	22.28	59.48
November	17.13	13.68	57.62	18.15	56.83	18.24	56.54	18.15	56.83
December	15.21	11.14	60.25	16.29	58.81	16.35	58.63	16.29	58.81