Investigating and analysing the summer season soil temperature conditions on the extensive green roofs in Oslo, Norway

By Mahsa Atefeh og Stefanie Reinhardt

Mahsa Atefeh er M.Sc. i Environmental Science ved institutt for natur, helse og miljø, Campus Bø, Universitetet i Sørøst-Norge.
Stefanie Reinhardt (Ph.D) jobber som førsteamanuensis ved fakultet for teknologi, naturvitenskap og maritime fag, institutt for natur, helse og miljø, Campus Bø, Universitetet i Sørøst-Norge.

Sammendrag
I dag har grønne tak blitt undersøkt mer og mer for å forbedre kvaliteten i lokalmiljø, særlig for å redusere den urbane varmeøy-effekten og avrenning av overvann. Jordtemperatur er en av de mest grunnleggende faktorene i denne forbindelse. Dette bør også betraktes som et viktig element for plantesamfunnenes sammensetning og utbredelse på grønne tak. Målet med denne studien er å undersøke sommersesongens jordtemperaturforhold på ulike grønne tak i Oslo. Studien er utført på 37 målepunkter fra 17 grønne tak. Jordtemperaturer ble registrert av dataloggere som var lokalisert 2 cm under jordoverflaten, og disse ga fire målinger pr. døgn. Forholdet mellom jordtemperaturparametere og vegetasjonsdekke ble testet ved prinsippkomponent analyser, regresjons- og korrelasjonsanalyser, og presentert som boksplott. De statistiske resultatene indikerer at vegetasjonsforekomsten er sterkt negativt korrelert med jordtemperatur. Resultatene fra jordtemperatur målingene viser at bortsett fra to tak har jordtemperaturene vært innenfor et optimalt område for plantesamfunnene.

Summary
Recently, green roofs have been investigated increasingly to improve the quality of municipal environment particularly to reduce the urban heat island effect and storm water runoff. Soil temperature is one of the most fundamental factors influencing these topics. This should also be considered as an important element for plant distribution and community composition on extensive green roofs. The aim of this study is to investigate summer season soil temperature conditions on extensive green roofs in Oslo. The study has been performed on 37 plots on 17 extensive green roofs. Soil temperatures were recorded by data loggers located 2cm beneath the soil surface, providing four recordings each day. The relationship between soil temperature parameters and vegetation cover was tested by Principle Component Analyses (PCA), regression and correlation analyses, and presented as box plot figures. The statistical results indicate that vegetation abundance is highly negatively correlated with soil temperature. The results of the soil temperature measurements demonstrate that, apart from two roofs, soil temperatures varied within an optimum range.

Introduction

The increasing rate of urbanization has led to more areas becoming covered by different constructions, and a corresponding decrease in open-green spaces in many cities (Jim and Tsang, 2011). Nowadays, planted roofs are one of the best ways to increase the green areas in cities (Teemusk and Mander, 2010; Sutton, 2015). All green roofs are built in different layers. These layers consist of a root-barrier, a drainage, a filter membrane, a growing medium and a layer of vegetation (Bianchini and Hewage, 2012; Berndtsson, 2010; Liu and Baskaran, 2005).

Green roofs can be categorised in two major types, extensive and intensive roofs (Berndtsson, 2010). There is also a third type of green roof, the so-called semi-intensive ones, which is a mixture of both extensive and intensive roofs (Yang et al. 2008).

Researchers believe that due to different benefits of green roofs, they have been promoted worldwide, especially in European countries and United States. Green roofs can reduce and delay storm water runoff (Bengtsson, 2002), decrease energy conservation for heating and cooling, mitigate urban heat island where urban area is crucially warmer than its surrounding because of human activities (Akbari et al. 2001) and reduce noise and air pollution (Van Renterghem and Botteldooren, 2008; Yang et al. 2008; Getter et al. 2009). Aesthetic values and ecological benefits could be considered as other reasons for designing green roofs in construction projects (Brenneisen, 2003).

Plant diversity is constrained by the harsh environment of a green roof, especially summertime water deficit and heat stress have an efficient role on the green roofs function. Physiological processes such as root growth, nutrient and water uptake together with decomposition of organic matter, are fundamentally influenced by soil temperature. The impact of high soil temperature differs among plants and also different genotypes within particular plant species (Kaspar and Bland, 1992). Franklin and Wigge (2013) pointed out that high temperatures have the capacity to affect phycological processes and yield of plants, depending on the rate of temperature increase, its intensity, high-temperature duration, and the development stage of the plants. Normally, the total average temperature for root plant growth for relevant species are between 4and 30 °C. Higher temperatures may impede or alter root physiological process. (Sutton, 2015; Xu and Huang, 2000). Cooper (1973) found that root diameter will decrease with temperature increase. Al-Ani and Hay (1983), however, observed soil temperature from 5 to 25°C had only weak influence on diameters of individual root axes. In addition, in soils with low temperatures, biological activity will decline. For soil temperatures lower than 5-10 °C, certain process of plants will be slowed down (Rabenhorst, 2005). It has been also found that low temperature could be harmful for plants due to reduction in their defensive mechanisms (Franklin and Wigge, 2013).

In other words, variations in temperature may lead to plant stress reactions which can have a direct effect on plant growth. Particularly, reproductive events and pollination of the plant community could be harmfully affected by disposal of plants adapted to higher and lower threshold temperatures (Klein et al. 2007; Sacks and Kucharik, 2011; Hatfield and Prueger, 2015).

Soil temperature is influenced by many variables, including meteorological factors such as air temperature, soil physical properties such as albedo of surface, water content and texture, along with topographical parameters such as altitude, slope and vegetation cover (Liu and Luo, 2011). When albedo is low, the amount of reflected energy by the surface decrease. Therefore, a majority of the energy will be absorbed by the soil and its temperature will increase, which eventually will be lead to reduction of the soil moisture.

Soil temperature is regarded as a more effective factor to reflect microclimatic temperature in alpine vegetation than air temperature (Scherrer et al. 2011) where low stature plants are dominating species and decoupled from air temperature (Körner, 2003). As plants in

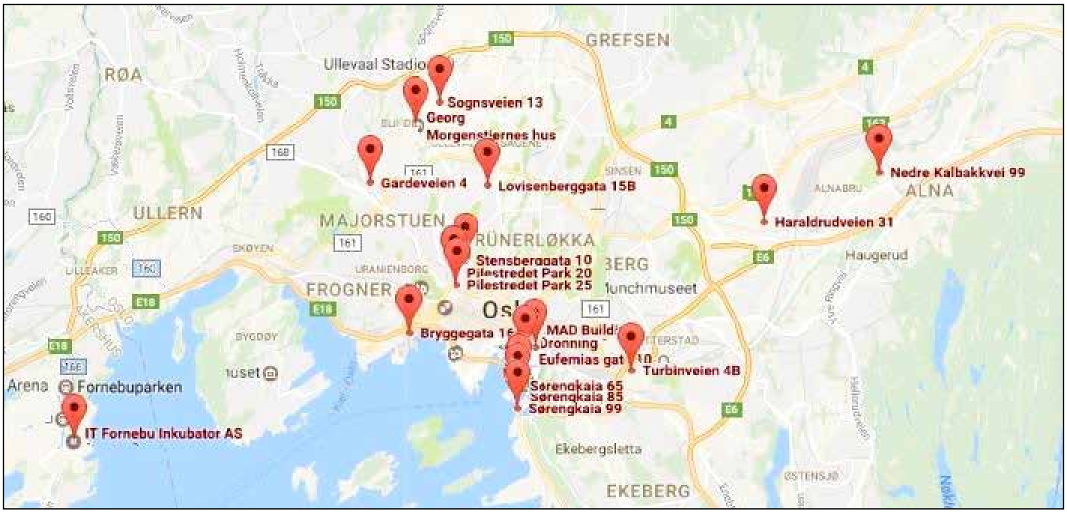

Figure 1. Locations of 17 studied extensive green roofs in Oslo

extensive green roofs are low stature, this finding can be expanded for extensive green roofs as well.

In the present study, soil temperature in seventeen extensive green roofs in Oslo were recorded during summer, to answer the following questions:

- How does summer season soil temperature conditions vary on studied extensive green roofs?
- Is there any significant relationship between soil temperature parameters and vegetation groups on studied extensive green roofs?

Material and methods

Site descriptions

This study was started in June 2016 on seventeen extensive green roofs. The study area was located in Oslo city and Bærum municipality. Figure 1 shows the location of the seventeen studied extensive green roofs.

The roofs were constructed on both old and new buildings raised within the period from 2002 to 2014 and they were used in an area with a combination of industrial and residential buildings. The general information about all studied extensive green roofs are summarized in Table 1.

Study design

Data collection were based on data-logger recordings of soil temperatures (maximum and minimum) of 37 plots in 17 green roofs. The size of measuring section was 30cm x 70cm. The geographic location of each plot was identified with a handheld Garmin GPS 62s and information of vegetation groups were obtained by Bakhtina (2015) from the same places. The field work was started in June 2016 and finished in July 2016.

Data loggers (LogTag TRIX-8, Measuring range: -40°C to 85°C) were buried approximately 1-2 cm beneath the surface of the soil depending on depth of soil in each roof. Each of the loggers were recording four times per day. In the middle of September (two times) all devices were collected simultaneously (15th and 20th of September).

Statistical analyses

Data processing was performed by using SPSS, MS Excel and PCA in MINITAB software. The average and maximum soil temperature were recorded for the warm period between 20th and 26th of July. The average soil temperature was calculated by averaging all observed temperatures in the period for each roof, and maximum average soil temperature for each roof was

Table 1. General information on studied extensive green roofs in Bærum municipality, Oslo city

Roof No.	Abbreviation	Building Name	Building Address	Area (m^2)	Supplier Company	Year of Implemen-tation	Numbers of Plot
1	BARN I	Sognsveien barnehage	Sognsveien 13, Oslo	270	Veg Tech	2007	2
2	BARN II	Solbærtorvet barnehage	Gardeveien 4, Oslo	334	Vital Vekst	2010	2
3	KVAR	Kværnerbyen	Turbinveien 4B, Oslo	600	Bergknapp	2013	2
4	HOEG	LovisenbergDiaconal University College	Lovisen breggata 15B, Oslo	320	Zinco	2013	2
5	STEN	PilestredetPark, Stensberggata10,12	Stensberggata 10-12, Oslo	700	Veg Teg	2006	2
6	PI20	Pilestredet Park 20	Pilestredet Park 20, Oslo	380	Veg Teg	2006	2
7	SORE I (build85)	Sørenga I,85	Sørengkaia 85, Oslo	110	Bergknapp/Byggors	2011	2
8	SORE I (build99)	Sørenga I,99	Sørengkaia 99, Oslo	120	Bergknapp/Byggors	2011	2
9	SORE II	Sørenga II, 65	Sørengkaia 65, Oslo	150	Blomstertak	2012	2
10	BJOR	Barcode Project, 10	Dronning Eufemias gate 10, Oslo	60	Vital Vekst	2009	2
11	BJOR II	Barcode project, 18	Dronning Eufemias gate 18, Oslo	400	Vital Vekst	2013	2
12	KREM	Alfaset Krematorium(cermation center)	Nedre Kalbakkvei 99, Oslo	1050	Vital Vekst	2009	4
13	AKER	Aker Brygge	Bryggegata 16, Oslo	700	Bergknapp	2014	2
14	PI 25	Pilestredet Park 25	Pilestredet Park 25, Oslo	120	Veg Tech	2006	2
15	FORN	Statoil (IT Fornebu)	Martin Linges vei15, Fornebu	9000	Blomstertak	2012	4
16	UNIV	University of Oslo, Blindern	Georg Morgenstierneshus, Blindernveien 31, Oslo	250	ReiersølPlanteskole	2002	2
17	GJEN	Norsk Gjenvinning As	Haraldrudveien 31, Oslo	27000	Blomstertak	2006	2

found by calculating the average of the maximum temperatures recorded at each plot for the same period.

The Principal Components Analyses (PCA) was performed to illustrate the correlations among abundance and richness of vegetation groups and soil temperature variables. In fact, the PCA summarizes the correlation among the variables (Tabachnick et al. 2001). Table 2 gives an overview of all soil temperature parameters and vegetation groups with abbreviations and measurement units.

Regression analyses was performed to find the relation between variables. The confidence interval defined as 95%. Correlation coefficient was measured in SPSS to demonstrate the strength of association between variables (Whitlock and Schluter, 2009).

Results

Soil temperature variation on extensive green roofs

Recordings of the soil temperature of thirty-seven plots from seventeen green roofs demonstrated, as expected, that the soil temperature vary during the summer months.

Generally, soil temperatures in June (average: 17.96°C) were observed to be lower than in July. It reached to maximum level in July (average: 19.48°C). Then, temperature decreased by some degrees in August (average: 15.95°C) and September (average: 16.09). Soil temperature did

Table 2. Summary of all soil temperature parameters and vegetation groups with abbreviations and measurement units used in PCA diagram

Abbr.	Environmental variables/ Vegetation Groups
Jmea	Mean soil temperature during warm period of July (°C)
Smax	Maximum soil temperature during summer (°C)
Scu	Abundance of Succulent Species
Rsuc	Richness of Succulent Species
Moss	Abundance of mosses
Rmoss	Richness of mosses
Lich	Abundance of lichens
Rlich	Richness of lichens
Herb	Abundance of herbs
Rherb	Richness of herbs
Gram	Abundance of graminoids
Rgram	Richness of graminoids
Woody	Abundance of woody plants
Rwoody	Richness of woody plants
Bare ground	Abundance of bare ground

Table 3. The soil temperature variations during summer in all studied extensive green roofs

	Number of days				
Roof No.	Extensive Green Roofs	Temperature X < 4°C	Temperature 4°C< X <30°C	Temperature X > 30°C	Temperature X > 48°C
1	BARN I	6	35	36	1
2	BARN II	0	73	5	0
3	KVAR	0	70	7	0
4	HOEG	0	61	15	0
5	STEN	2	45	28	1
6	PI 20	0	63	6	0
7	SORE 85	0	62	3	0
8	SORE 99	0	61	4	0
9	SORE II	0	58	7	0
10	BJOR	0	50	15	0
11	BJOR II	0	65	0	0
12	KREM	0	60	1	0
13	AKER	0	57	5	0
14	PI 25	0	51	8	0
15	FORN	0	54	4	0
16	UNIV	0	50	0	0
17	GJEN	0	45	0	0

not vary considerably during August and September.

The variations of soil temperature during summer for all studied extensive green roofs are presented shown in Table 3. Results indicate that in roof number one, soil temperature during 35 days varied with in the temperature range of 4 to 30°C, of which 6 days were recorded with temperatures below 4°C, and 36 days above 30°C. However, for one day the soil temperature was reached above 48°C. In the roof number five, soil temperature had a normal temperature range of to 30°C during 45 days, of which two days provided soil temperatures below 4°C and 28 days between 30 °C to 48°C. During one day the soil temperature exceeded 48°C. The soil temperature of the rest of 15 studied extensive green roofs exceeded 30°C in only 15 days.

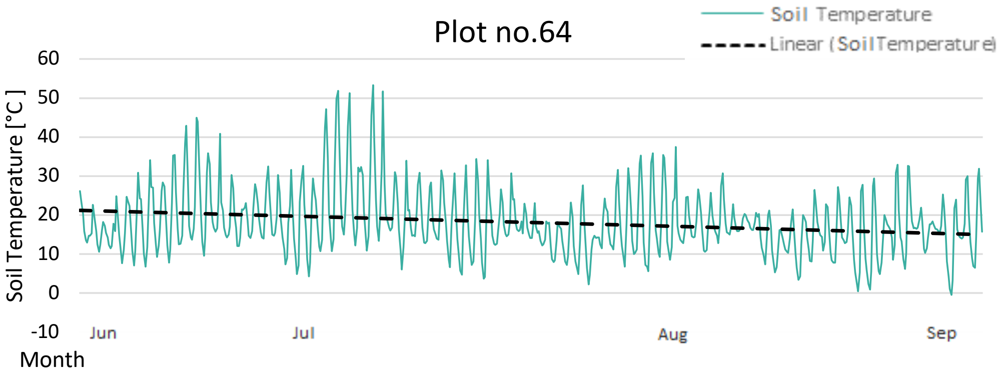

Figure 2. Soil temperature measurement in plot.no 64 of BARN I at summer 2016

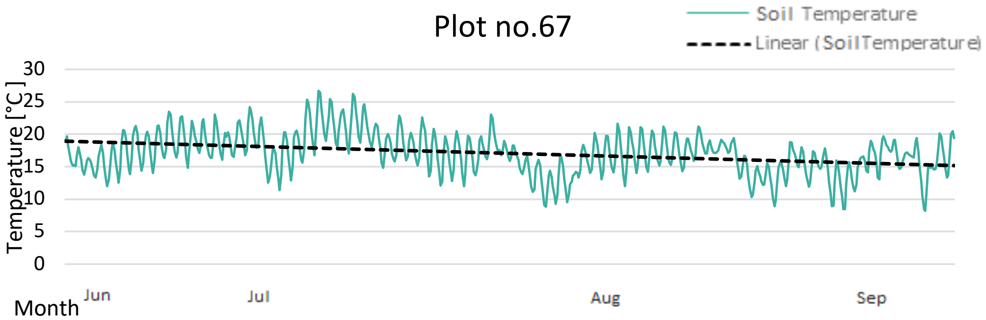

Figure 3. Soil temperature measurement in plot.no 67 of BARN II at summer 2016

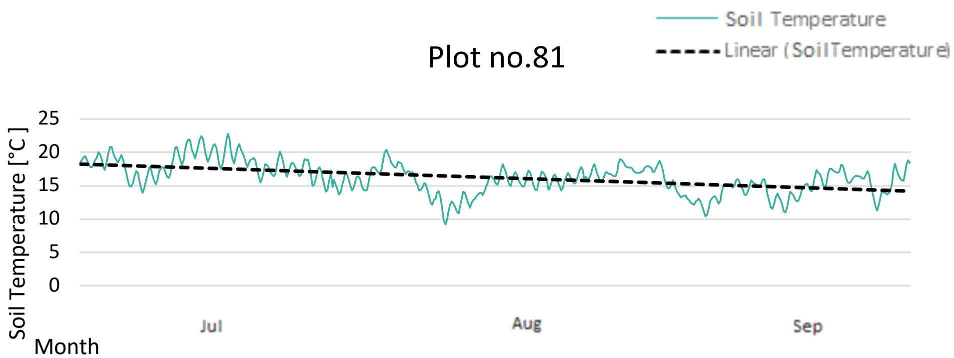

Figure 4. Soil temperature measurement in plot.no 81 of KREM at summer 2016

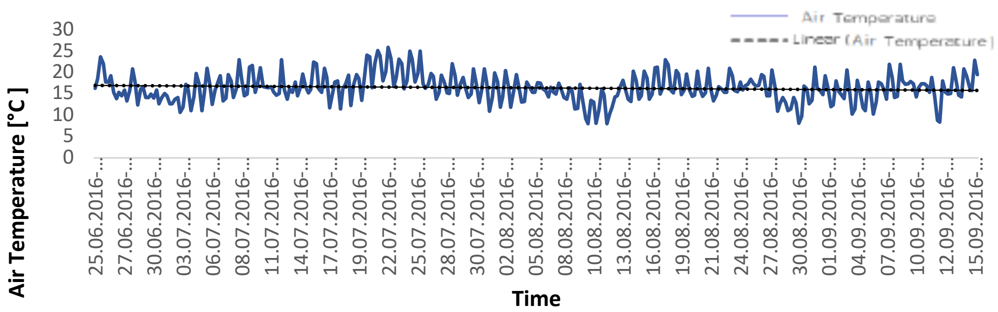

Figure 5. Air temperature measurements from Norwegian Meteorological Institute – June to September

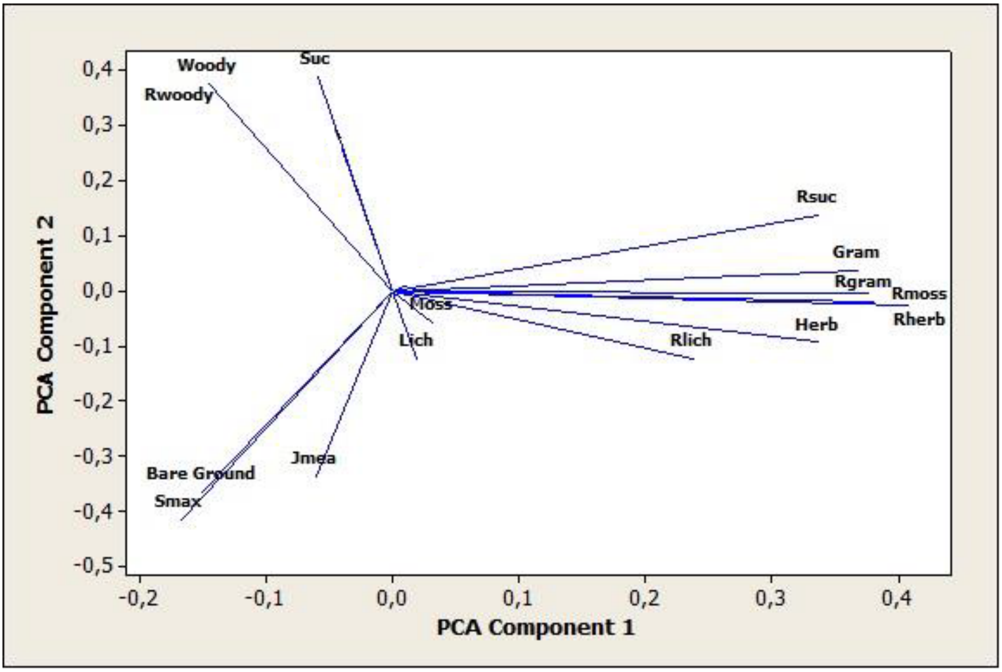

Figure 6. PCA diagram with vectors show the relation between different group of vegetation with soil temperature parameters (abbreviations are explained in Table 1).

Figure 2, 3 and 4 illustrate that during summer, particularly in June and July, soil temperatures showed an increasing trend. By the end of summer and earlier autumn, soil temperatures were decreasing, as expected. The highest soil temperature among all the measured plots was in plot number 64 in July (53°C) while the lowest temperature occurred in September with (- 0.5°C) at the same plot in roof number one (Figure 2).

Other plots show less variation in soil temperatures. Figure 3 shows soil temperature variation for plot number 67 as an example. Here, soil temperature varied between 11°C and 26 °C in July, and between 9and 23 °C in August.

Lowest variation in soil temperature was measured in plot number 81 on roof number 12 (Figure 4) where soil temperature varied between 13 and 22°C in July.

Figure 5 shows the air temperature fluctuations in the period of late June to middle of September, which indicates that the highest temperature occurred in late July whilst the lowest one in the middle of August (Data provided

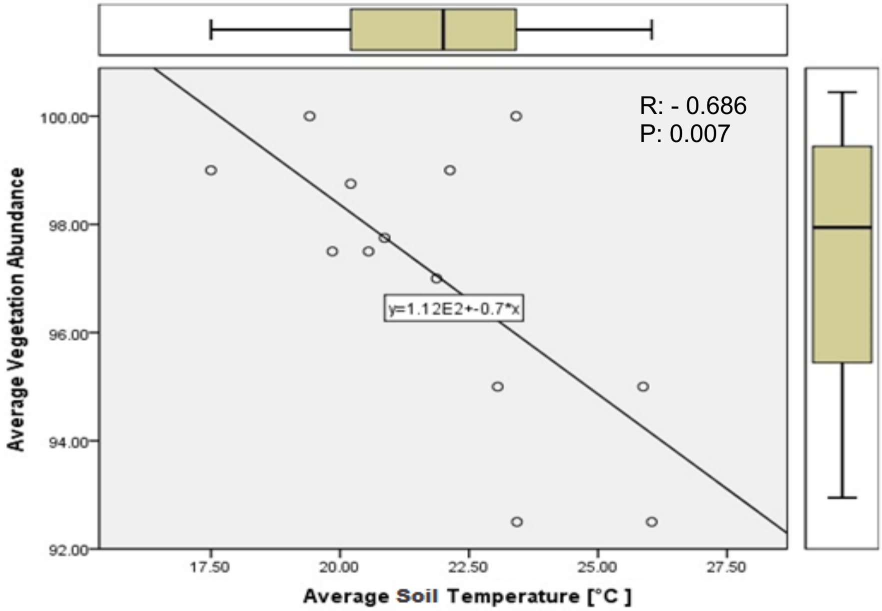

Figure 7. Median, 25-75% quantile, and minimum-maximum values of daily average soil temperatures on studied extensive green roofs and regression between abundance of vegetation and average soil temperature with regression equation without outlier's points during warm period in July.

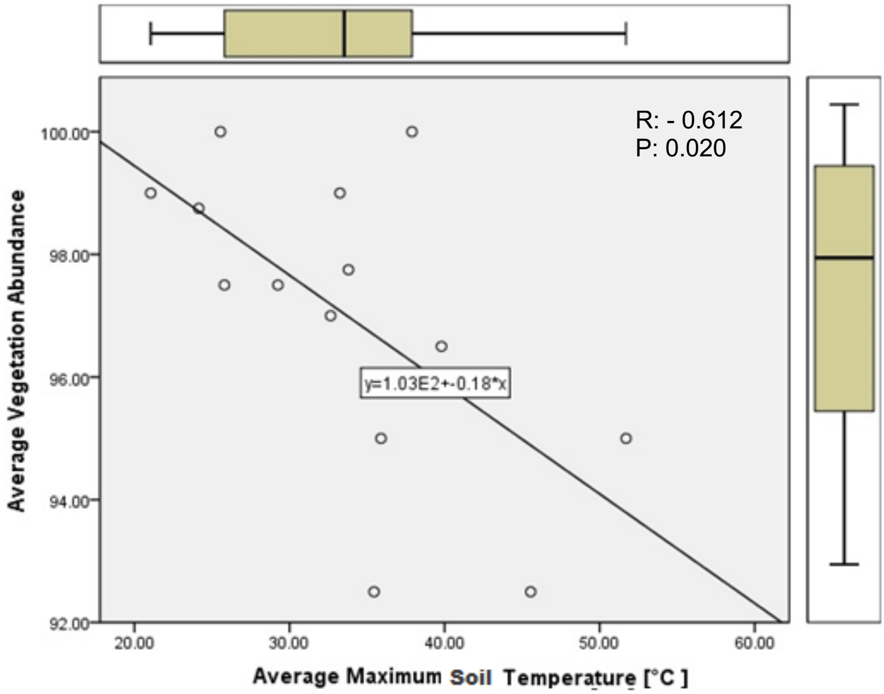

Figure 8. Median, 25-75% quantile, and minimum-maximum values of daily average of highest soil temperatures on studied extensive green roofs and regression between abundance of vegetation and average maximum soil temperature with regression equation without outlier's points during summer.

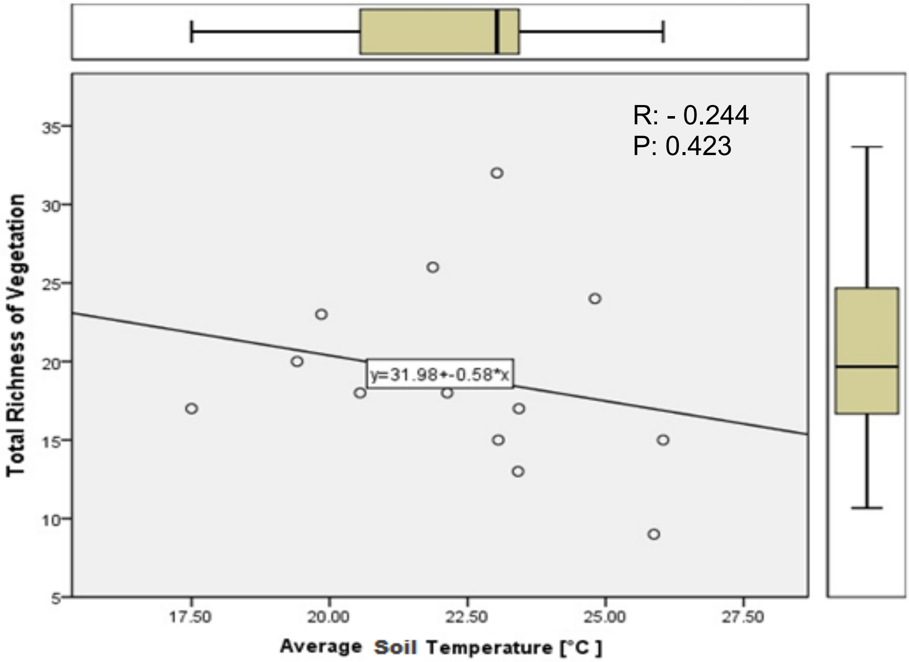

Figure 9. Median, 25-75% quantile, and minimum-maximum values of daily average soil temperatures on studied extensive green roofs and regression between total richness of vegetation and average soil temperature with regression equation without outlier's points during warm period in July.

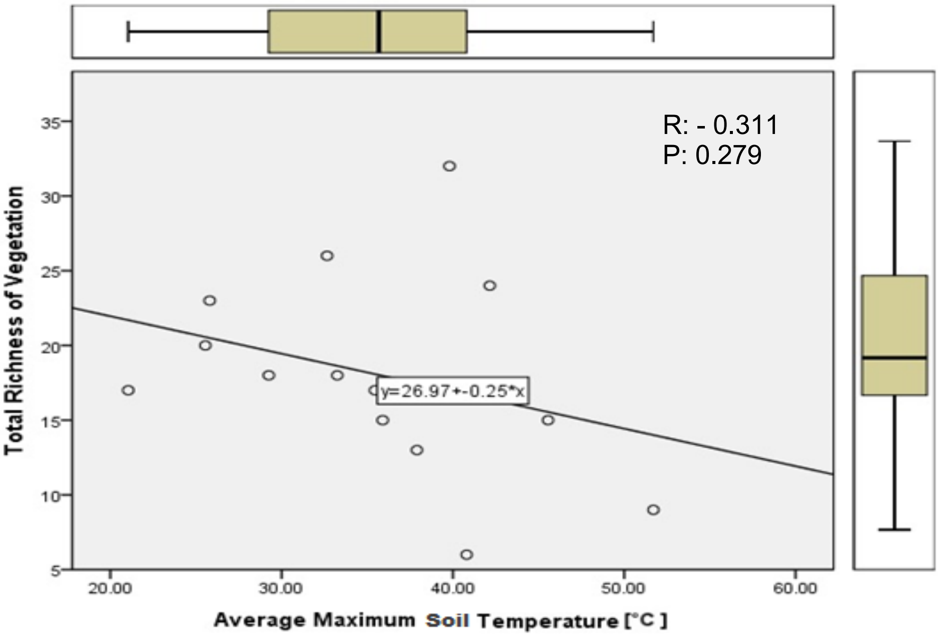

Figure 10. Median, 25-75% quantile, and minimum-maximum values of daily average of highest soil temperatures on studied extensive green roofs and regression between total richness of vegetation and average maximum soil temperature with regression equation without outlier's points during summer.

by Norwegian Meteorological Institute, (2016)). Then, during summer, it is predictable that soil temperature variation followed air temperature with a slight fluctuation.

PCA analyses of soil temperature with vegetation groups

The PCA analysis showed how environmental variables such as soil temperature is related to different groups of vegetation (Figure 6). It is shown that abundance and richness of mosses, lichens, herbs, graminoids are positively correlated to each other. However, the correlation between these plant groups and succulent species with maximum soil temperature in summer, and mean soil temperature in July, is weaker. Abundance of succulents decreased with mean soil temperature during warm periods in July. Soil maximum temperature (Smax) is strongly positively correlated with presence of bare ground. Figure 6 shows the summarizes of the correlation among the soil temperature variables with vegetation abundance and plant richness. Eigenvalues for PCA axis 1 was 4.07 and for PCA axis 2 was 2.94.

Relationship between vegetation parameters and soil temperature in the warm period of July

SPSS were run to investigate the correlation between soil temperature variables with vegetation parameters (Figure 7). The results also indicated which soil temperature variables were significant for vegetation groups. The analysis of abundance and richness of vegetation in relation to soil temperature variables showed that there is a negative significant correlation between both average soil temperature and maximum soil temperature with vegetation abundance (Figure 7 and Figure 8). While both average soil temperature and maximum soil temperature are negatively correlated with total richness of vegetation groups, there is not significant relation between these variables in all studied plots (Figure 9 and Figure 10).

In the following, the observations in the warm period (20th – 26th of July) illustrate that even if the maximum and minimum soil temperature in some parts of vegetation cover are distinguished, the highest percentage of vegetation abundance was recorded in the average soil temperatures between 19.41 and 23.41°C during this period (Figure 7). Highest percentages of vegetation was registered from 25.55 to 37.9°C in the maximum soil temperature level (Figure 8).

Discussion

Soil temperature and vegetation

During summer from June to September (28.06 to 15.09) soil temperature of most studied plots remained within a normal range of 4 to 30°C. While in a short period, soil temperature of some of them were increased up to more than 30°C. Generally, the appropriate temperature range for the root physiological process is around 4 to 30°C. When the soil temperature exceeds 30°C, all the processes of the roots, such as respiration, will be reduced quickly and certain processes, especially the secondary material synthesis, will proceed slowly. The negative high temperature effect of more than 30°C will be harmful for plants until it exceeds 48°C where the root mortality will occur. Therefore, plant physiological processes are highly sensitive to high temperatures (Sutton et al. 2012). In fact, temperature of the soil and its surrounding could affect both root growth processes and its development. The processes of growth, such as cell elongation, will increase the length of root and its diameter. However, development processes will control the growth duration and initiation processes of new roots. By considering that both these processes will be affected by soil temperature, it is important to emphasize that every plant species has also its particular maximum, minimum and optimum range.

The results of this study indicate that soil temperature and vegetation parameters are well correlated and soil temperature can be considered as an important factor for the distribution and composition of plants on green roofs. This could be an explanation for why short extreme temperature events during the summer inflict negative impact on vegetation cover. Dufault, Ward, and Hassell (2009) also reported that temperature should be considered as an important environmental element which can affect the plant production. This could be clarified by some specific factors such as hot day periods, minimum and maximum temperatures of a day, overall growing season, climate and the time of stress relevant to developmental stage. In this study, the maximum soil temperature has proven to be an effective factor on the studied plants. The importance of maximum temperature should be explained as its effect on increasing the daily mean temperature which will lead to harmful condition for pollen liability, fertilization and grain yield (Meehl et al. 2007). During the warm period in July (20th to 26th of July) the soil temperature in all the studied plots in 17 roofs varied from 10°C to 39°C. Only three out of 37 plots in two roofs recorded soil temperatures above48°C. The maximum soil temperatures registered in this study was 50.4°C and 53.3°C on plot 63 and 64 in roof number one, and 49.5°C on plot 31 in roof number five.

On the other hand, low temperatures could have negative effect on the plant ability of grain productivity (Hatfield and Prueger, 2015). The registered soil temperatures by the data loggers show the minimum soil temperature of -0.05 °C (plot 64 in roof number). The inappropriate plant situation of roof number one proves the importance of maximum and minimum temperature effects on plant viability and could be the best explanation for differences between the vegetation groups. Previous studies have shown that when plants are subjected to moderate heat stress (1 to 4°C above optimal growth temperature), their efficiency decrease gradually (Sato, 2006; Timlin et al. 2006; Tesfaendrias et al. 2010). To put it simply, it was found that exposure of these plants on the same roof in the highest soil temperatures could be one of the reasons for the negative impact on viability of the vegetation and growth limitation on this place. However, it could be vice versa because the vegetation maybe reduced first, and it decreased the albedo which has been led to increase the soil temperature. In roof number 5, although the soil temperature was exceeded above 48°C for a short period, the appearance of vegetation cover remained in a good condition.

One possible source of error in data collection may have been that the loggers were moving due to wind and rainfalls. The devices on roof number five were most likely moved and exposed to direct sunlight. This is regarded as the main reason for remaining a good vegetation condition where data loggers showed high temperature. Whereas in roof number four, soil temperatures reached to 41 and 42°C in each plot for one day and the vegetation cover was not so rich in this roof. It could be predicted that a negative effect of warmer soil temperature on different group of plant species could lead to lack of the vegetation. The maximum soil temperature in roof number four was relatively high, but below the mortality temperature of 48°C. The vegetation in roof number one were in poorer condition compared to roof number four, where the soil temperature exceeded 48°C.

In addition, the shallowest substrate was more prone to higher soil temperature, which again have a negative impact on vegetation growth. As much as substrate is deeper, the soil condition for maintaining the stability of soil temperature will be more powerful. Providing the larger space for the plants roots of green roofs should be considered as another positive aspect of deeper substrate. This might explain the differences in soil temperatures in studied plots especially in roof number one where the highest level of soil temperature associated with variable of depth substrate was recorded. Boivin et al. (2001) found that temperature fluctuations of shallower extensive green roof substrates are higher compared to deeper substrates, particularly during the growing season period.

During summer, it is predictable that there is a mutual interaction between soil temperature and vegetation cover. In fact, soil temperature regimes can affect plant growth, and vegetation cover can affect soil temperature on the other hand. Vegetation cover might be important for the soil temperature conditions during warm period because temperature amplitudes differ between bare ground and sites covered with plants. Vegetation cover which includes abundance and total richness of species, had a strong influence on decreasing the root zone temperature, compared to bare ground, resulting in warmer root zone temperatures. In fact, due to absence of vegetation cover in bare ground, albedo will be decreased and eventually soil temperature will rise. In the present study, the PCA shows that soil temperature seems to be correlated with plant cover on the roofs, which strengthen the previous assumptions that vegetation cover affects soil temperatures on green roofs.

Soil temperature and *Sedum* species

The genus *Sedum* is a low growing succulent plant which is a popular choice for extensive green roofs. It is considered as almost dominant plant species in most of the studied plots in this study, as previously reported by Bakhtina (2015). Many of *Sedum* species are considered to be able to cope with extreme temperature and limited water supply (VanWoert et al. 2005).

Furthermore, *Sedum* species can decrease peak soil temperature and provide better conditions and increased performance of neighbouring plants in water deficit situation during summer period. Butler and Orians (2011) showed that *Sedum album*, *S. rupestre*, *S. sexangulare* and *S. spurium* decreased peak soil temperature by 5-7°C. Butler and Orians (2009) found that during a warm period, a soil sample with only *Agastache black adder* is a hybrid of *A. rugosum and A. foeniculum* was considerably hotter than soil sample with mixture of one of the four of this *Sedum* species. Beside this, soil modules with *S. sexangulare* would be cooler than soil in modules with *S. album*. Although this study did not focus on *Sedum* and its features, the results seem to provide support to earlier findings that *Sedum* has the ability to reduce the soil temperature on green roofs. *Sedum* species may also contribute to reduce the abiotic stress on non-sedum species (Butler and Orians, 2009).

Conclusions

Soil temperature in 88% of studied extensive green roofs were in an optimum range, whereas 12% of roofs soils became hotter. Vegetation abundance was highly negative correlated with soil temperature, confirming that limiting effects on soil temperature among different groups of plant species. This may lead to reduction of the vegetation cover on green roofs. Variation in soil temperature has a large impact on vegetation growth and vegetation cover again will affect the albedo. On the other hand, albedo will influence soil temperature by its effect on vegetation cover. Hence, soil temperature features such as maximum and minimum are important factors to distinguish between different vegetation groups. In addition, shallow substrate was subject to much more temperature fluctuation and less water retention and would also inflict intense stress on plant species.

Moreover, the relationship between soil temperature and vegetation are interactive. Simply put, soil temperature and vegetation condition could be affected by each other simultaneously. Vegetation cover could be expected to reduce the soil temperature, compared with bare ground resulting in warmer root zoon temperatures.

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