SET 2015 NOTTINGHAM

Theoretical investigation of soil-based thermal energy storage system for greenhouses

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Abstract: In this short communication, a novel thermal energy storage system for greenhouses is presented. The novel system is based on directly heating a particular mass of soil through the solar power and utilizing the energy stored in critical months such as November, December, January and February. The target mass of soil is placed beneath the greenhouse with a height of 2m and the boundaries are well-insulated via vacuum insulation panels to provide adiabatic conditions yielding to no heat loss from the edges. Through electric heaters placed inside the target mass of soil, thermal energy is stored inside the soil via the power coming from photovoltaic (PV) panels fixed on the roof of the greenhouse. A specific thin film PV glazing technology called heat insulation solar glass (HISG) is preferred for the power input to the greenhouse. As the first aim of the research, heating demand of the greenhouse is determined for each month. Temperature difference and overall heat transfer coefficient between indoor and outdoor environment are considered to be independent variables in the analyses. Secondly, soil-based thermal energy storage system is introduced and its potential contribution to the heating demand is discussed. The preliminary results indicate that the soil mass is a dominant parameter in soil temperature and hence the thermal energy storage capacity. For a soil mass of 250 tonne, around 600K soil temperature is achieved by the end of year, which is very remarkable.

Keywords: Greenhouses, energy consumption, heating demand, thermal energy storage, solar power

1. INTRODUCTION

In this short communication, a novel thermal energy storage system for greenhouses is presented. The novel system is based on directly heating a particular mass of soil through the solar power and utilizing the energy stored in critical months such as November, December, January and February. The target mass of soil is placed beneath the greenhouse with a height of 2m and the boundaries are well-insulated via vacuum insulation panels to provide adiabatic conditions yielding to no heat loss from the edges. Through electric heaters placed inside the target mass of soil, thermal energy is stored inside the soil via the power coming from photovoltaic (PV) panels fixed on the roof of the greenhouse. A specific thin film PV glazing technology (heat insulation solar glass) is preferred for the power input to the greenhouse [1-4].

2. METHODOLOGY

Within the scope of this short communication, theoretical investigation of this novel energy storage system is given. As the first aim of the research, heating demand of the greenhouse is determined for each month. Temperature difference and overall heat transfer coefficient between indoor and outdoor environment are considered to be independent variables in the analyses. Monthly heating demand of the greenhouse is determined as illustrated in Figure 1 depending on the aforesaid independent variables. As it is understood from the 3D graphs that the critical months in heating demand are December, January and February as expected for Nottingham. The calculations are made with respect to characteristic climatic conditions of Nottingham given in Figure 2 and 3 for ambient temperature and relative humidity, respectively.

3. RESULTS AND DISCUSSION

The main governing equation of the heat loss from the greenhouse is given by:

$$Q = U\,A\,\Delta T$$

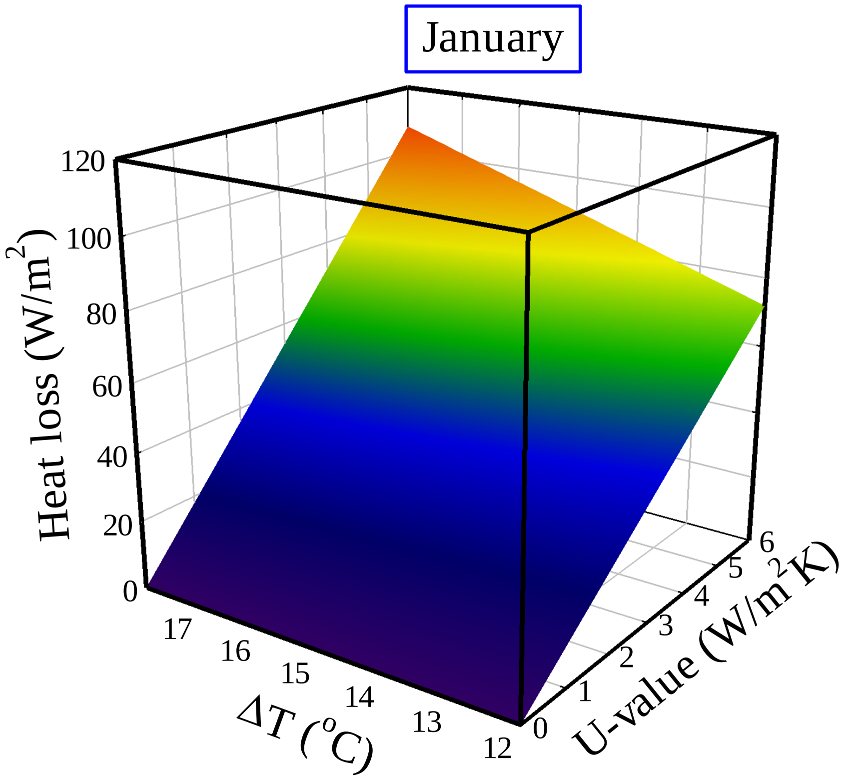
where U is the overall heat transfer coefficient between indoor and outdoor environment, A is the heat transfer surface area and ΔT is the temperature difference. In Figure 4, maximum solar power and its available part are illustrated for the climatic conditions of Nottingham. The figures are provided for per m^2 for easier understanding and data utilization. Although Nottingham does not have abundant solar energy potential, there is a remarkable potential in the summer time to be considered for thermal energy storage. In the second part of the research, soil temperatures are calculated for each month and for various amounts of soil. The driving governing equation to determine the soil temperatures is given by:

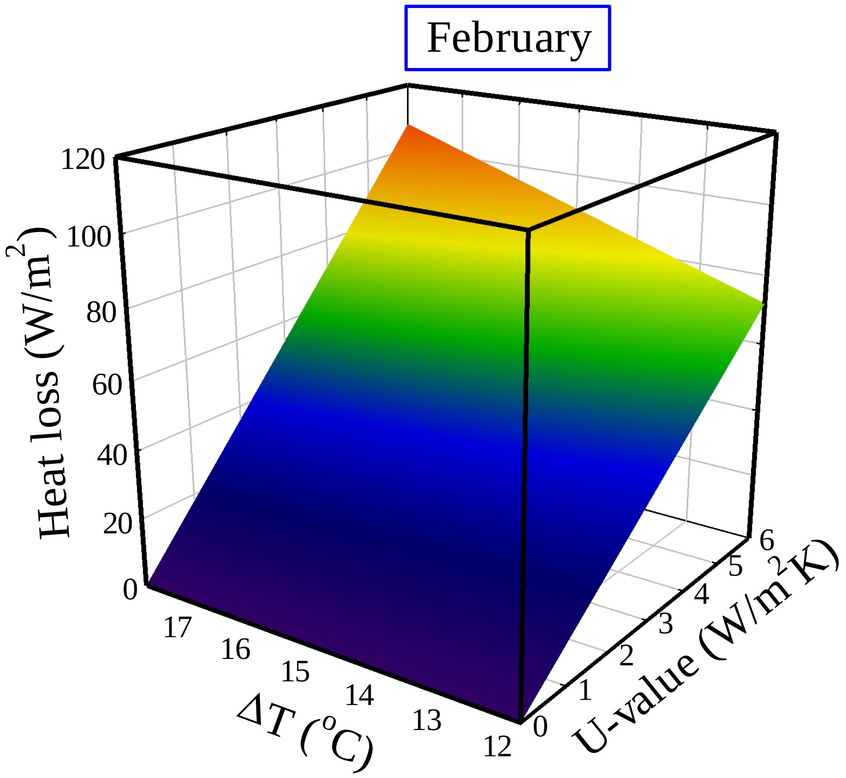
$$Q = m\,c_p\,\Delta T$$

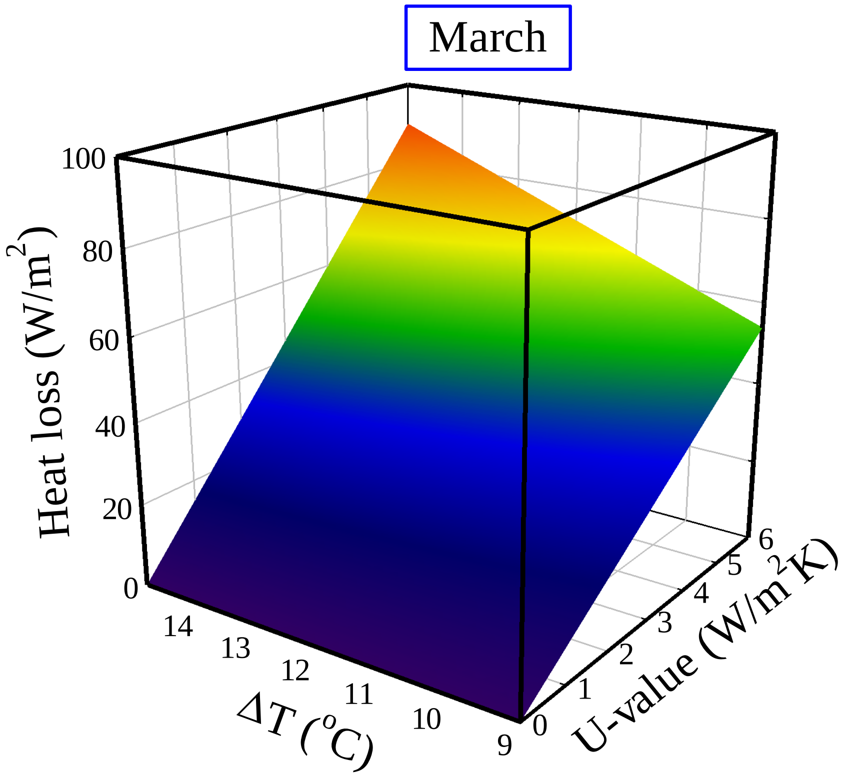
where m is the mass of soil, c is the specific heat capacity of soil and ΔT is the temperature difference. As considering the potential soil mass beneath the greenhouse, the soil mass as an independent variable is varied from 250 to 2000 tonne and the soil temperatures are calculated as shown in Figure 5. As it is clearly seen from the results that the soil mass is a dominant parameter in soil temperature and hence the thermal energy storage capacity. For a soil mass of 250 tonne, around 600 *K* soil temperature is achieved by the end of year, which is very remarkable.

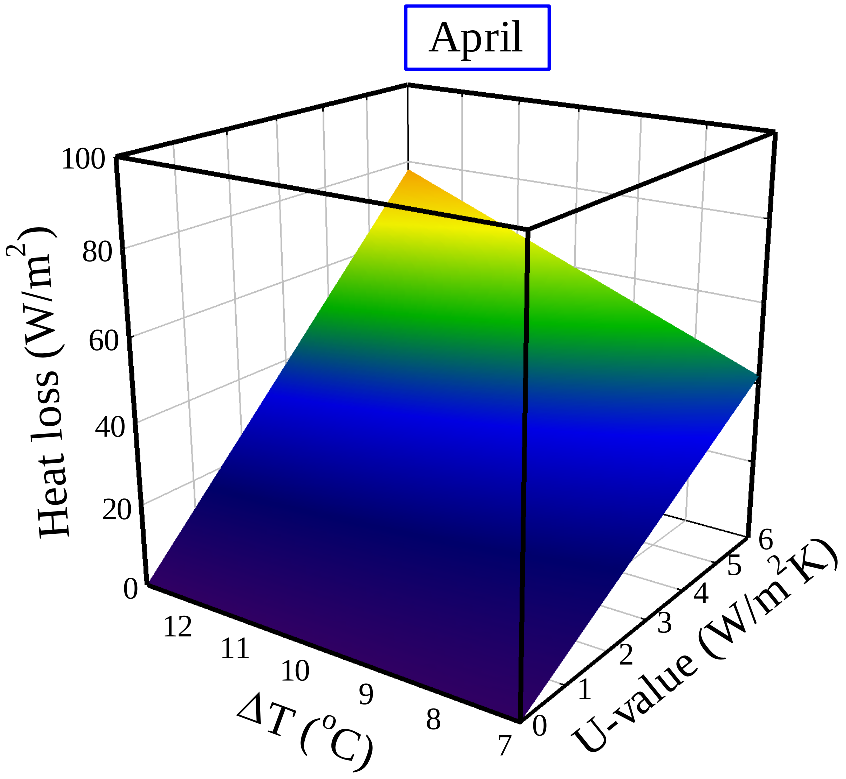
4. CONCLUSIONS

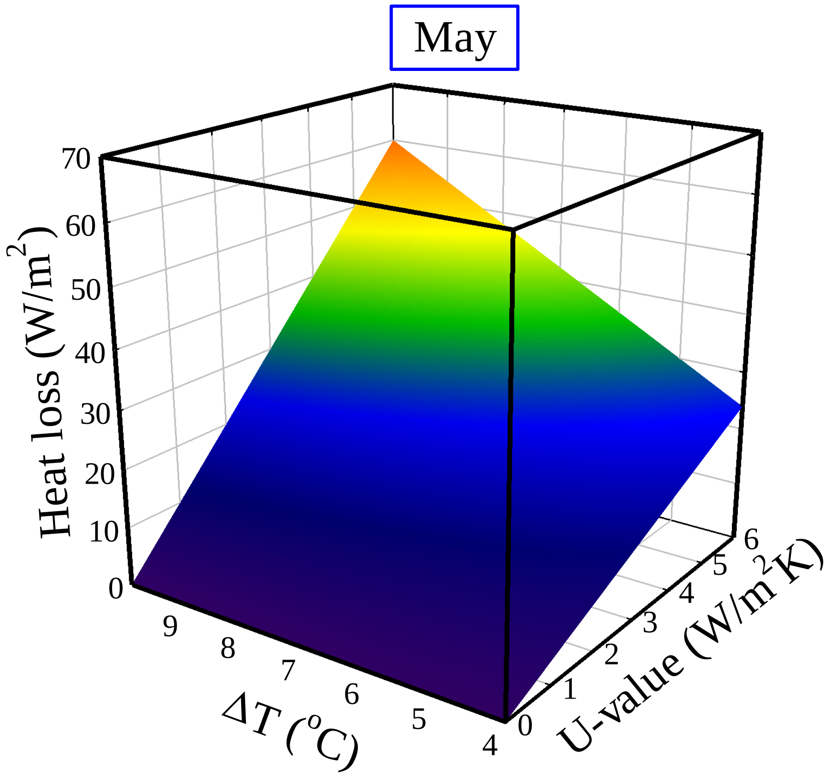
This short communication clearly indicates that solar powered soil-based thermal energy storage for greenhouses is attractive and can be preferred to contribute in reducing operational costs of greenhouses.

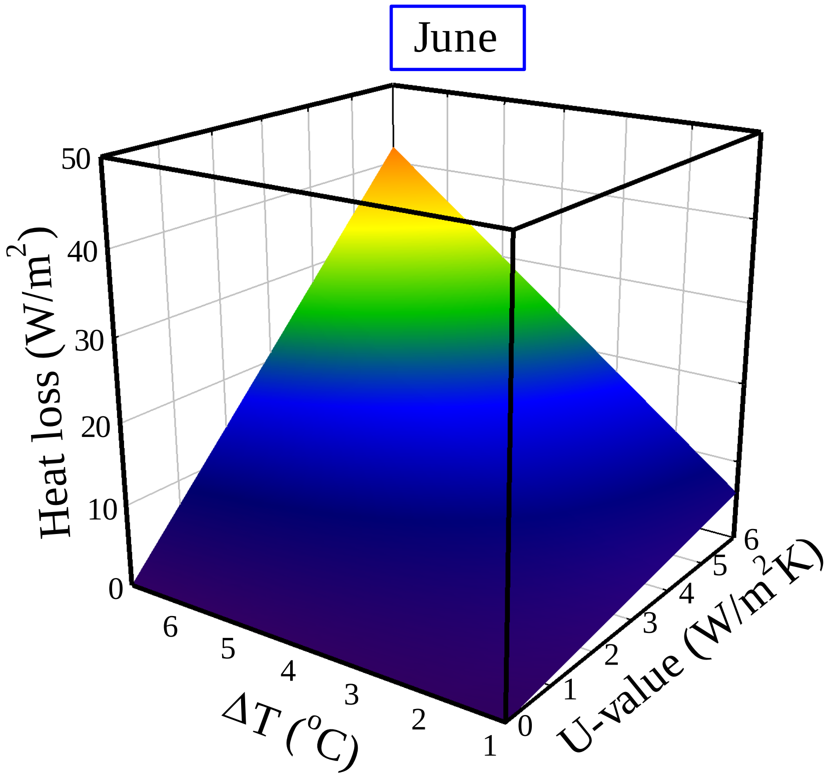

January
Heat loss (W/m^2)
0
20
40
60
80
100
120
ΔT (°C)
17
16
15
14
13
12
U-value (W/m^{2}K)
0
1
2
3
4
5
6

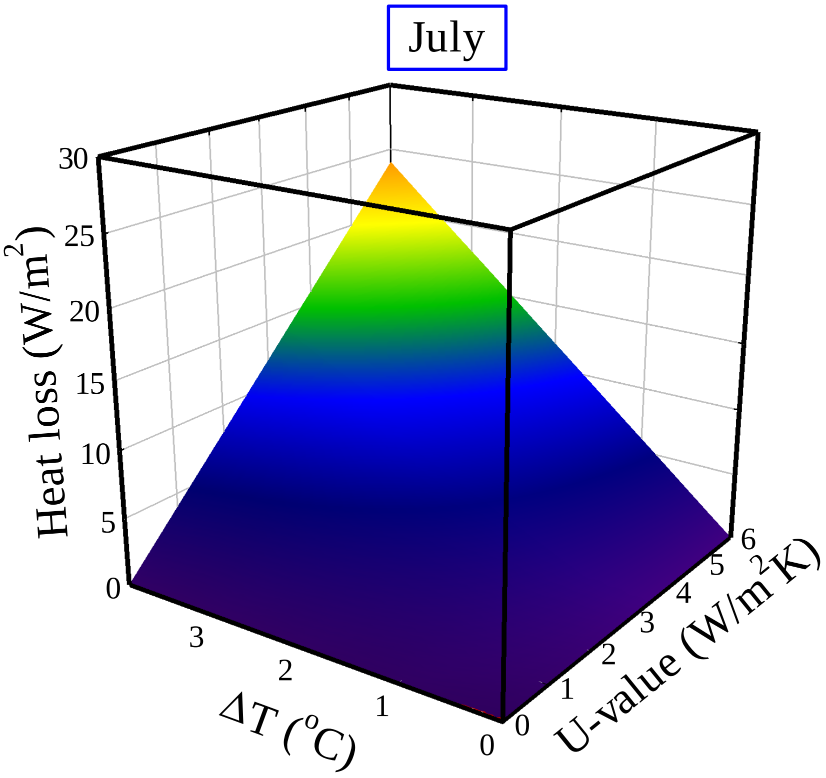

February
Heat loss (W/m^2)
0
20
40
60
80
100
120
ΔT (°C)
17
16
15
14
13
12
U-value (W/m^{2}K)
0
1
2
3
4
5
6

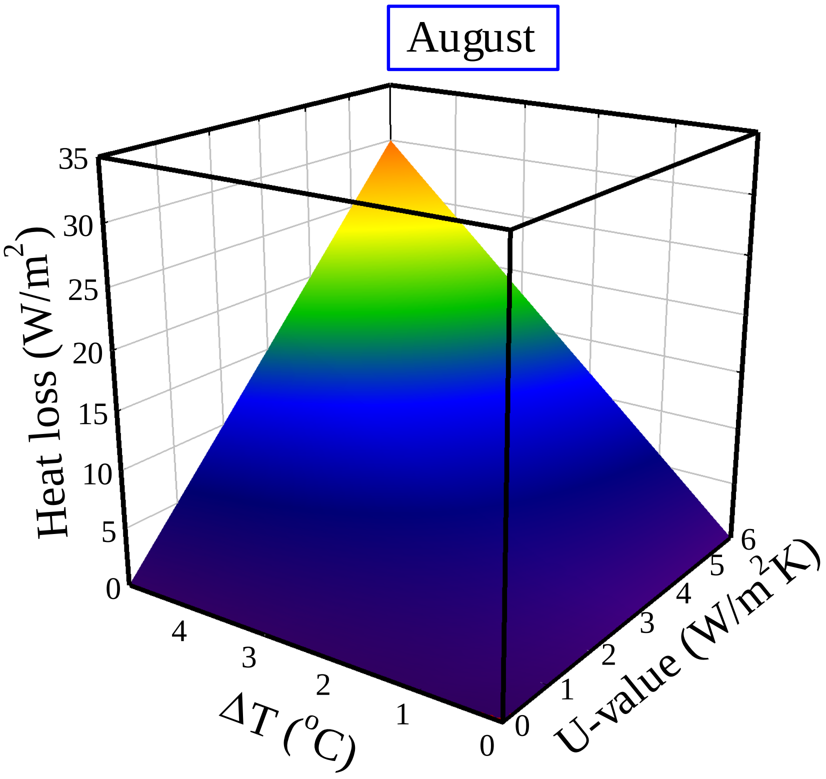

March
Heat loss (W/m2)
100
80
60
40
20
0
14
13
12
11
10
9
ΔT (oC)
0
1
2
3
4
5
6
U-value (W/m2K)

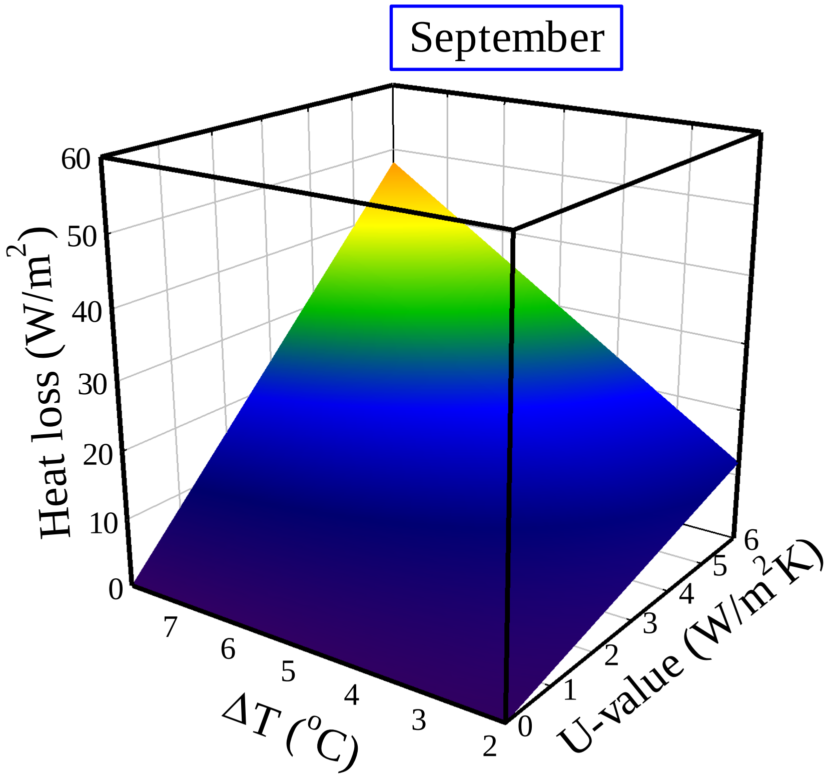

April
Heat loss (W/m2)
100
80
60
40
20
0
12
11
10
9
8
7
ΔT (oC)
0
1
2
3
4
5
6
U-value (W/m2K)

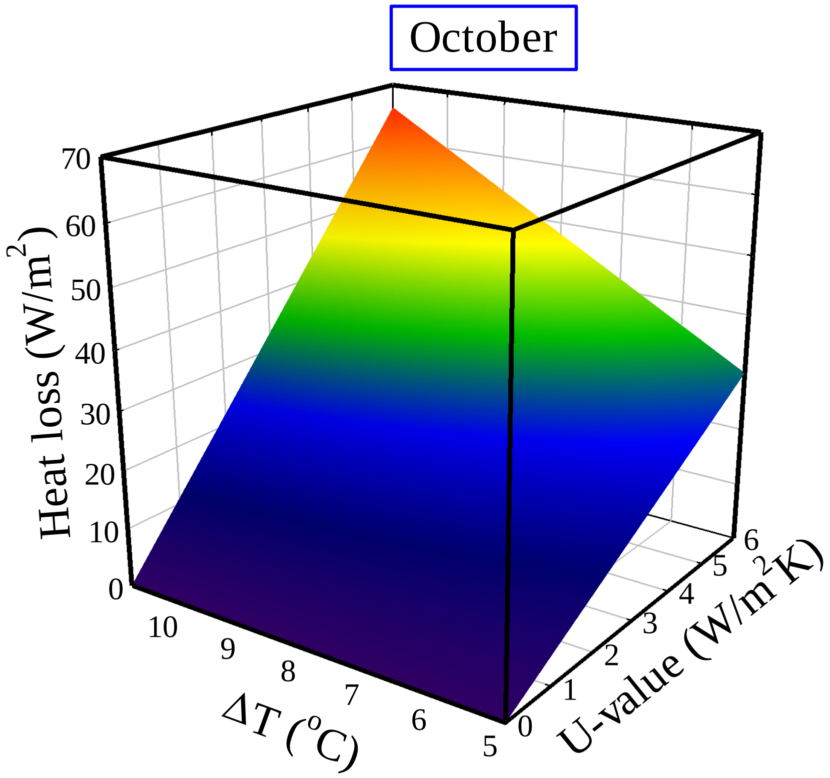

May
Heat loss (W/m^2)
70
60
50
40
30
20
10
0
9
8
7
6
5
4
ΔT (°C)
0
1
2
3
4
5
6
U-value (W/m^{2}K)


June
Heat loss (W/m^2)
50
40
30
20
10
0
6
5
4
3
2
1
ΔT (°C)
0
1
2
3
4
5
6
U-value (W/m^{2}K)


July
Heat loss (W/m^2)
0
5
10
15
20
25
30
ΔT (^{o}C)
0
1
2
3
U-value (W/m^{2}K)
0
1
2
3
4
5
6


August
Heat loss (W/m^2)
0
5
10
15
20
25
30
35
ΔT (^{o}C)
0
1
2
3
4
U-value (W/m^{2}K)
0
1
2
3
4
5
6


September
Heat loss (W/m2)
0
10
20
30
40
50
60
ΔT (°C)
7
6
5
4
3
2
U-value (W/m2K)
0
1
2
3
4
5
6


October
Heat loss (W/m2)
0
10
20
30
40
50
60
70
ΔT (°C)
10
9
8
7
6
5
U-value (W/m2K)
0
1
2
3
4
5
6

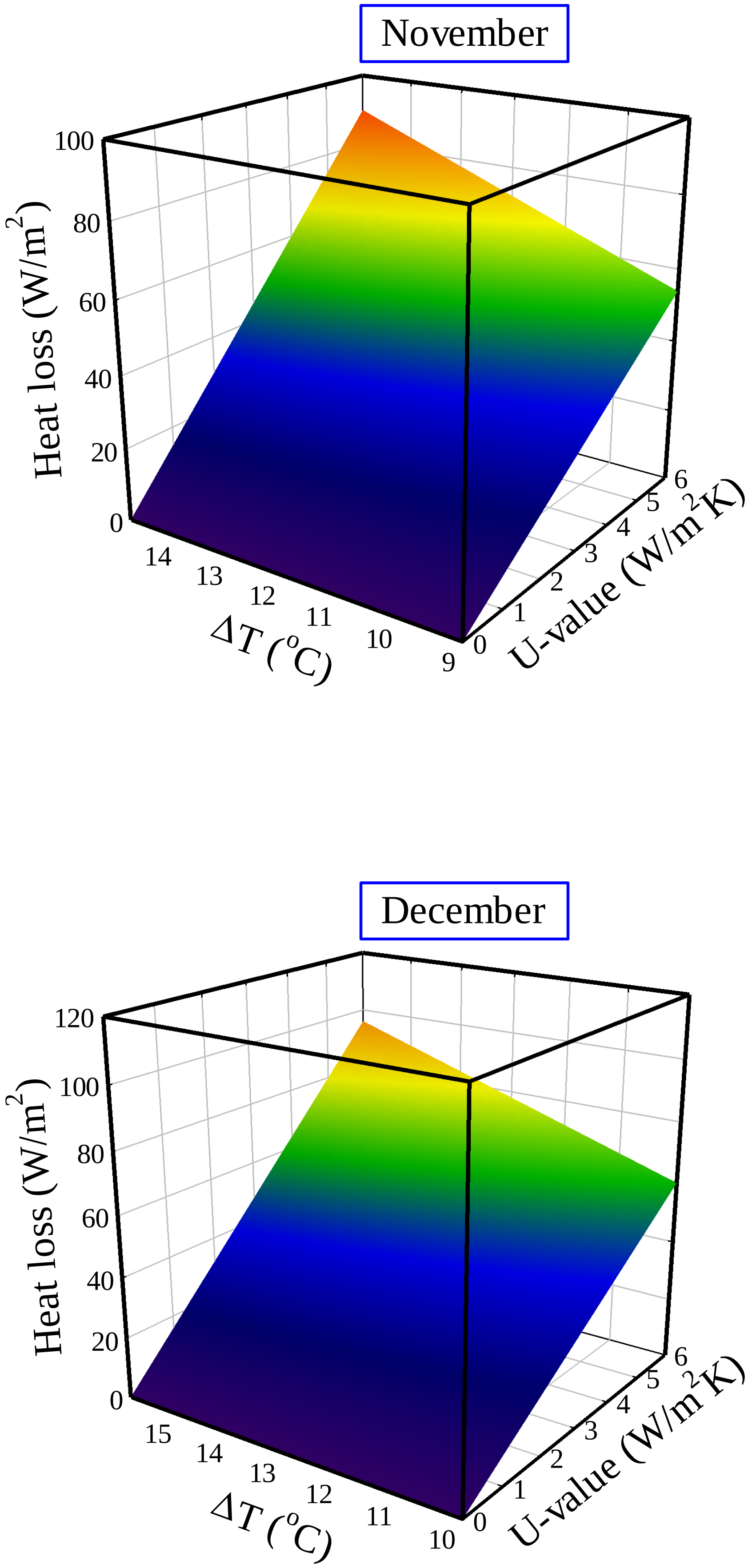


Figure 1: Monthly heating demand of the greenhouse for various temperature differences and overall heat transfer coefficients.

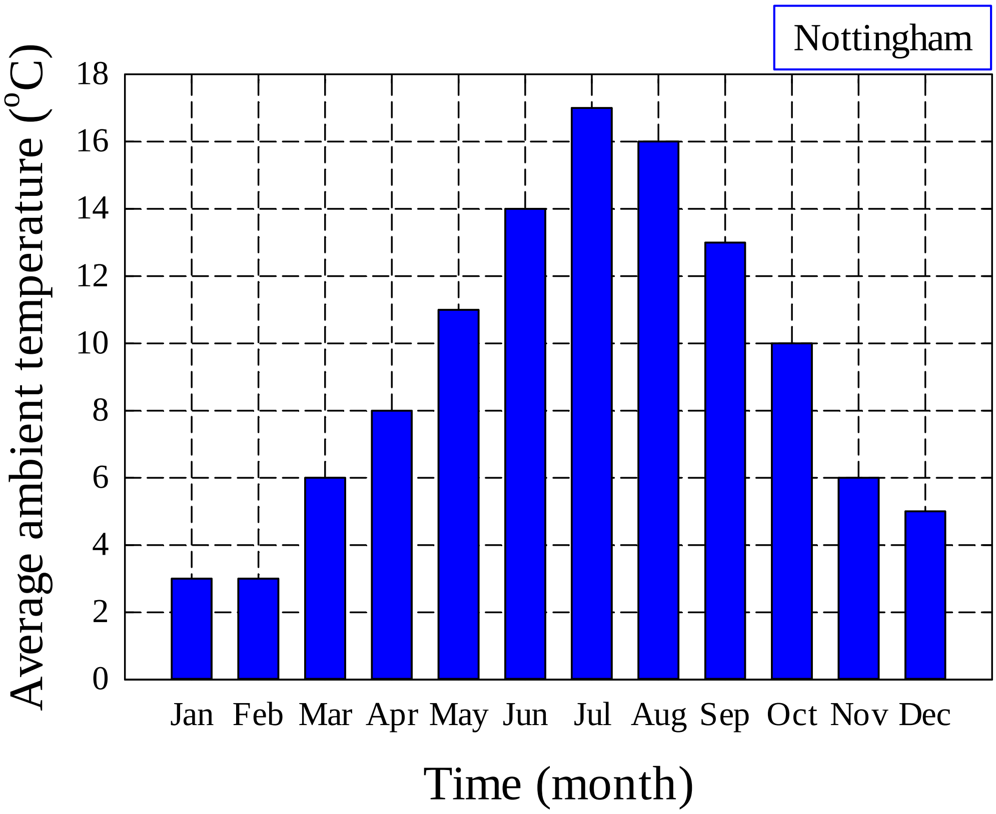


Figure 2: Monthly average ambient temperatures for Nottingham.

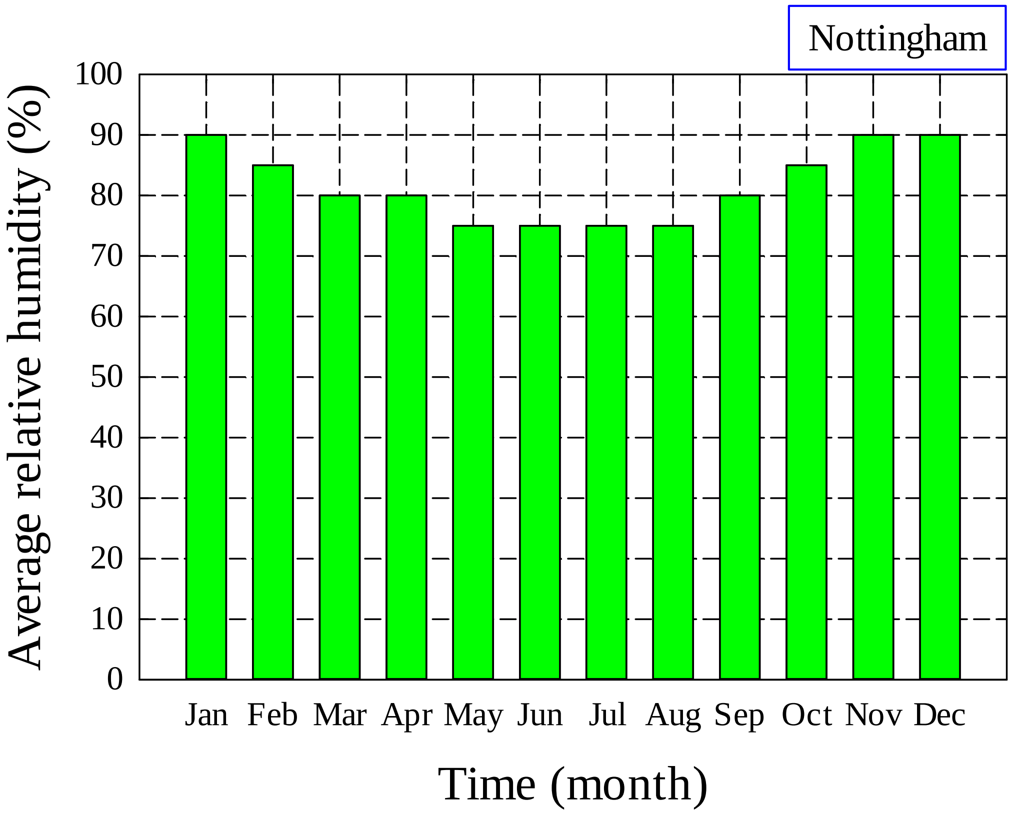


Figure 3: Monthly average relative humidity values for Nottingham.

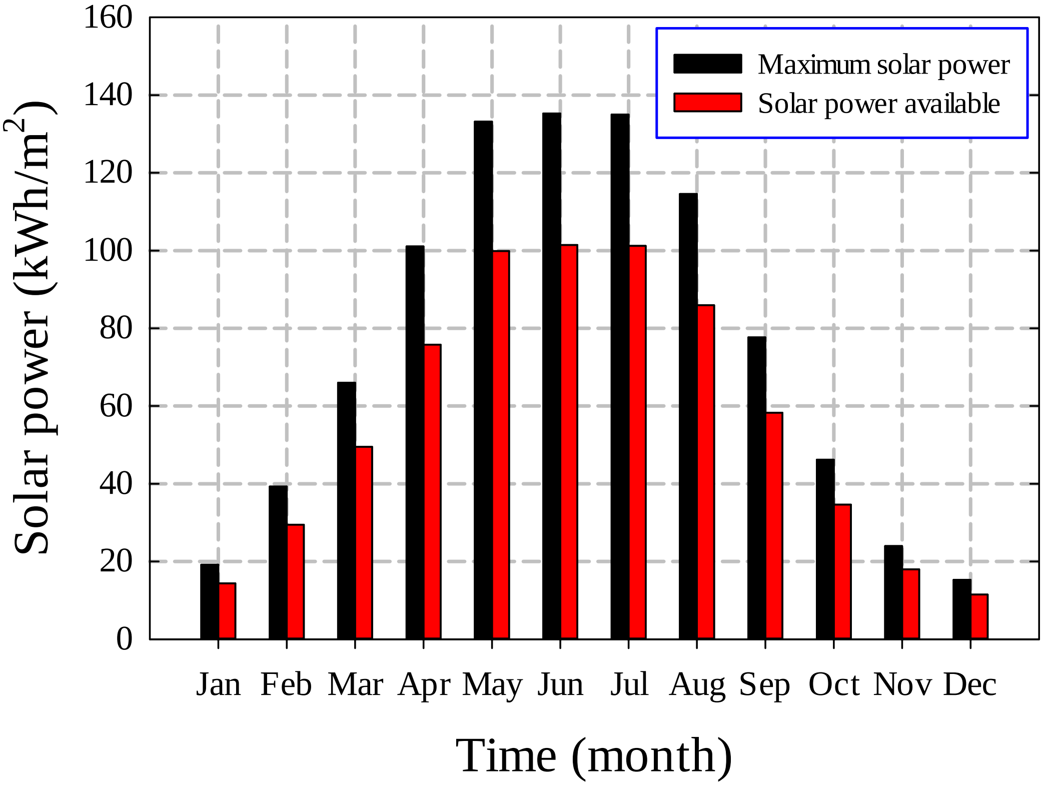
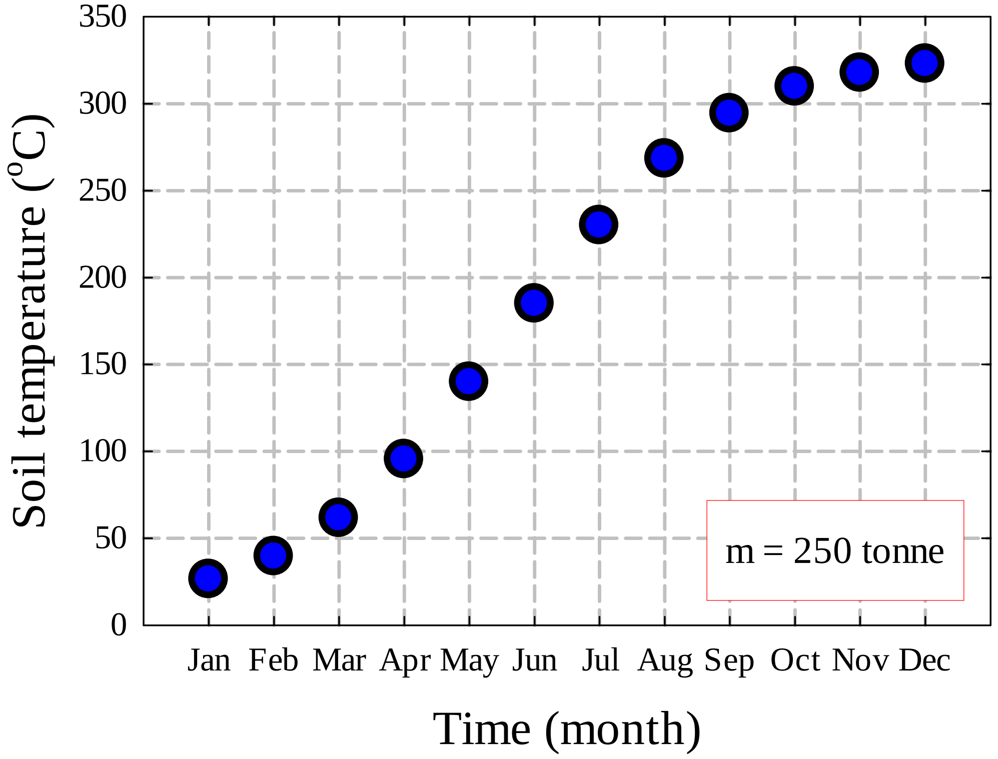
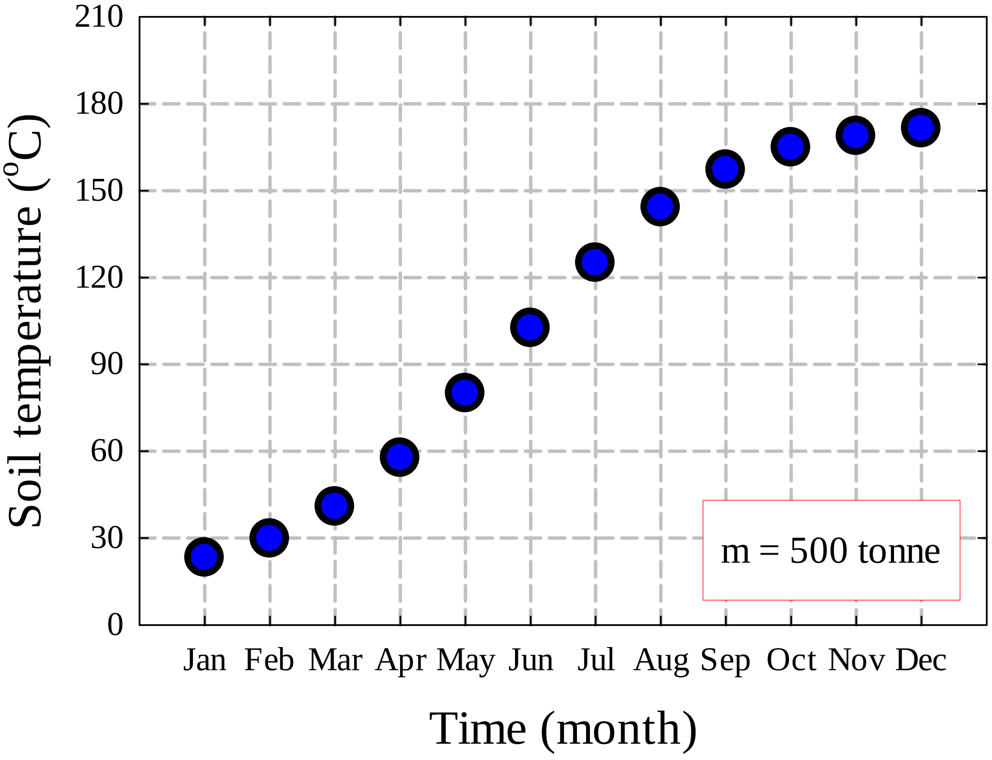
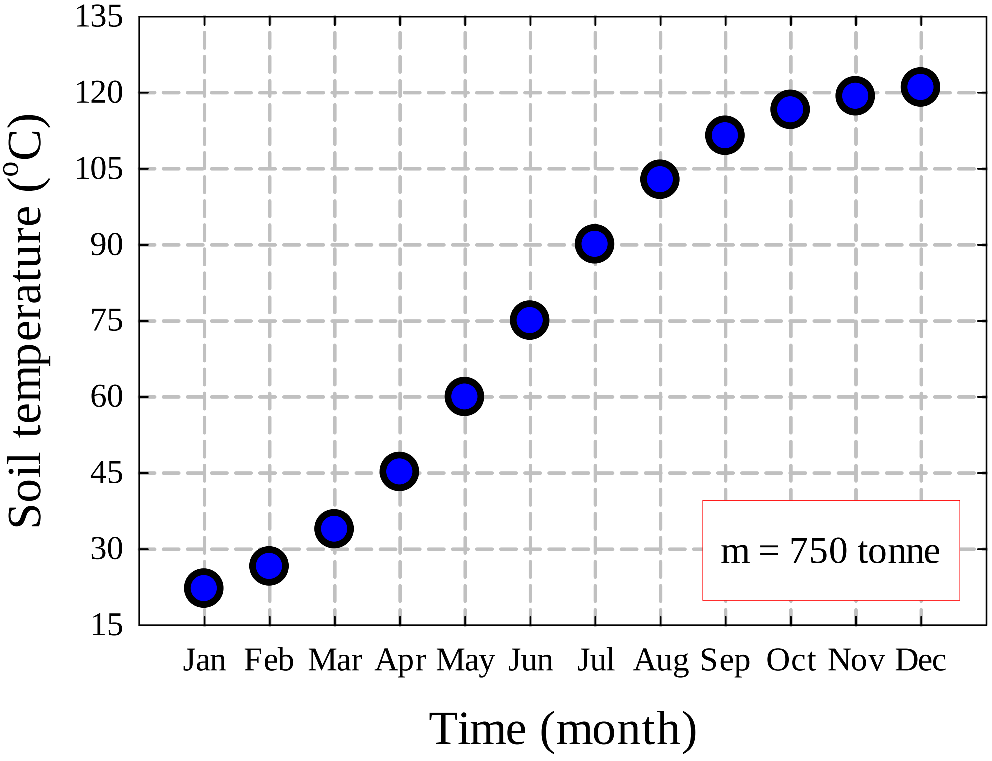
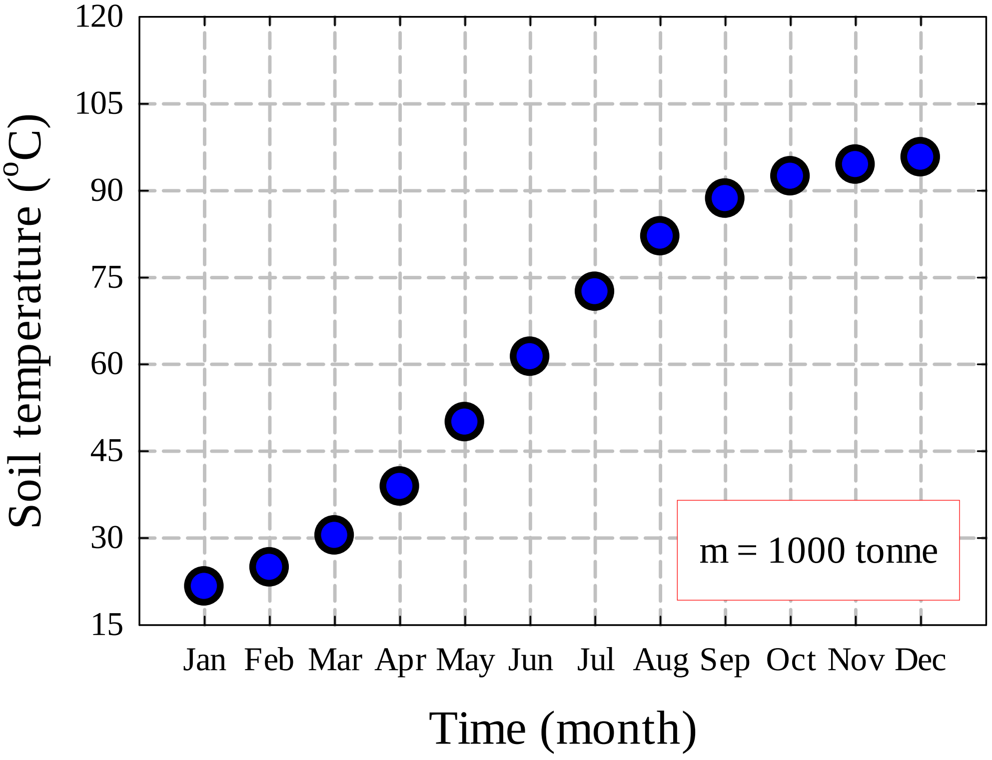


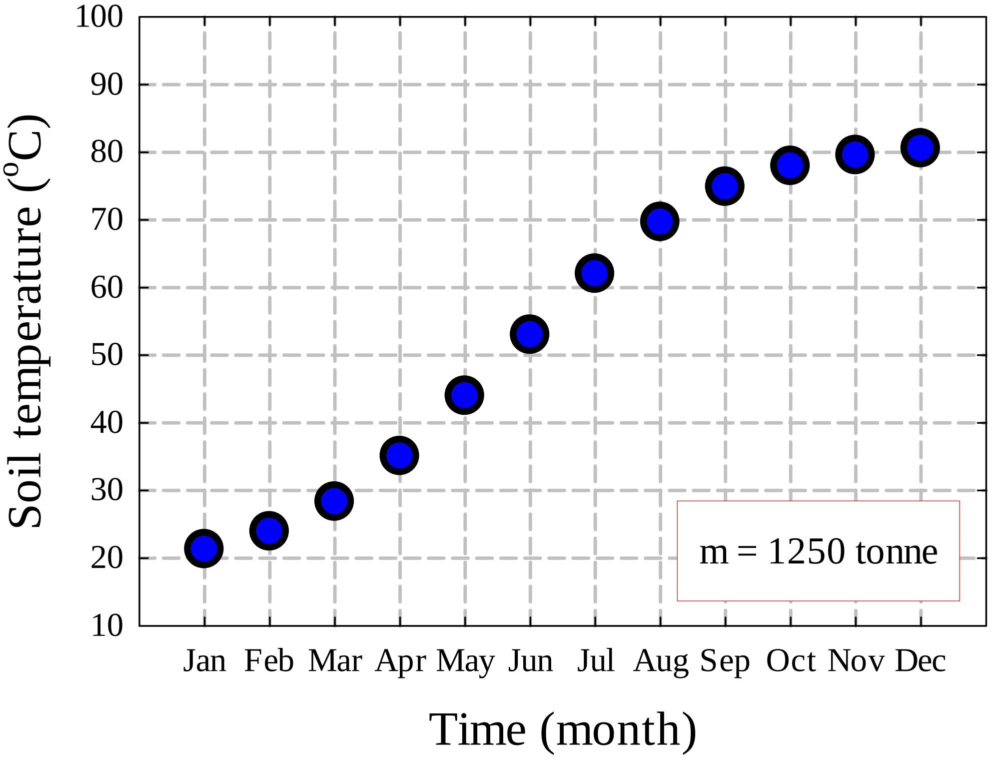
Figure 4: Monthly solar power potential and available power for Nottingham.

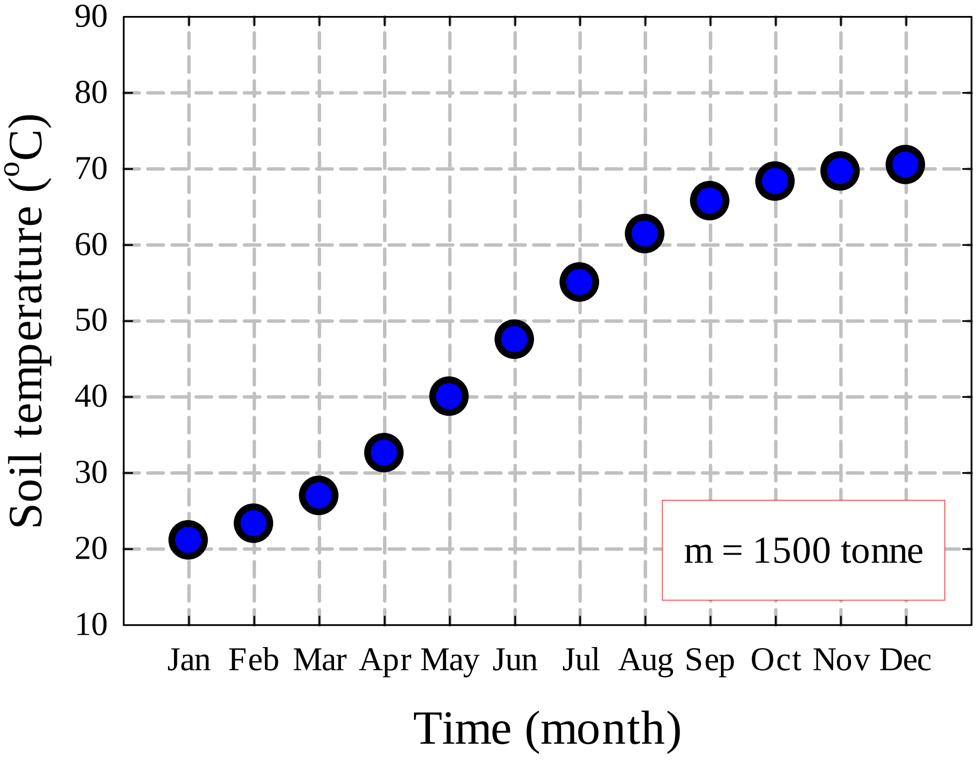


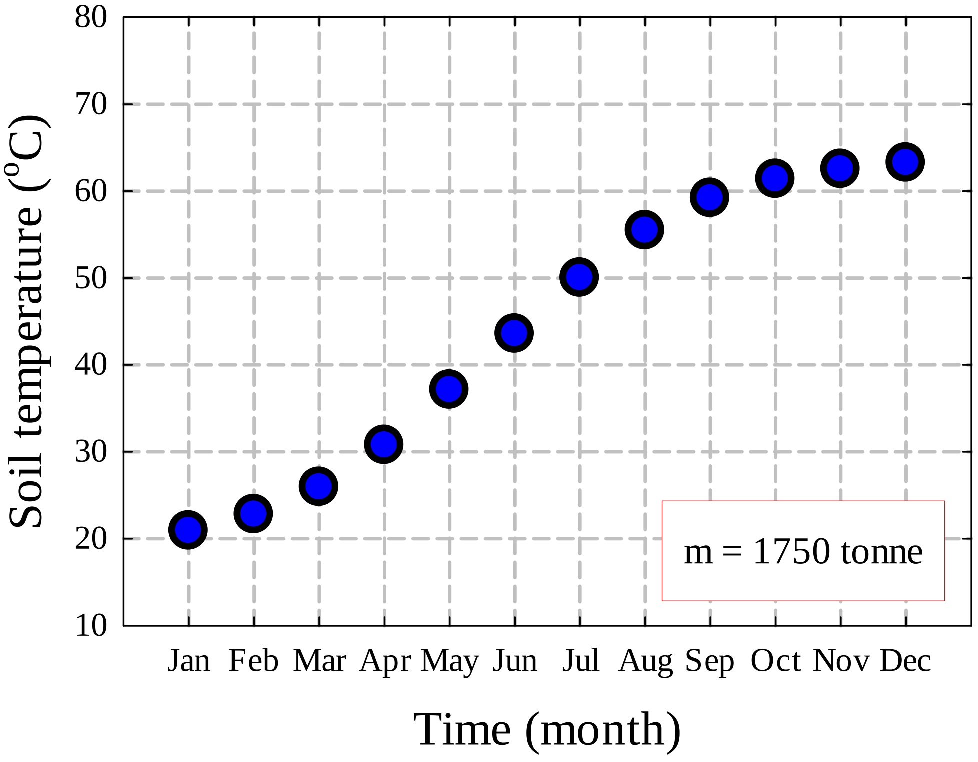

m = 500 tonne
Soil temperature (°C)
Time (month)
0
30
60
90
120
150
180
210
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


m = 750 tonne
Soil temperature (°C)
Time (month)
15
30
45
60
75
90
105
120
135
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Soil temperature (°C)
120
105
90
75
60
45
30
15
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Time (month)
m = 1000 tonne


Soil temperature (°C)
100
90
80
70
60
50
40
30
20
10
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Time (month)
m = 1250 tonne


Soil temperature (°C)
90
80
70
60
50
40
30
20
10
m = 1500 tonne
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Time (month)


Soil temperature (°C)
80
70
60
50
40
30
20
10
m = 1750 tonne
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Time (month)

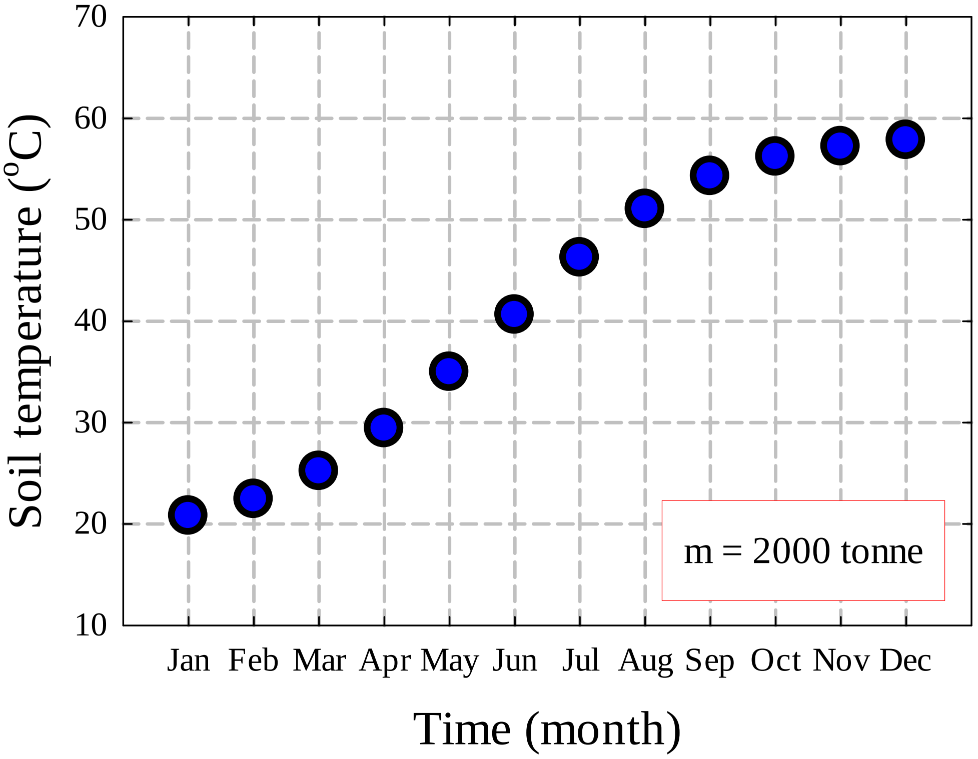


Figure 5: Monthly average soil temperatures achieved through seasonal thermal energy storage system.

5. REFERENCES

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