Appendix-2

1- **Introduction:** Climate conditions in Cairo, Egypt (Table with Ave. Cycle variance, and Standard deviation)

2- Air Temperature (Ta) and Frequency Plot

- Annually (Daily average) and Frequency Plot
- Monthly

3- Relative humidity (RH) and Frequency Plot

- Annually (Daily average)
- Monthly
- Seasons (Spring-Summer-Autumn-Winter) and Frequency Plot
- Air Temperature (C) VS Air Relative Humidity (%)

4- Solar Radiation and Frequency Plot

- Annually (Total daily average)
- Monthly
- Seasons (Spring-Summer-Autumn-Winter)
- Daily (one day in each season=4 days)

5- Model – STONE Masonry material

➢ Material properties for data input of best energy software

1- Case (1)-stone walls WITHOUT INSULATION in roof or floor
2- Case (2)-stone walls WITH INSULATION in roof or floor

➢ Difference between the other cases (from case (1) to case (7)

➢ Building parameters of different cases

1- Case (1)
2- Case (2)
3- Case (3)
4- Case (4)
5- Case (5)
6- Case (6)
7- Case (7)

➢ Comparison between different cases in terms of indoor air temperature- (c^o)

➢ Impact of adding different techniques on the enhancements of the indoor air temperature (c^o) for the same model

1- Introduction: Climate conditions in Cairo, Egypt

Egypt is classified as arid or desert with hot climate. This climate characterizes by modest rain and vast daily temperature.

The Weather data of Cairo is extracted from weather station in Cairo number (623660-HECA) which is located in Cairo airport and Weather file (IWEC) using Best Energy software.

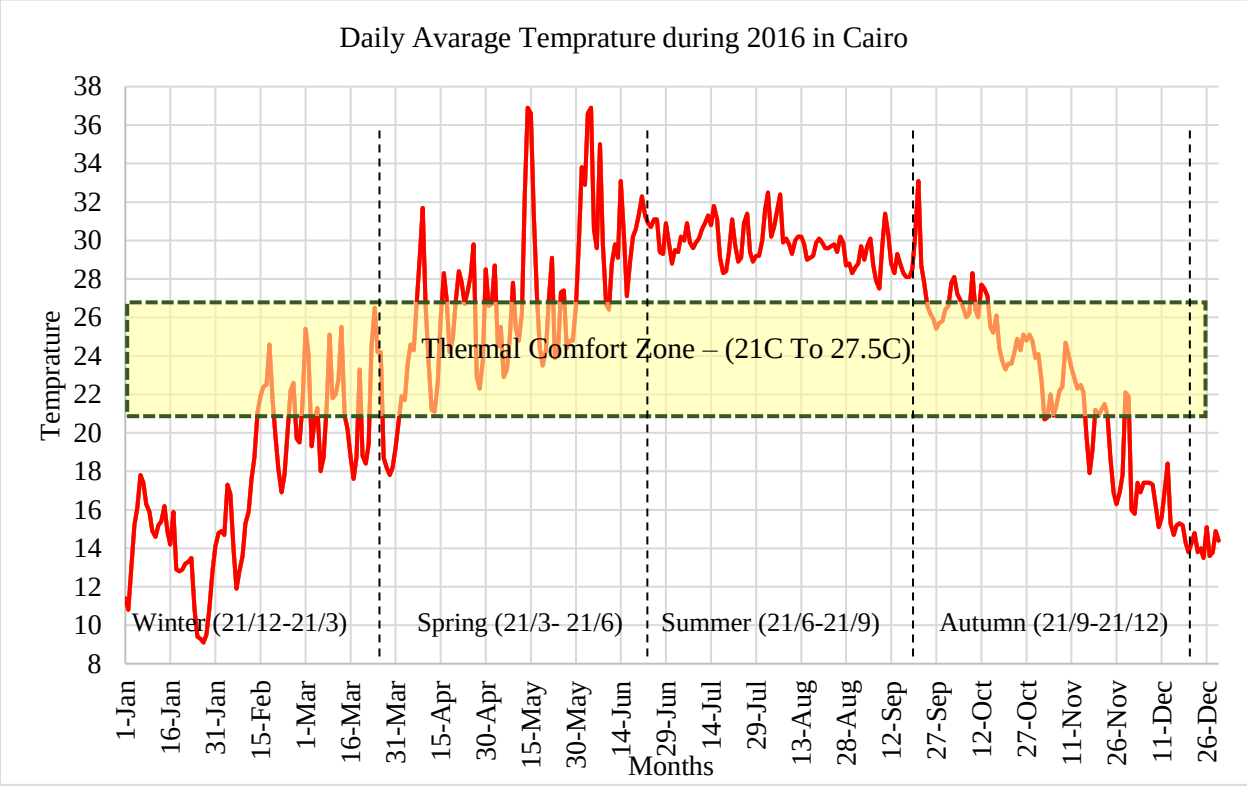
There are several parameterizes that should be analyzed to understand the climate conditions in Cairo with respect the thermal comfort level, as the following:

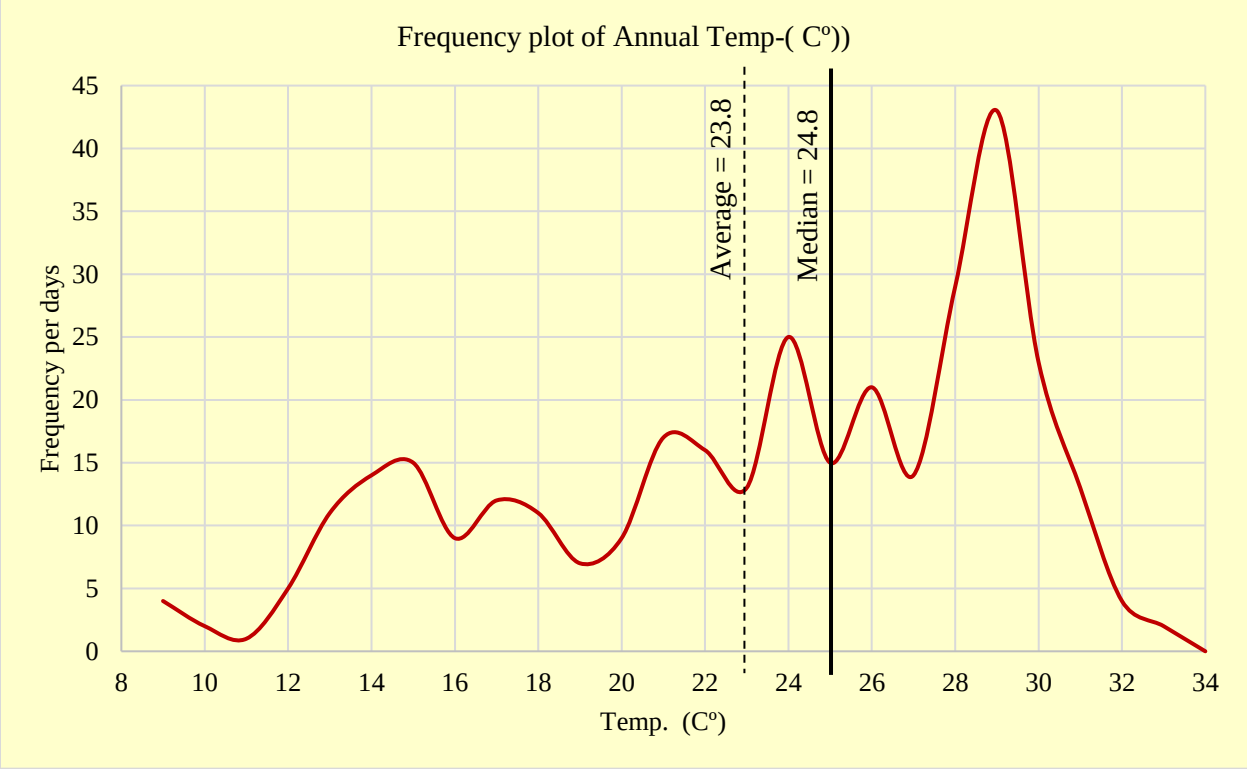
Climatic parameters	Periods	Ranges				Reference	Thermal Comfort level
		Average & Median	Average Cycle variation		Average Standard Deviation		
			Absolute MIN	Absolute MAX			
Air Temperature – (C°)	Annually (Daily Average)	Ave.=23.88 Med.= 24.8	9.1	36.9	6.10	weather station in Cairo number (623660-HECA)	From 21C-27.5C As per ASHRAE 55-2004
	Average Monthly	23.83	13.5	30.8	5.87		
	Spring 21/3-21-6	Ave.=23.77 Med. = 23.4	14.76	35.19	4.81	Weather file (IWEC)-Best Energy software	
	Summer 21/6-21-9	Ave.=27.78 Med.=27.7	25.10	30.29	1.13		
	Autumn 21/9-21-12	Ave.=20.43 Med.=20.5	12.98	27.783	3.98		
	Winter 21/12-21-3	Ave.=14.69 Med.=14.5	11.43	21.43	1.88		
Relative Humidity –(%)	Annually (Daily Average)	Ave.=51.61 Med.=54	16	80	12.17	weather station in Cairo number (623660-HECA)	From 30%-65% As per ASHRAE 55-2004
	Average Monthly	51.65	40.5	62.2	7.29		
	Spring 21/3-21-6	Ave.=48.66 Med.=50	15.98	71.75	11.53	Weather file (IWEC)-Best Energy software	
	Summer 21/6-21-9	Ave.=59.59 Med.=60.1	42.85	69.01	5.82		
	Autumn 21/9-21-12	Ave.=62.89 Med.=65	36.15	82.47	10.60		

	Winter 21/12-21-3	Ave.=64.98 Med.=66.1	38.17	90.73	11.25		
Irradiance (W/m^2) (Direct Solar+ Diffuse)	Annually (Daily Average)	Ave.=279.89 Me.= 295.55	57.21	416.85	92.88	Weather file (IWEC)-Best Energy software	
	Spring Season	Ave.= 332.96 Med.= 353.19	142.23	416.85	73.03		
	Summer Season	346.19 Med.= 346.85	221.82	402.99	41.21		
	Autumn Season	212.04 Med.= 217.25	57.21	325.53	75.70		
	Winter Season	226.43 Med.= 221.36	64.89	377.46	83.33		

2- Air Temperature (Ta)

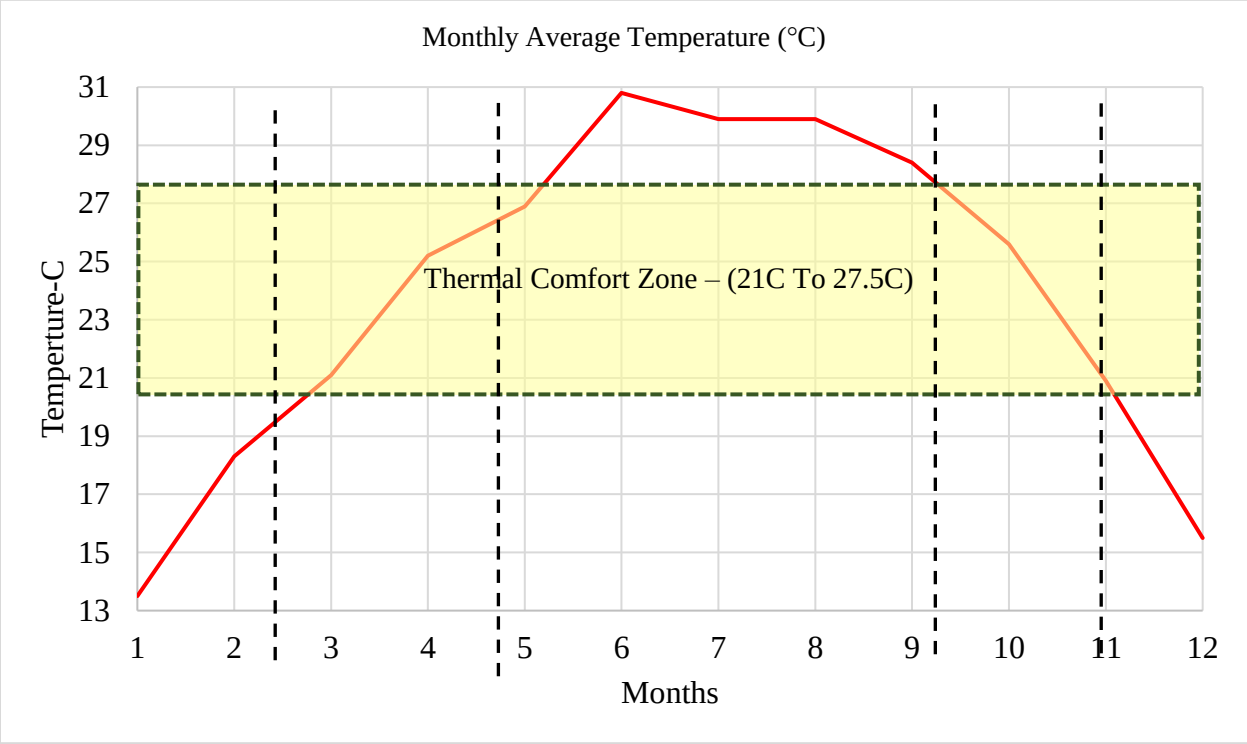
- **Annually Air Temperature (C) & Frequency plot**



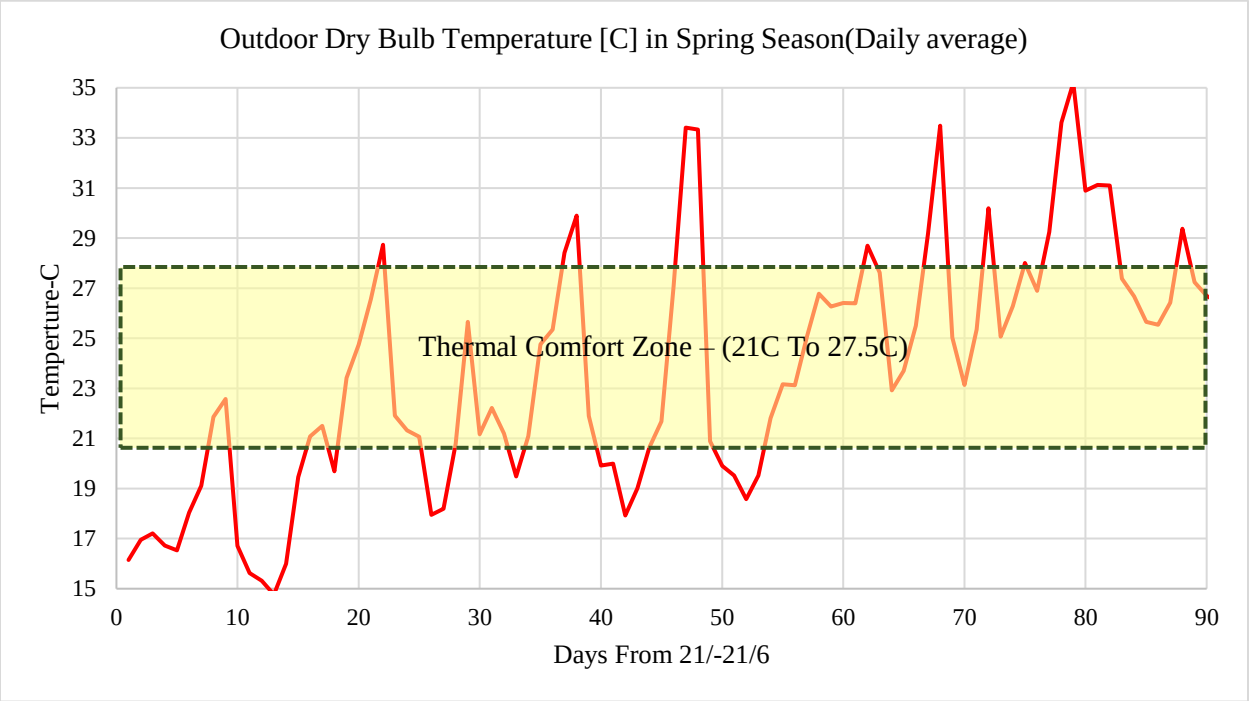


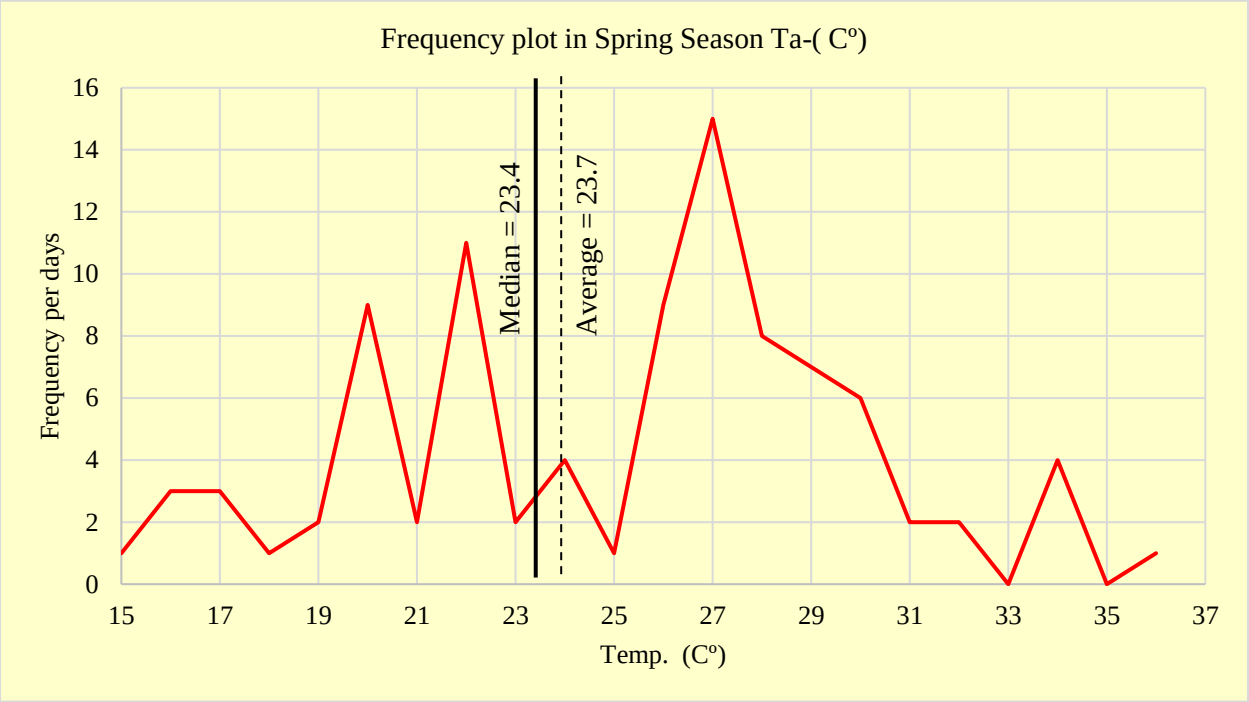
- **Monthly Air Temperature (C) & Frequency plot**

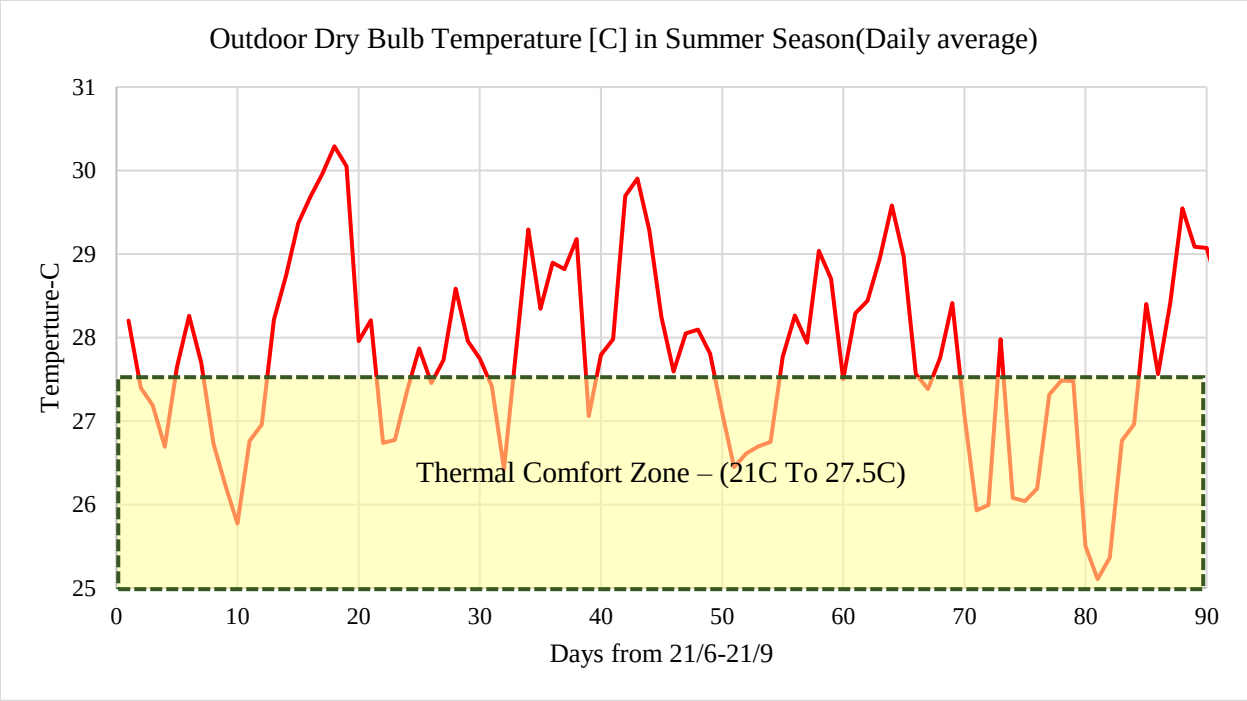
Year 2016	January	February	March	April	May	June	July	August	September	October	November	December
Monthly Average Temperature (°C)	13.5	18.3	21.1	25.2	26.9	30.8	29.9	29.9	28.4	25.6	20.9	15.5

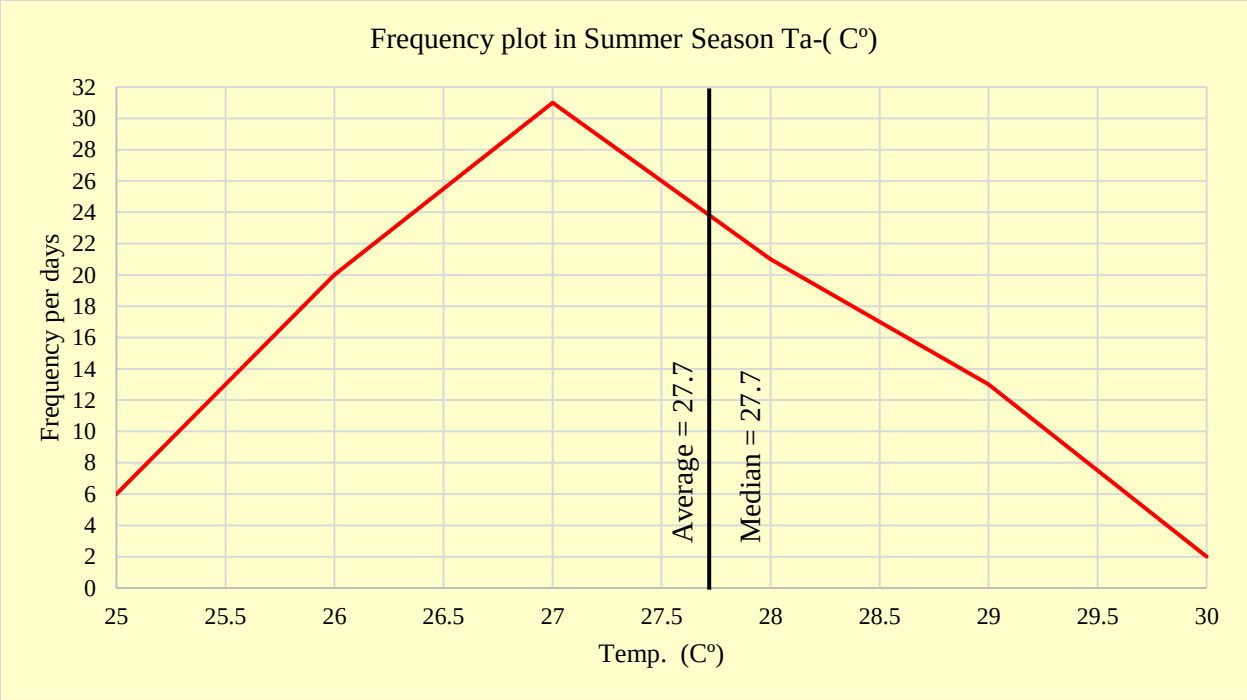


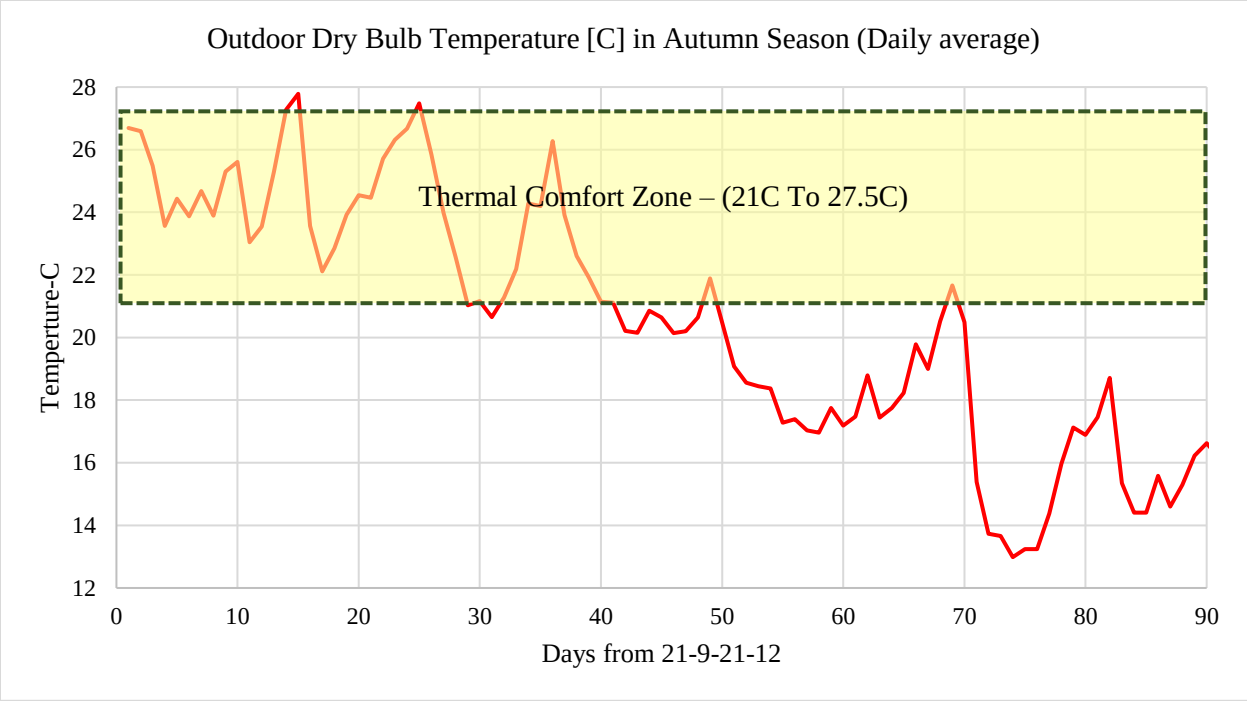
- Air Temperature by Seasons and Frequency Plot

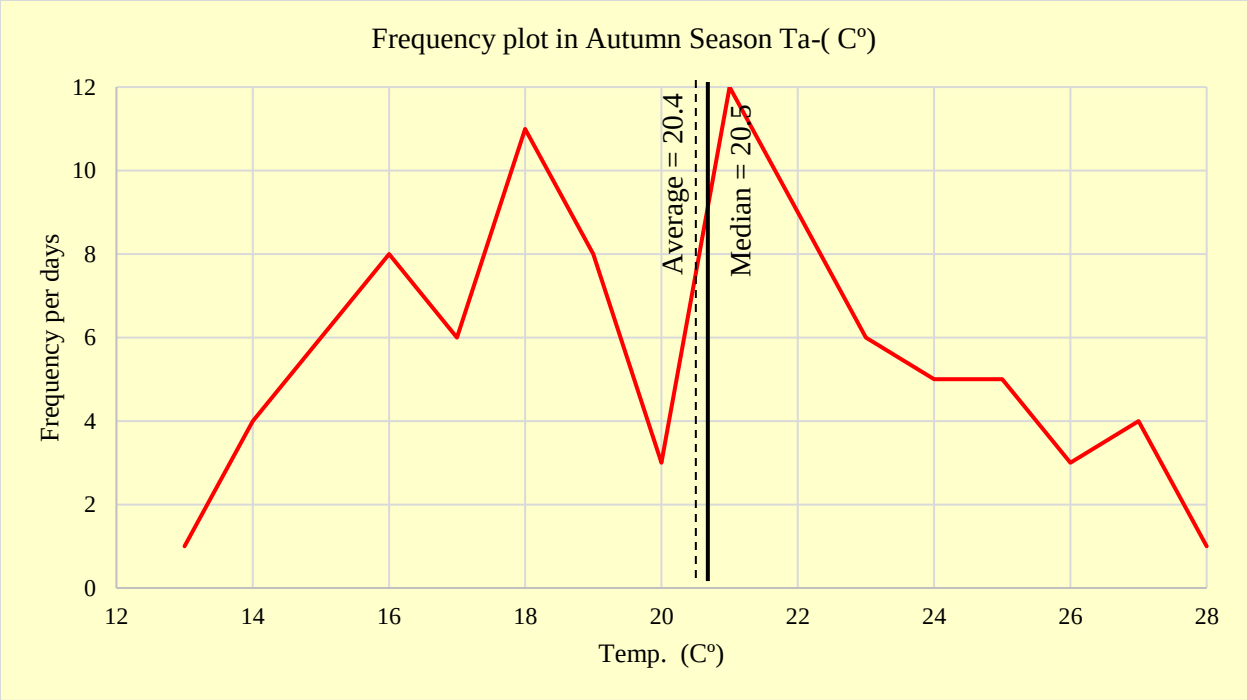


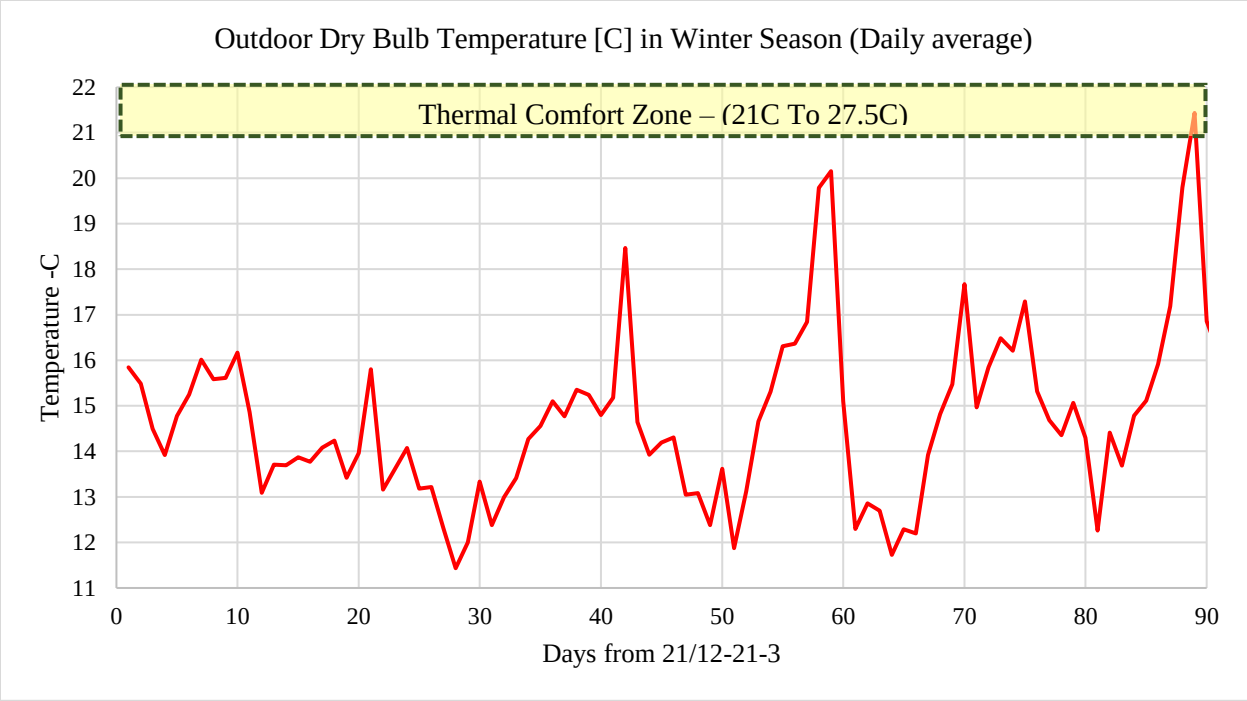


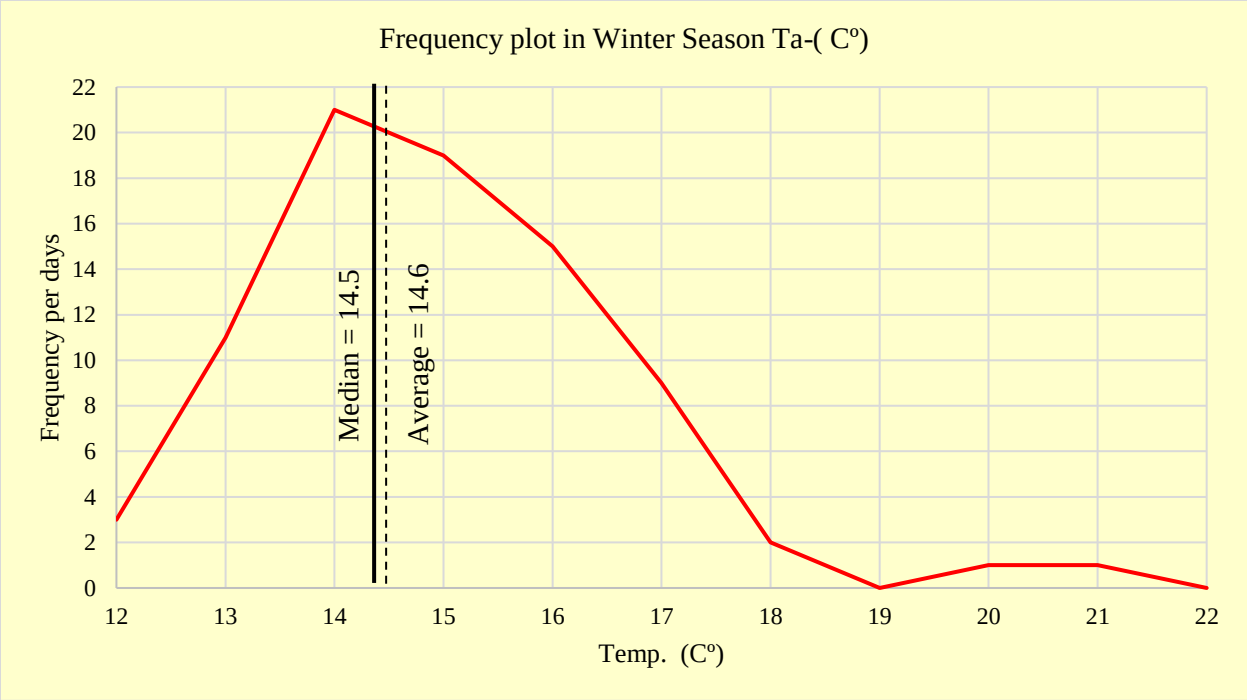

Outdoor Dry Bulb Temperature [C] in Summer Season(Daily average)
Temperture-C
31
30
29
28
27
26
25
Thermal Comfort Zone – (21C To 27.5C)
0
10
20
30
40
50
60
70
80
90
Days from 21/6-21/9


Frequency plot in Summer Season Ta-(Cº)
Frequency per days
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Average = 27.7
Median = 27.7
25
25.5
26
26.5
27
27.5
28
28.5
29
29.5
30
Temp. (Cº)


Outdoor Dry Bulb Temperature [C] in Autumn Season (Daily average)
Thermal Comfort Zone – (21C To 27.5C)
Temperture-C
Days from 21-9-21-12
28
26
24
22
20
18
16
14
12
0
10
20
30
40
50
60
70
80
90

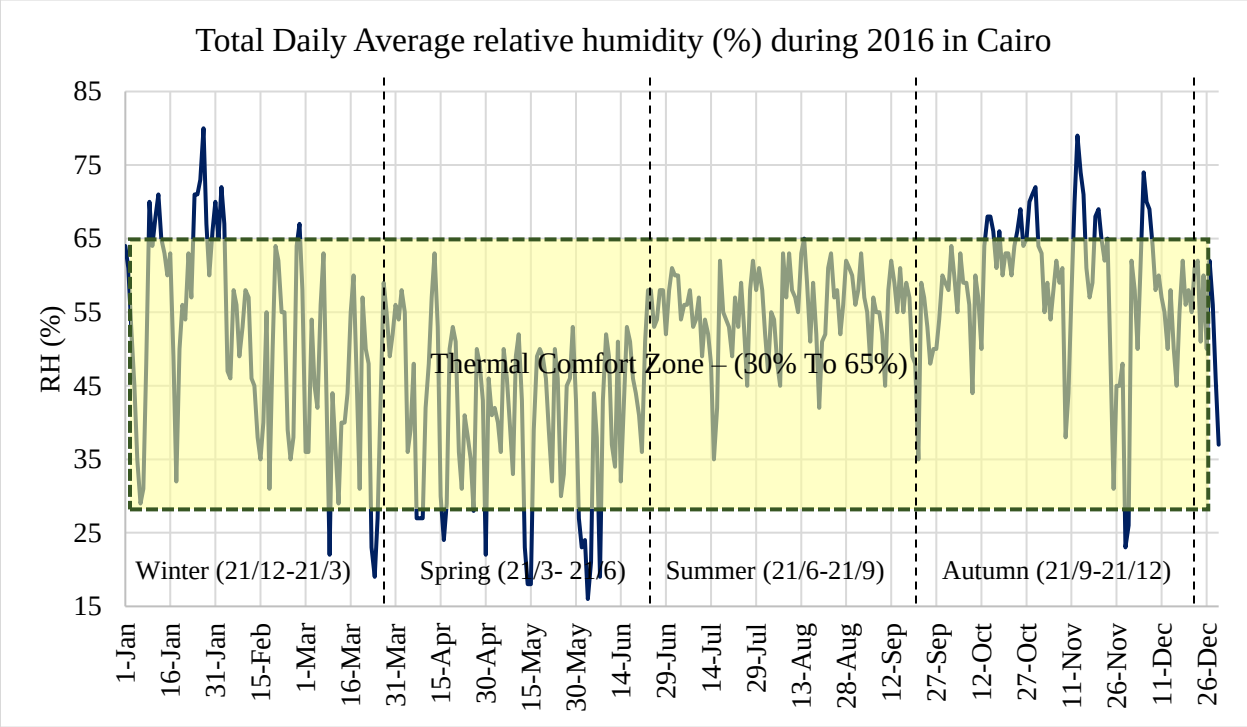

Frequency plot in Autumn Season Ta-(Cº)
Average = 20.4
Median = 20.5
Frequency per days
Temp. (Cº)
12
10
8
6
4
2
0
12
14
16
18
20
22
24
26
28

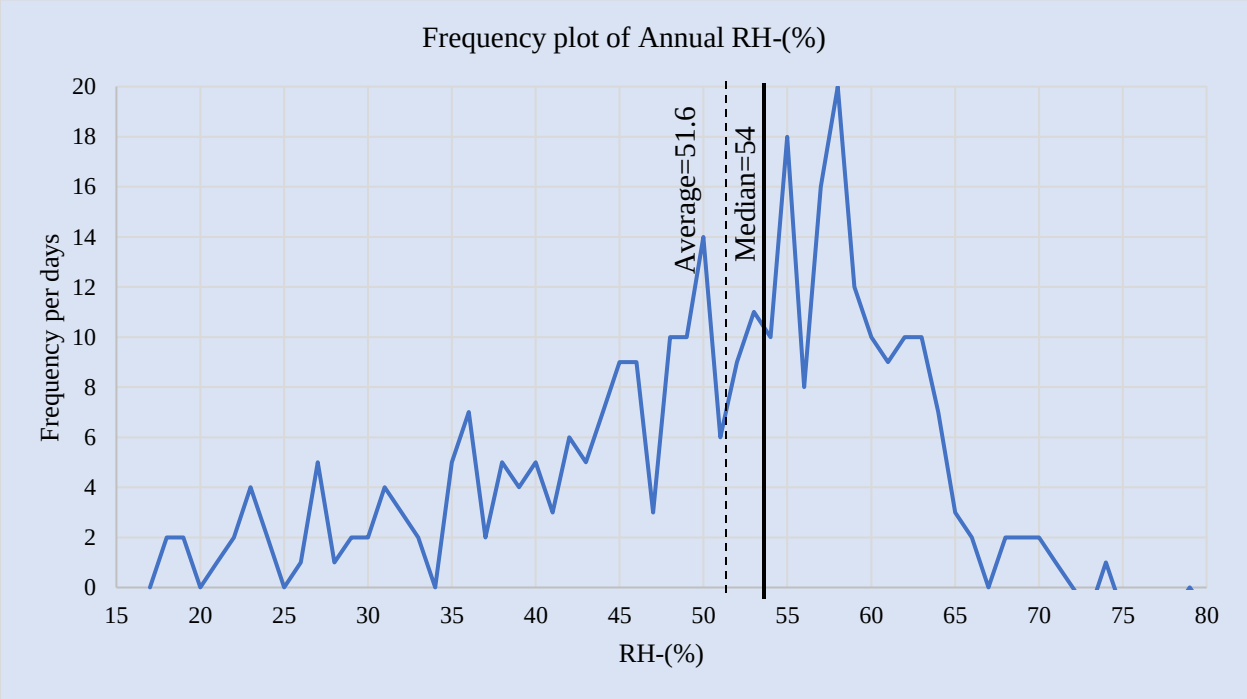

Outdoor Dry Bulb Temperature [C] in Winter Season (Daily average)
Thermal Comfort Zone – (21C To 27.5C)
Temperature -C
Days from 21/12-21-3


Frequency plot in Winter Season Ta-(Cº)
Median = 14.5
Average = 14.6
Frequency per days
Temp. (Cº)

3- Relative humidity (RH)

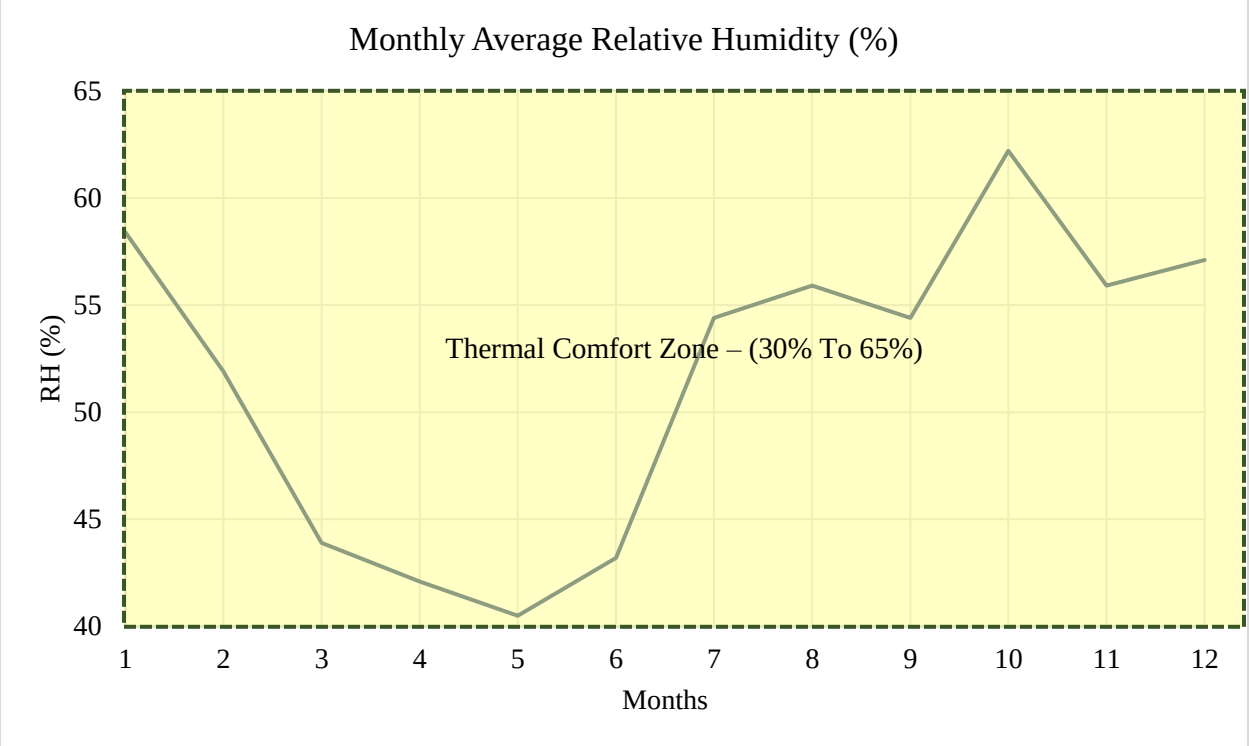
- **Annually relative humidity and Frequency Plot**



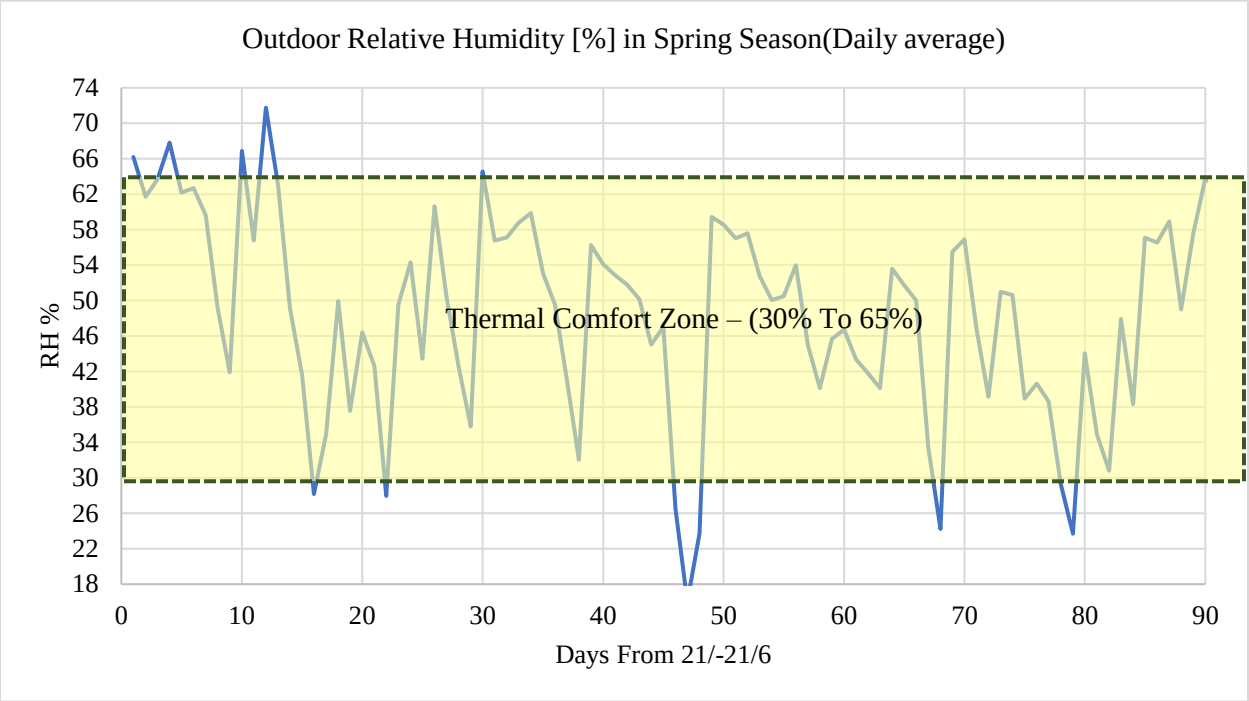


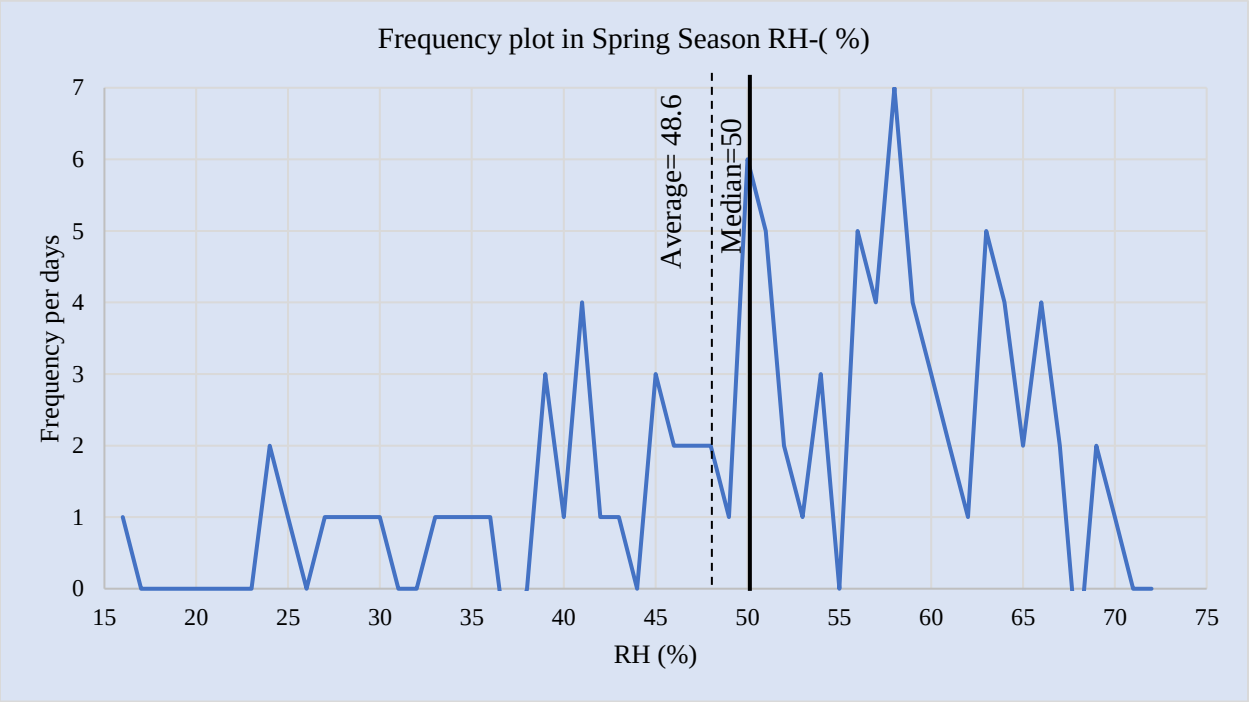
- **Monthly relative humidity**

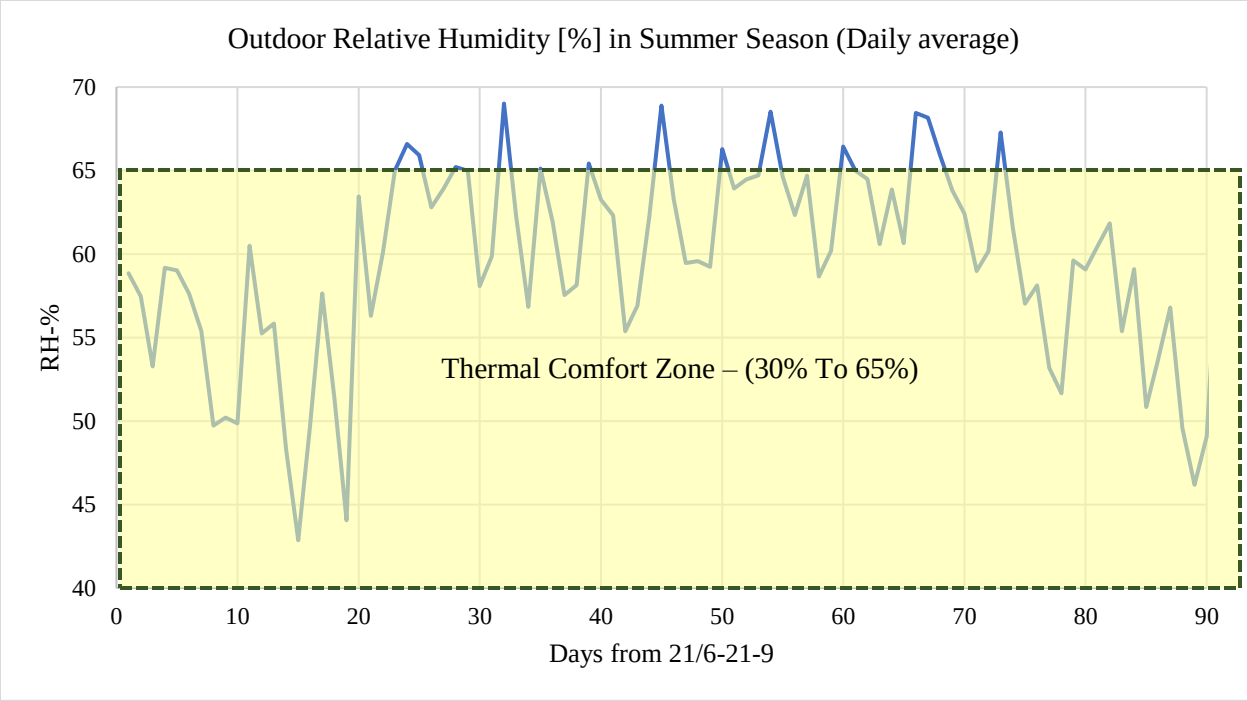
Year 2016	January	February	March	April	May	June	July	August	September	October	November	December
Monthly Average Relative Humidity(%)	58.4	51.9	43.9	42.1	40.5	43.2	54.4	55.9	54.4	62.2	55.9	57.1

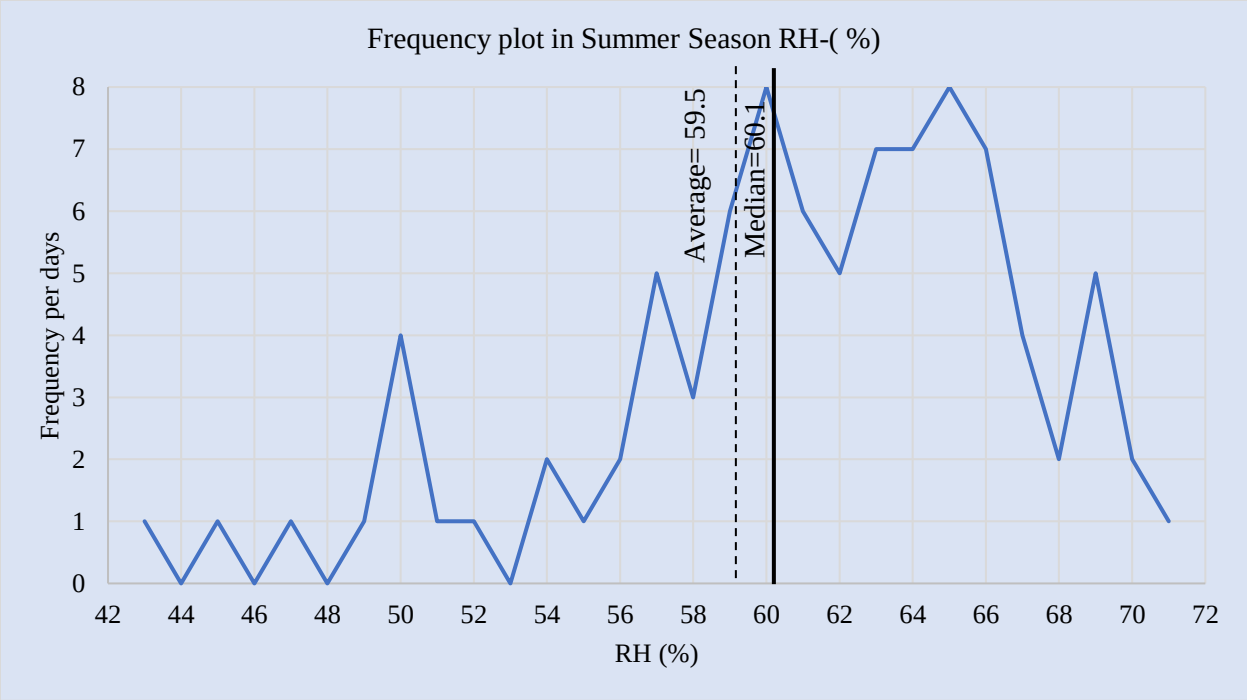


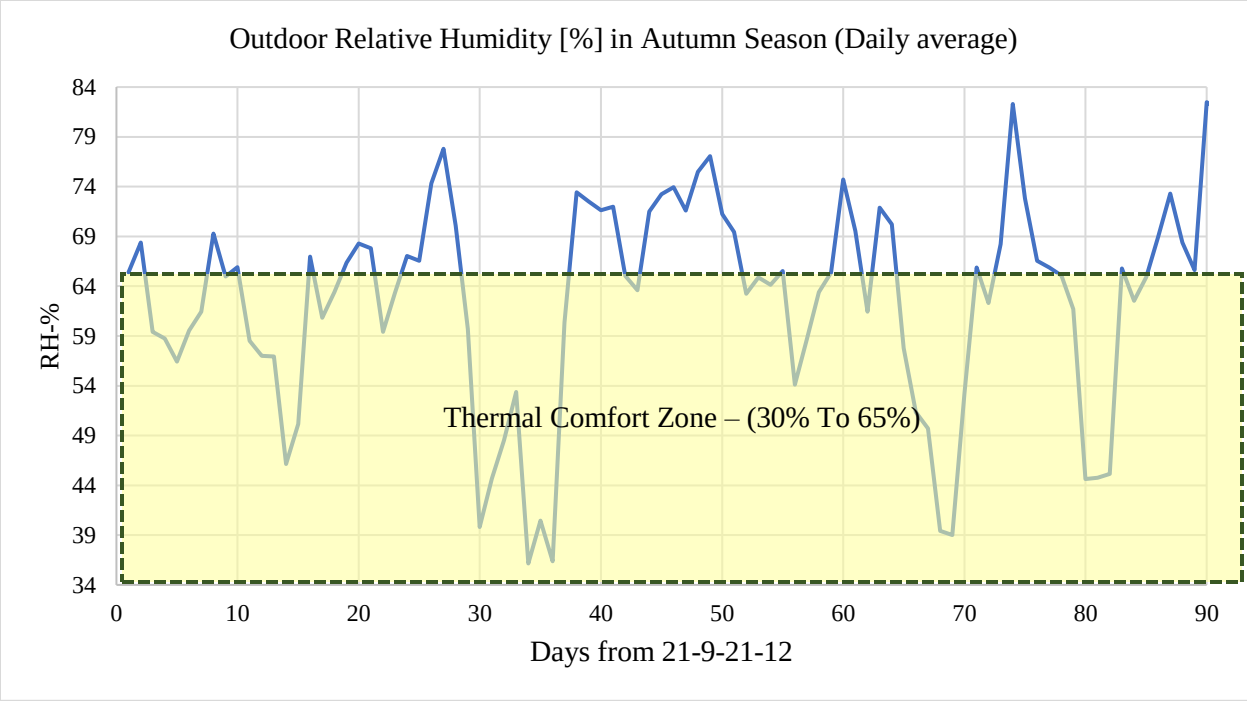
- **Relative Humidity by seasons and Frequency Plot**

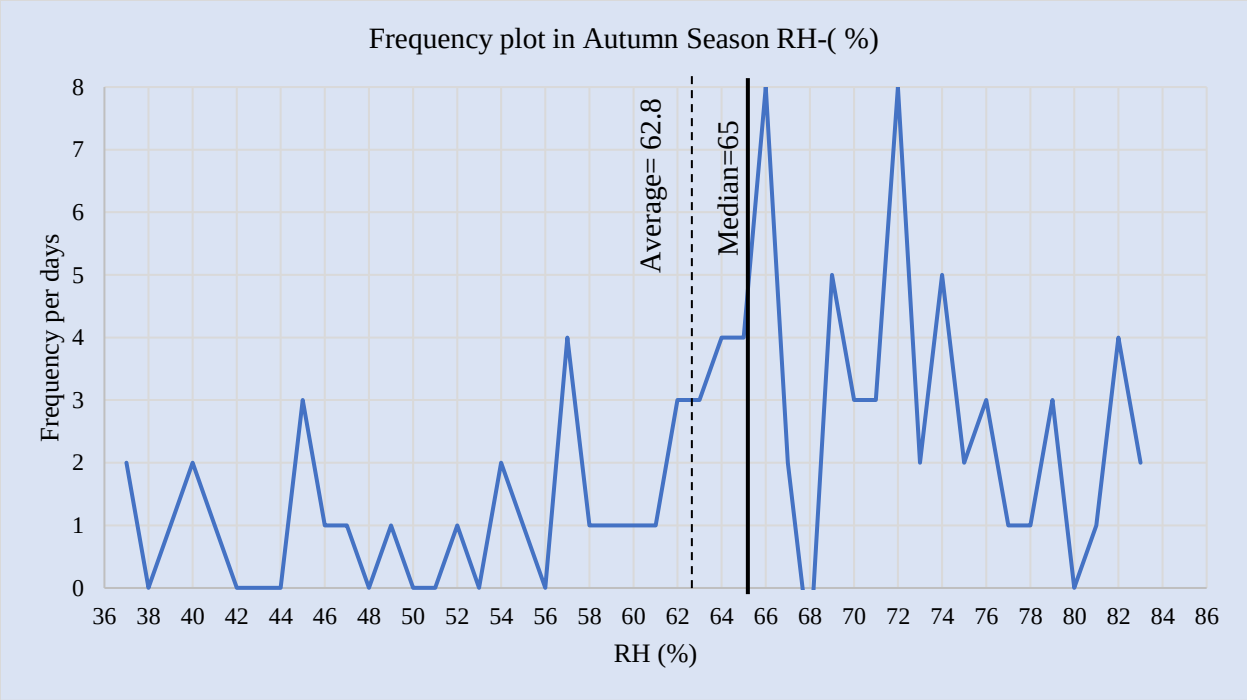


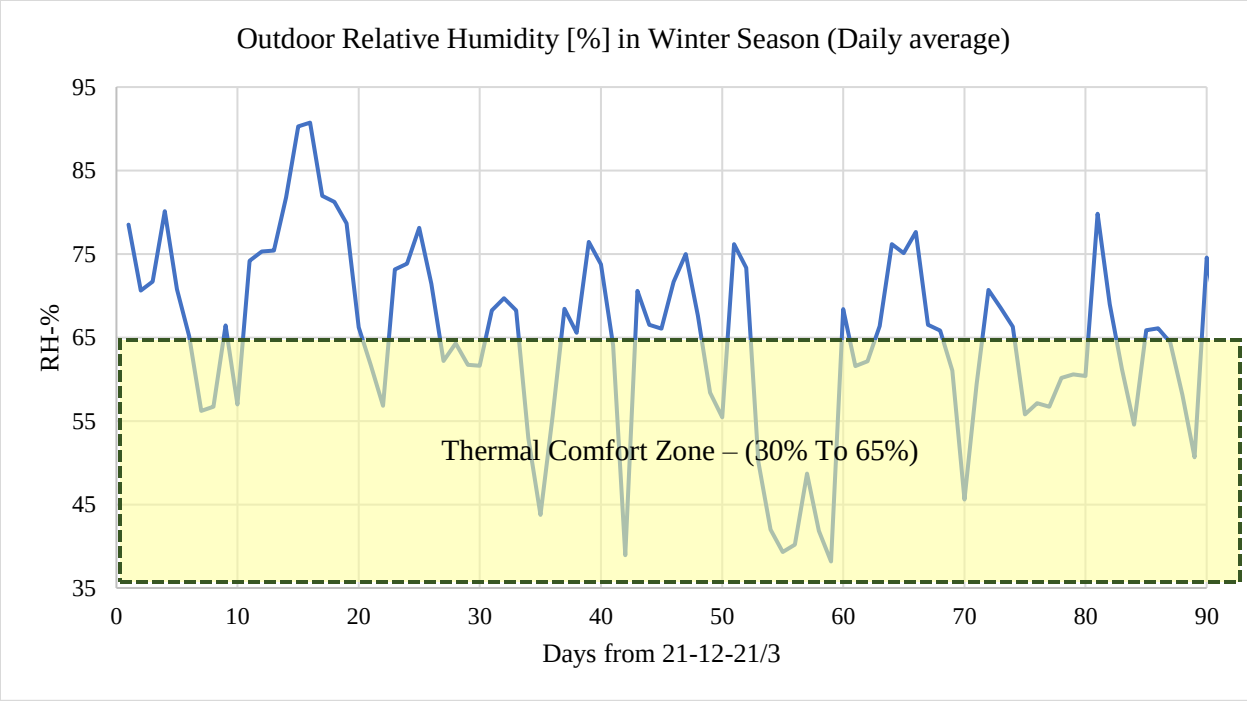


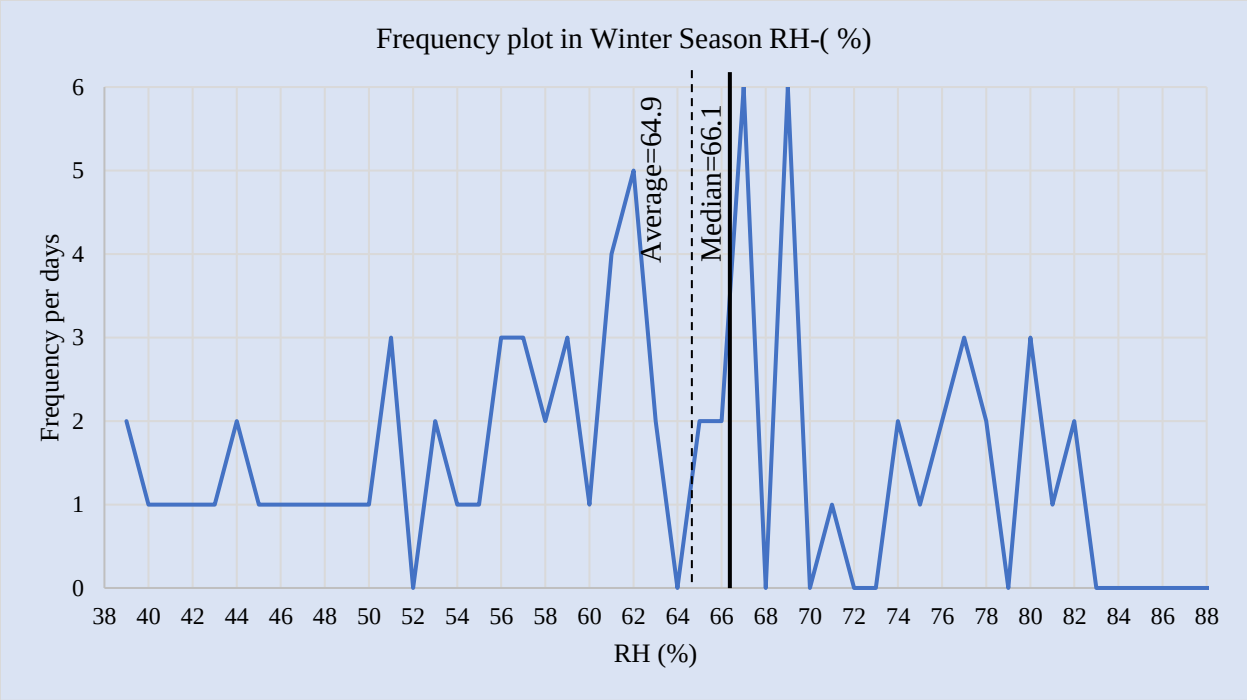

Outdoor Relative Humidity [%] in Summer Season (Daily average)
RH-%
70
65
60
55
50
45
40
Thermal Comfort Zone – (30% To 65%)
0
10
20
30
40
50
60
70
80
90
Days from 21/6-21-9


Frequency plot in Summer Season RH-(%)
Frequency per days
8
7
6
5
4
3
2
1
0
Average= 59.5
Median=60.1
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
RH (%)

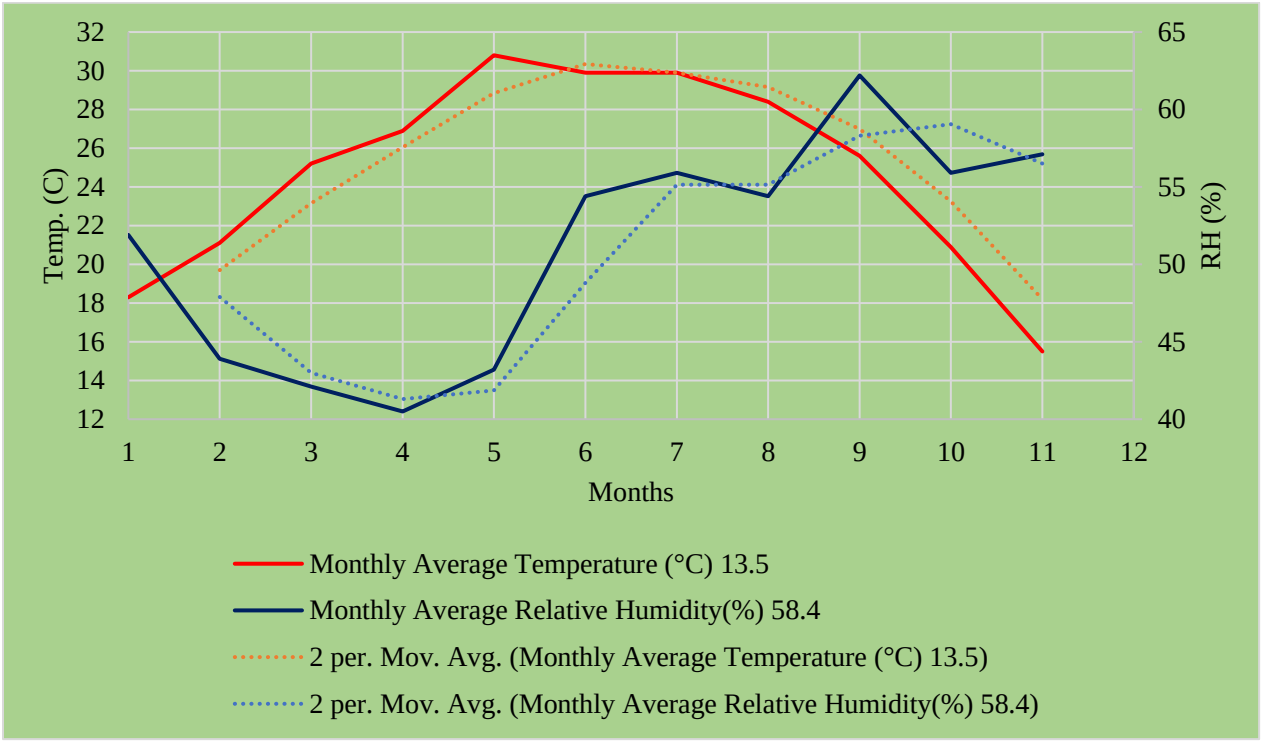

Outdoor Relative Humidity [%] in Autumn Season (Daily average)
RH-%
84
79
74
69
64
59
54
49
44
39
34
Thermal Comfort Zone – (30% To 65%)
0
10
20
30
40
50
60
70
80
90
Days from 21-9-21-12


Frequency plot in Autumn Season RH-(%)
Frequency per days
8
7
6
5
4
3
2
1
0
Average= 62.8
Median=65
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
RH (%)


Outdoor Relative Humidity [%] in Winter Season (Daily average)
RH-%
95
85
75
65
55
45
35
Thermal Comfort Zone – (30% To 65%)
0
10
20
30
40
50
60
70
80
90
Days from 21-12-21/3

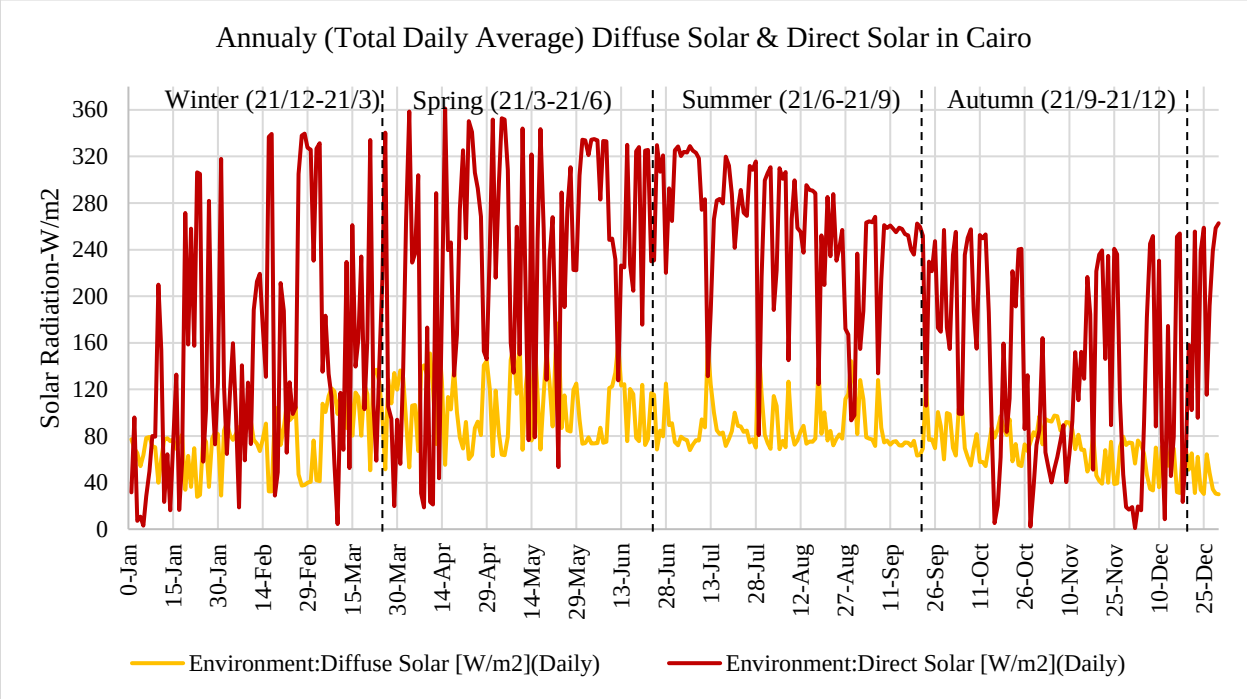

Frequency plot in Winter Season RH-(%)
Frequency per days
6
5
4
3
2
1
0
Average=64.9
Median=66.1
38
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
74
76
78
80
82
84
86
88
RH (%)

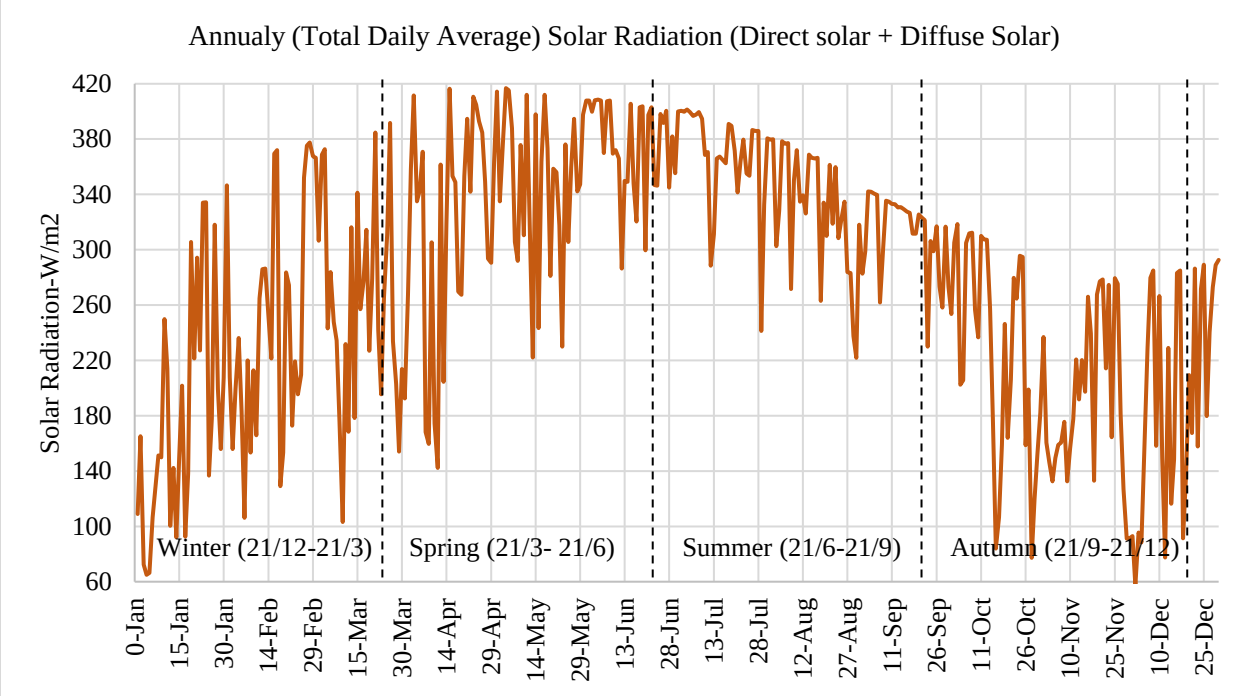
- **Air Temperature (C) VS Air Relative Humidity (%)- Monthly Average**

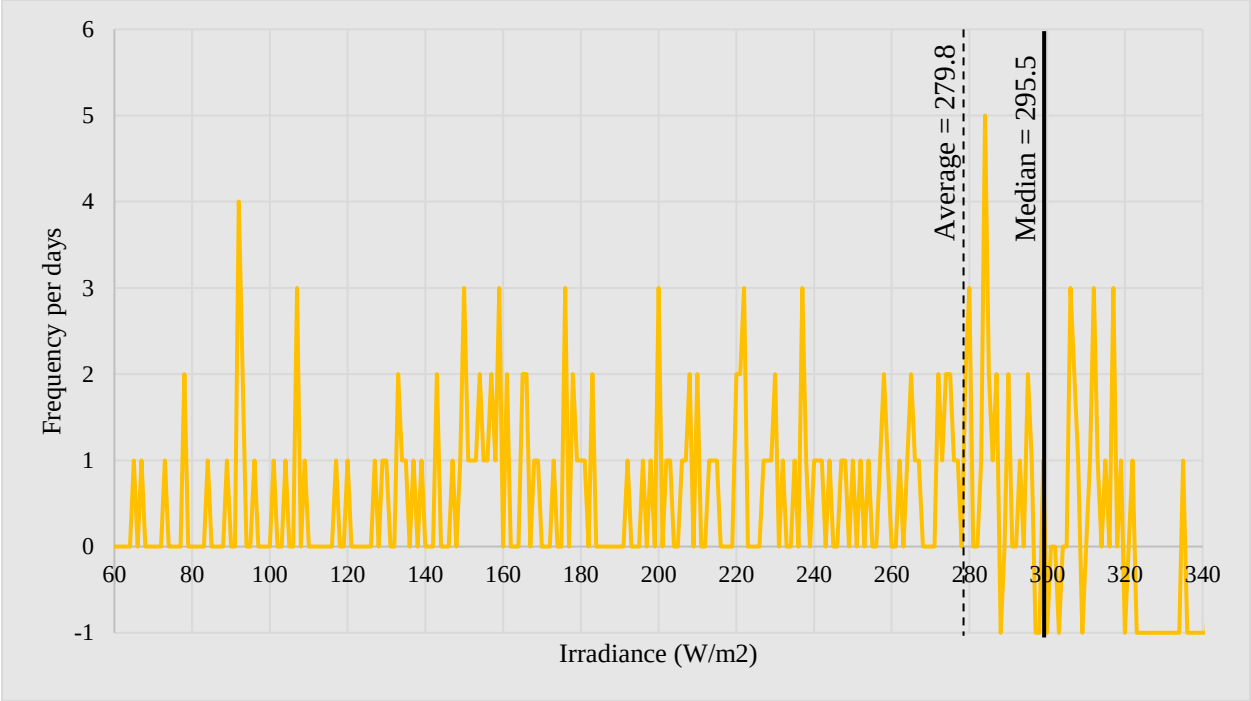


4- Solar Radiation

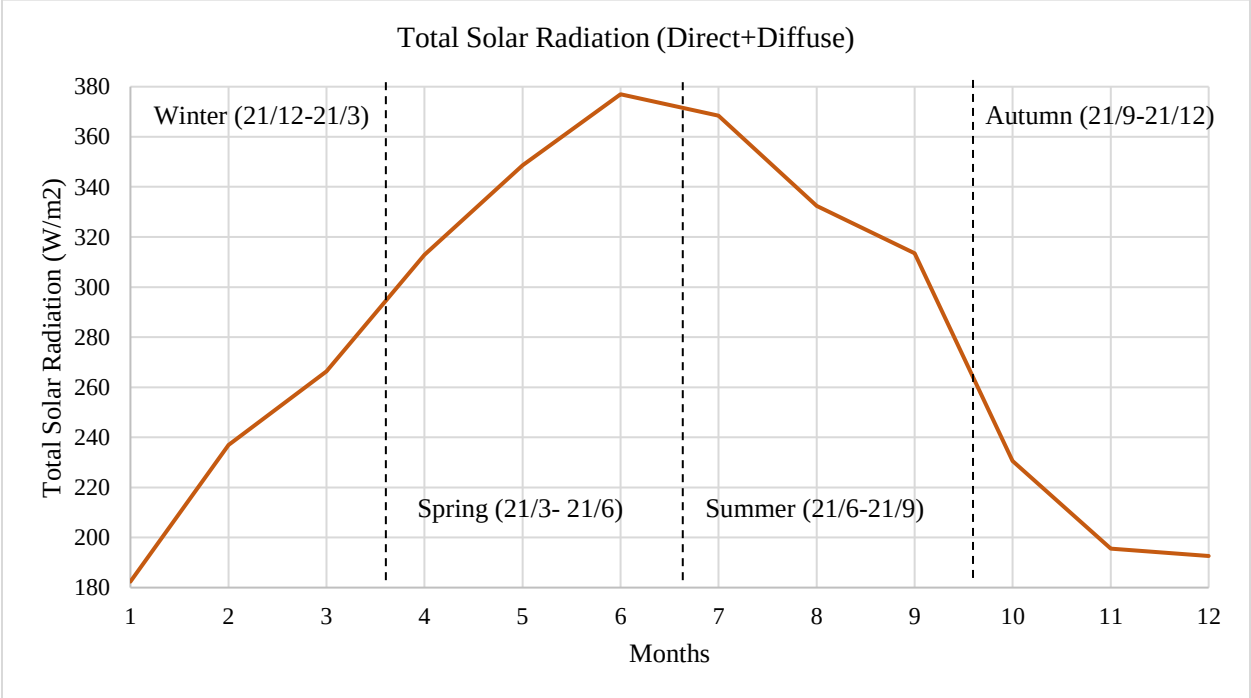
- **Solar Radiation Annually and Frequency Plot**

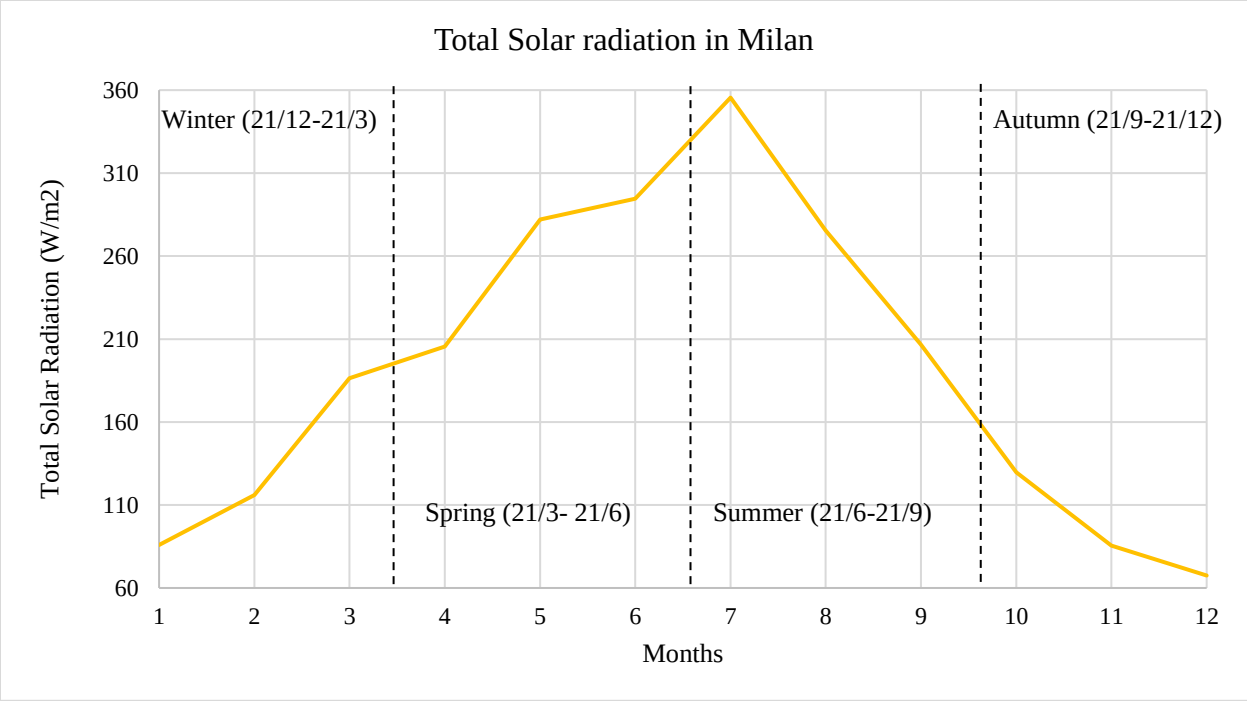




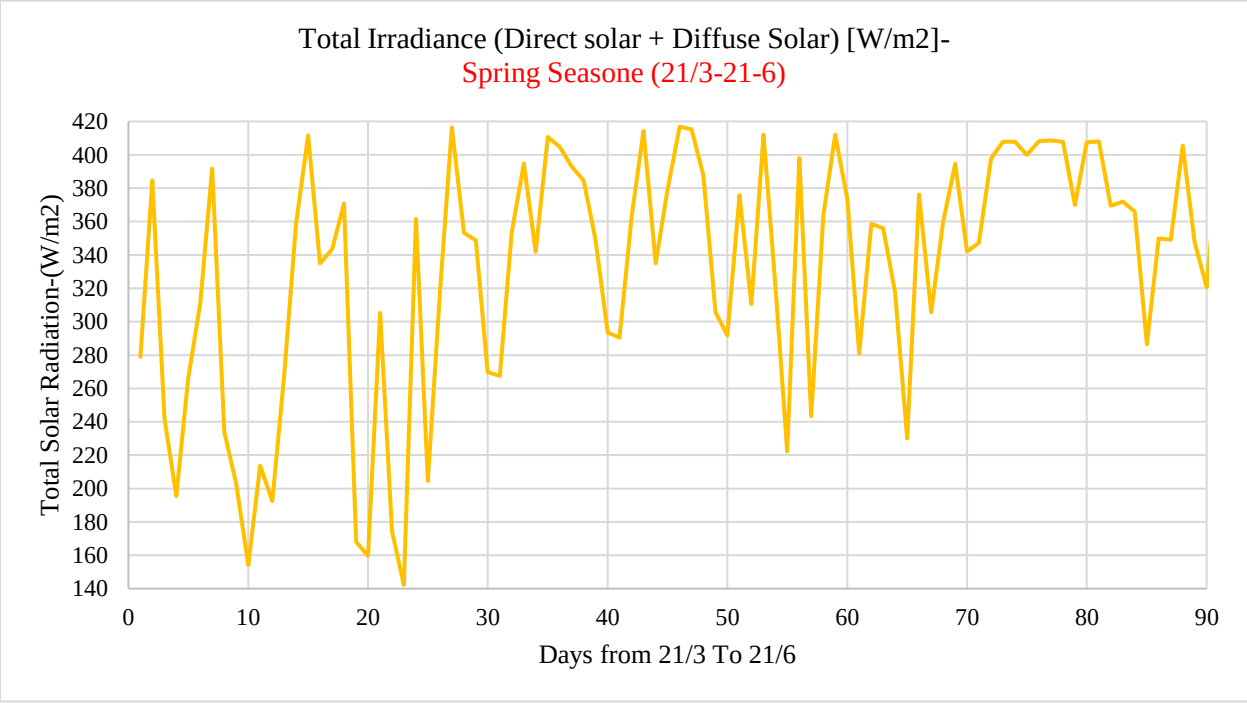


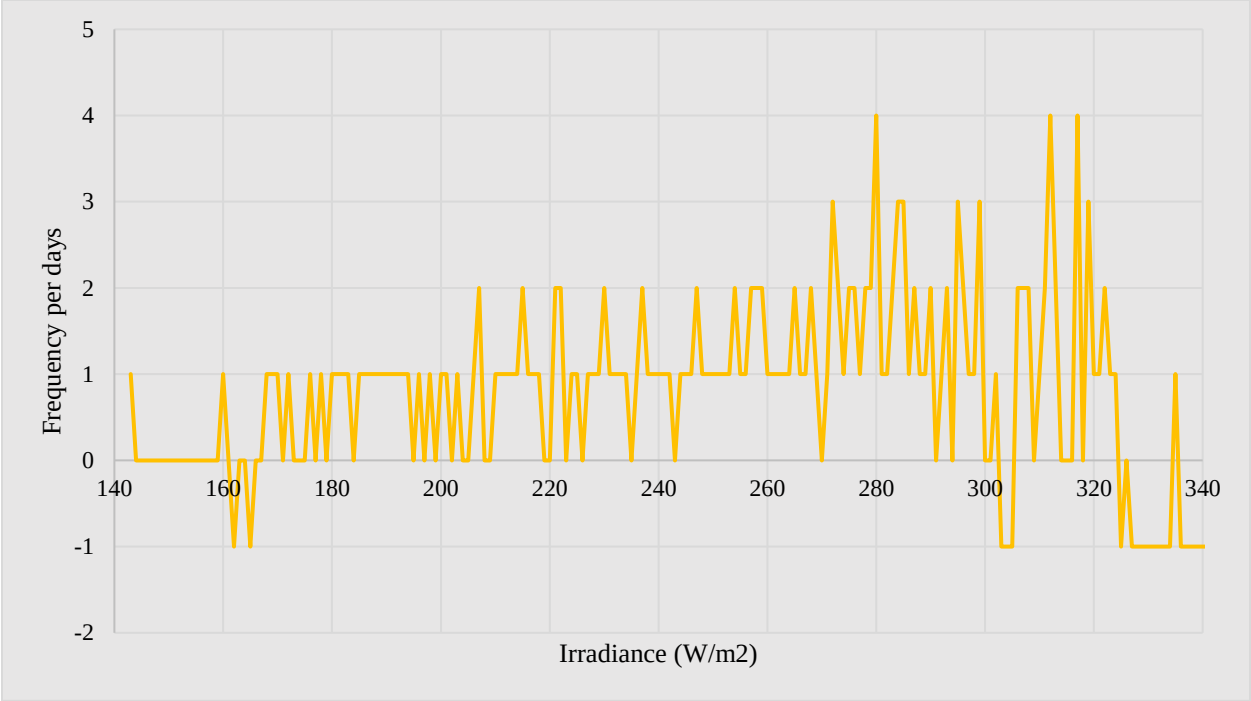
- **Solar Radiation Monthly**

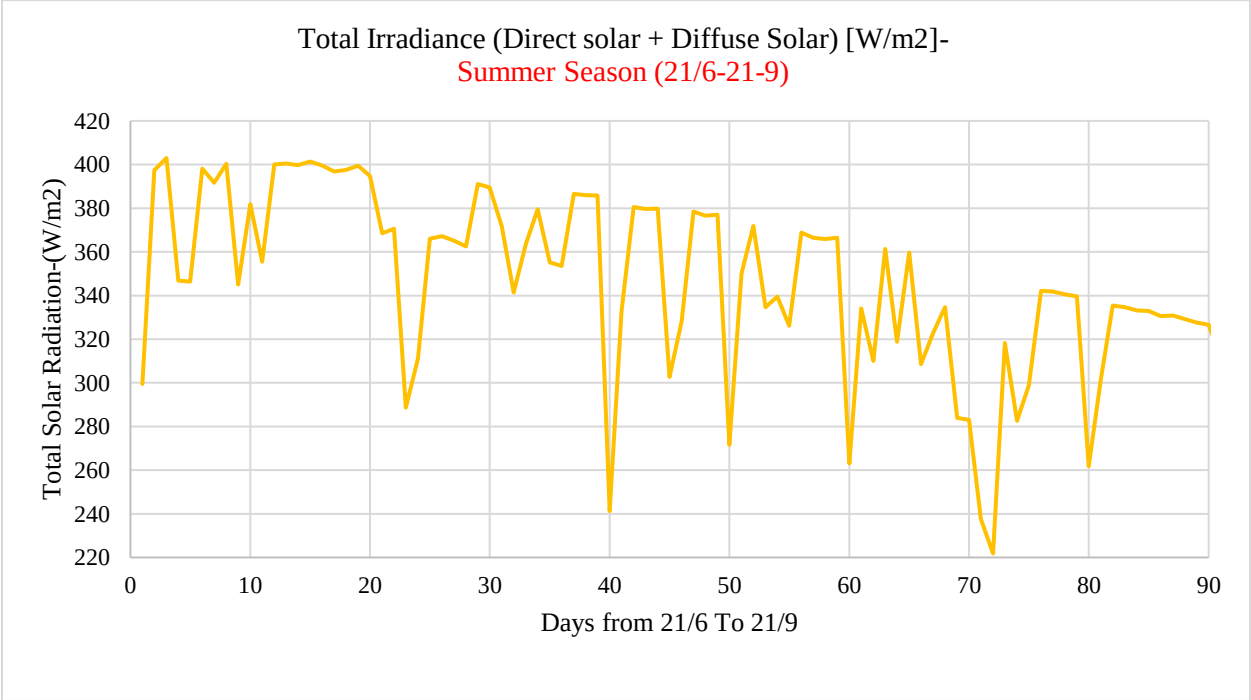


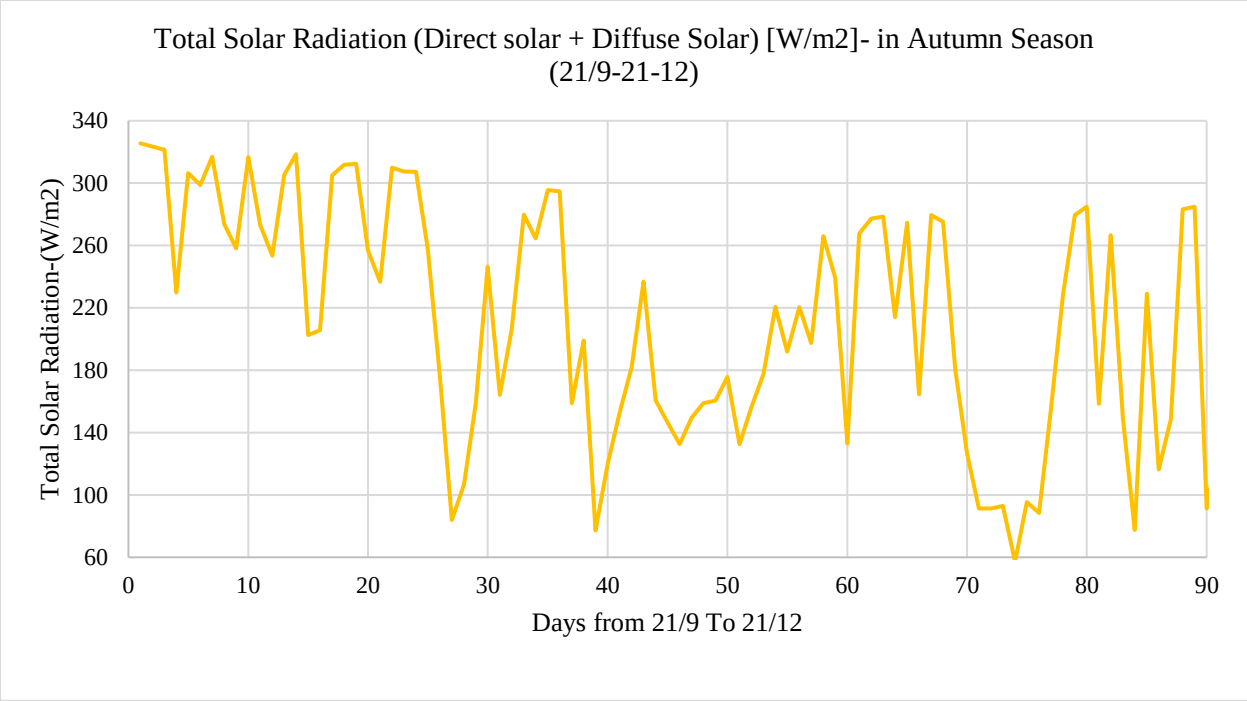


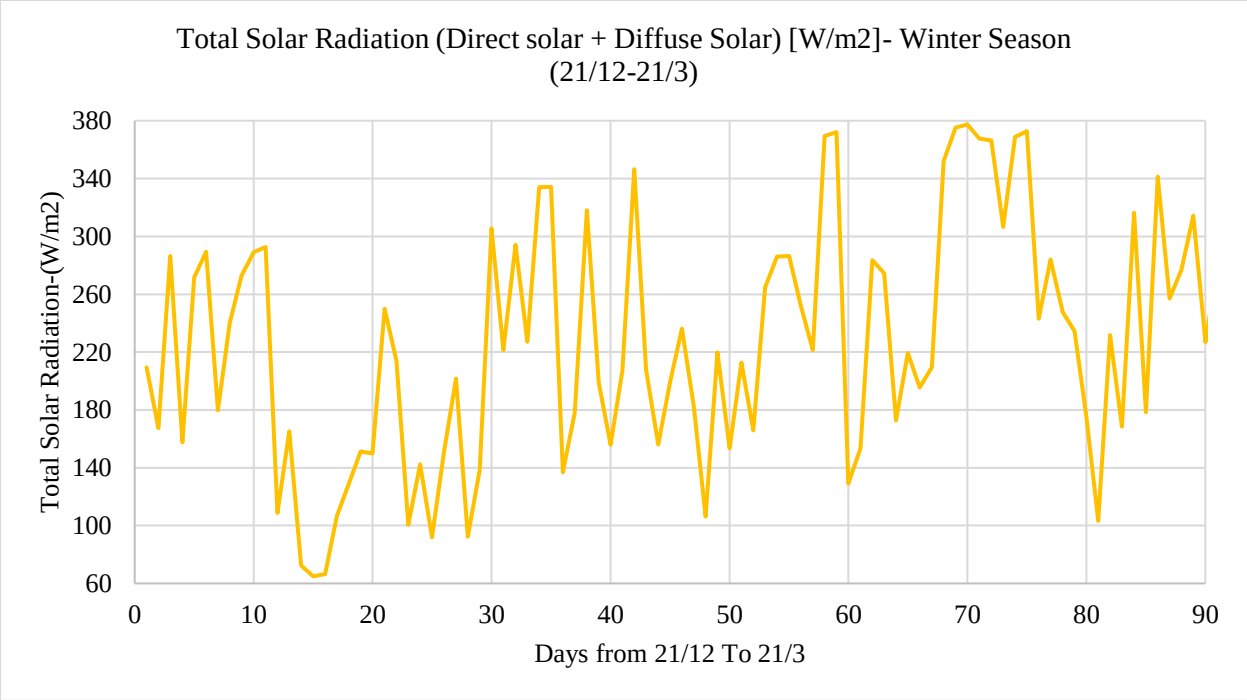
- **Solar Radiation by Seasons and frequency per days**



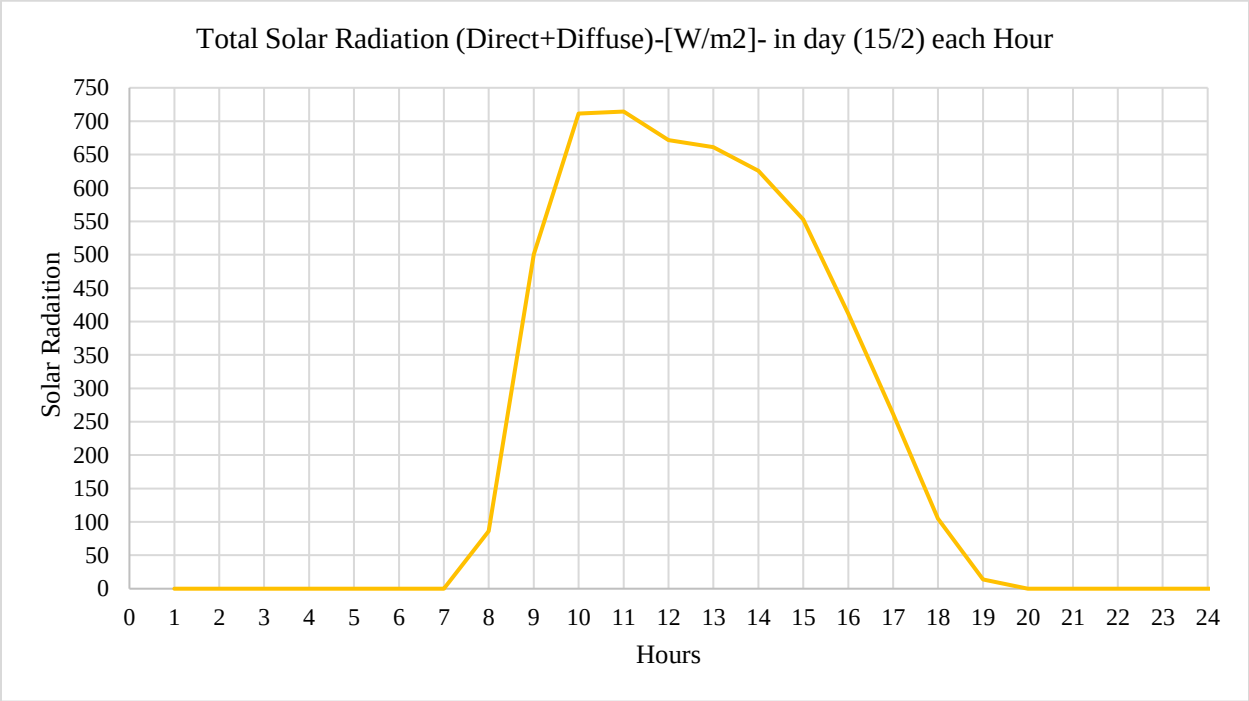

5
4
3
2
1
0
-1
-2
Frequency per days
140
160
180
200
220
240
260
280
300
320
340
Irradiance (W/m2)

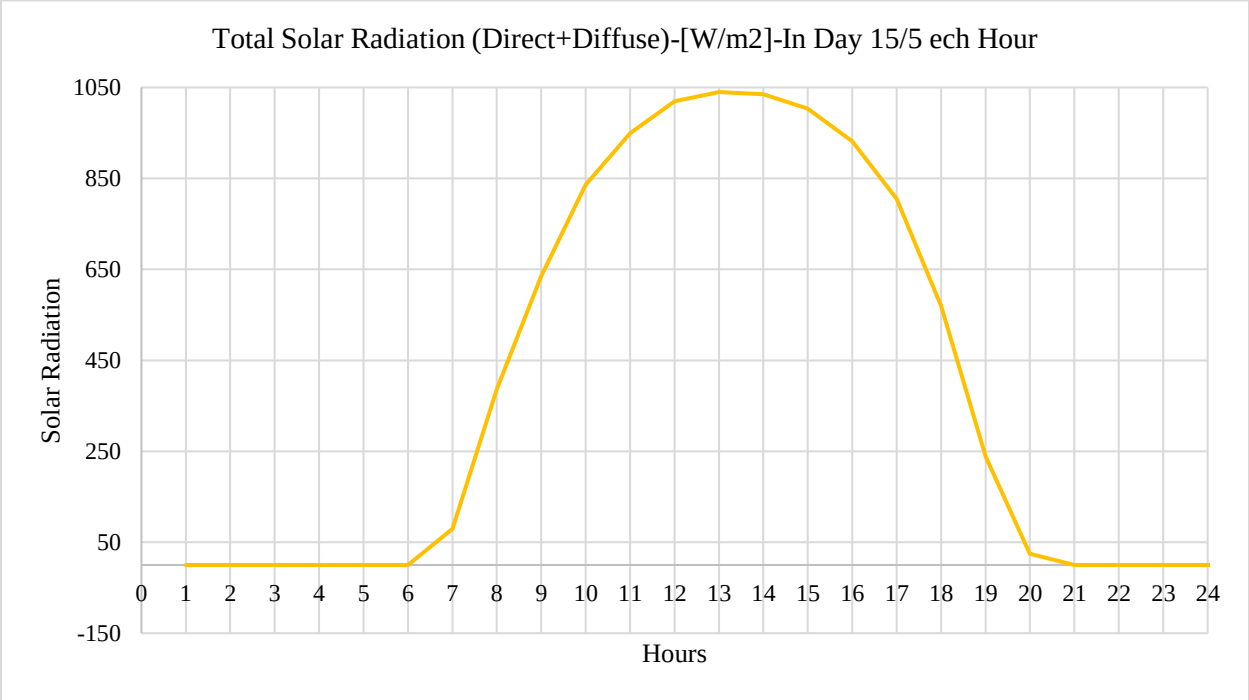

Total Irradiance (Direct solar + Diffuse Solar) [W/m2]-
Summer Season (21/6-21-9)
420
400
380
360
340
320
300
280
260
240
220
Total Solar Radiation-(W/m2)
0
10
20
30
40
50
60
70
80
90
Days from 21/6 To 21/9

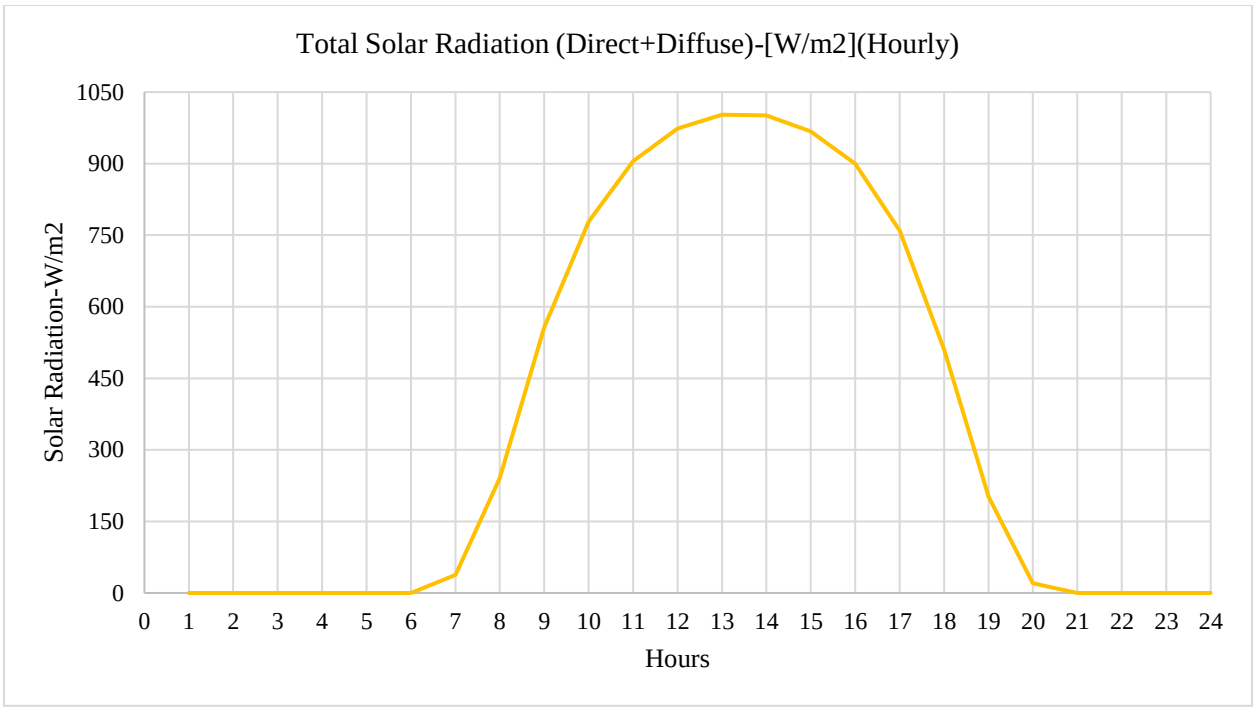

Total Solar Radiation (Direct solar + Diffuse Solar) [W/m2]- in Autumn Season (21/9-21-12)
Total Solar Radiation-(W/m2)
340
300
260
220
180
140
100
60
0
10
20
30
40
50
60
70
80
90
Days from 21/9 To 21/12

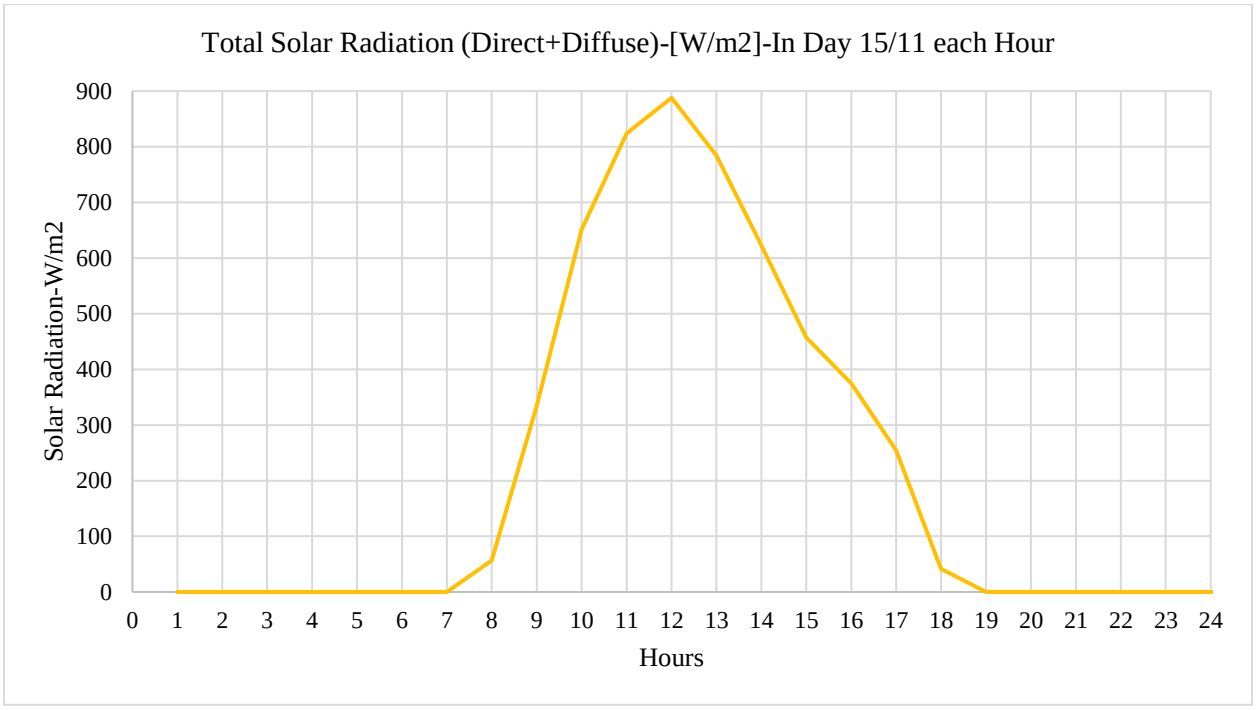

Total Solar Radiation (Direct solar + Diffuse Solar) [W/m2]- Winter Season (21/12-21/3)
Total Solar Radiation-(W/m2)
380
340
300
260
220
180
140
100
60
0
10
20
30
40
50
60
70
80
90
Days from 21/12 To 21/3

- Solar Radiation by Days






Total Solar Radiation (Direct+Diffuse)-[W/m2](Hourly)
Solar Radiation-W/m2
1050
900
750
600
450
300
150
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hours


Total Solar Radiation (Direct+Diffuse)-[W/m2]-In Day 15/11 each Hour
Solar Radiation-W/m2
900
800
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hours

5- MODEL – STONE MATERIAL

This model is for a building which is located in Cairo.

The dimension of this model is 5 m Length x 5 m Width x 4.5 m Height. It has one window with dimension 2m x 2m.

The weather file, which is used in BEST energy software to analyze this model, called IWEC.epw.

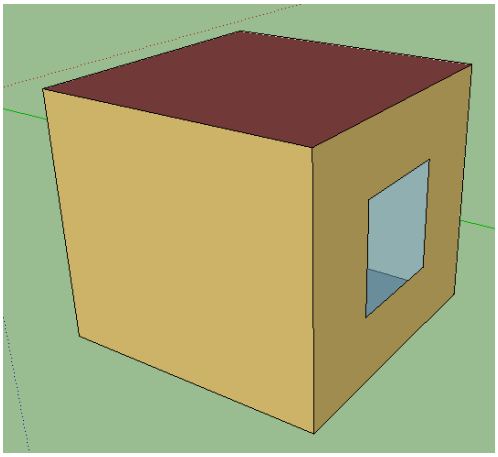


Fig. (1): Base Case

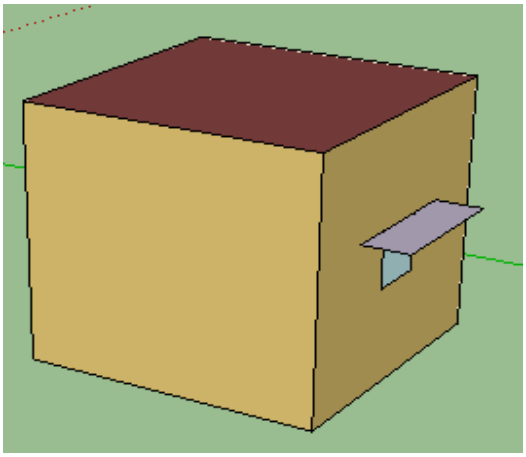
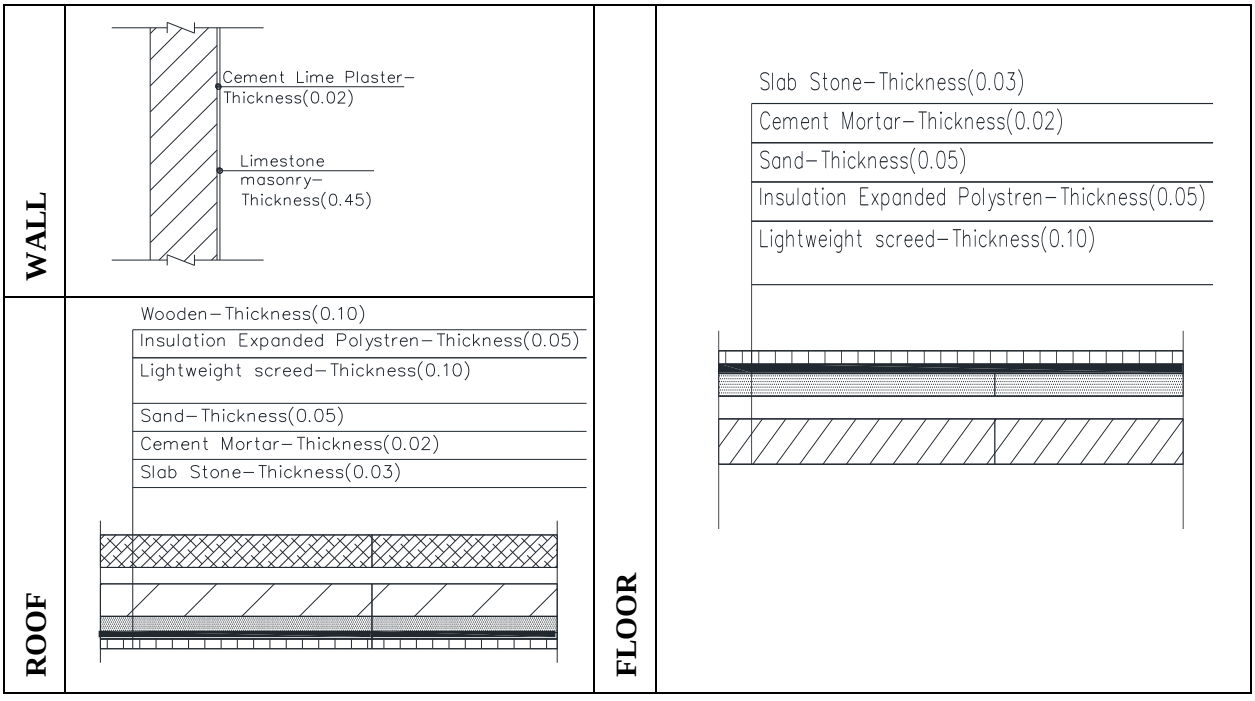


Fig. (2): Other Cases with Shading Device



- **Main parameters to be analyzed in order to understand the thermal comfort inside the building are:**
  - **Indoor Air Temperature -C**
  - **Relative Humidity -%**
  - **Ventilation Rate / Air velocity**

MATERIAL PROPERTIES FOR DATA INPUT OF BEST ENERGY SOFTWARE

- ***Note:***

(*) Number suggested by the Egyptian code of Energy

(#) Number suggested by "Natural Energy and Vernacular architecture- Principles and Examples with reference to hot arid climate" Hassan Fathy.

1- Case (1)-stone walls WITHOUT INSULATION in roof or floor

Opaque components								
Components	**Materials**	**Thickness (m)**	**Conductivity [W/mK]**	**Density [kg/m3]**	**Specific heat [J/kg K]**	**Thermal absorptance**	**Solar absorptance**	**Visible Absorptance**
Walls	Limestone masonry	0.45	0.79 (*)	1600 (*)	920	0.85 (#)	0.65 (#)	0.7
Ceiling	Wooden	0.10	0.14 (*)	660 (*)	1600	0.9	0.7	0.7
Floor	Stone Slab	0.03	1.4 (*)	2100 (*)	920	0.9	0.7	0.7
	Cement Mortar	0.02	0.719	1646	920	0.9	0.7	0.7
	Sand	0.05	0.93	1800	840	0.9	0.7	0.7
	Lightweight screed	0.10	0.083	600	880	0.9	0.7	0.7
OPENING COMPONENTS - DOORS								
Door	Wooden	0.05	0.13	500	1600	0.9	0.7	0.7
OPENING COMPONENTS - WINDOWS								

Components	**Materials**	**U-value W/m^2K**	**Solar heat gain coefficient**	**Visible transmittance**
Window	Single Glazed	4.7	0.8	0.7
THERMAL ZONE SETTING				
Num. of people	1 Person			

2- Case (2)-stone walls WITH INSULATION in roof or floor

Opaque components								
Components	**Materials**	**Thickness (m)**	**Conductivity [W/mK]**	**Density [kg/m3]**	**Specific heat [J/kg K]**	**Thermal absorptance**	**Solar absorptance**	**Visible Absorptance**
Walls	Limestone masonry	0.45	0.79 (*)	1600 (*)	920	0.85 (#)	0.65 (#)	0.7
Ceiling	Wooden	0.10	0.14 (*)	660 (*)	1600	0.9	0.7	0.7
	Expanded polystyrene	0.04	0.036	30	1340	0.9	0.7	0.7
	Lightweight screed	0.10	0.083	600	880	0.9	0.7	0.7
	Sand	0.05	0.93	1800	840	0.9	0.7	0.7
	Cement Mortar	0.02	0.719	1646	920	0.9	0.7	0.7
	Stone Slab	0.03	1.4 (*)	2100 (*)	920	0.9	0.7	0.7
Floor	Stone Slab	0.03	1.4 (*)	2100 (*)	920	0.9	0.7	0.7
	Cement Mortar	0.02	0.719	1646	920	0.9	0.7	0.7
	Sand	0.05	0.93	1800	840	0.9	0.7	0.7
	Expanded polystyrene	0.04	0.036	30	1340	0.9	0.7	0.7
	Lightweight screed	0.10	0.083	600	880	0.9	0.7	0.7
OPENING COMPONENTS - DOORS								
Door	Wooden	0.05	0.13	500	1600	0.9	0.7	0.7

OPENING COMPONENTS - WINDOWS				
Components	**Materials**	**U-value W/m^2K**	**Solar heat gain coefficient**	**Visible transmittance**
Window	Single Glazed	4.7	0.8	0.7

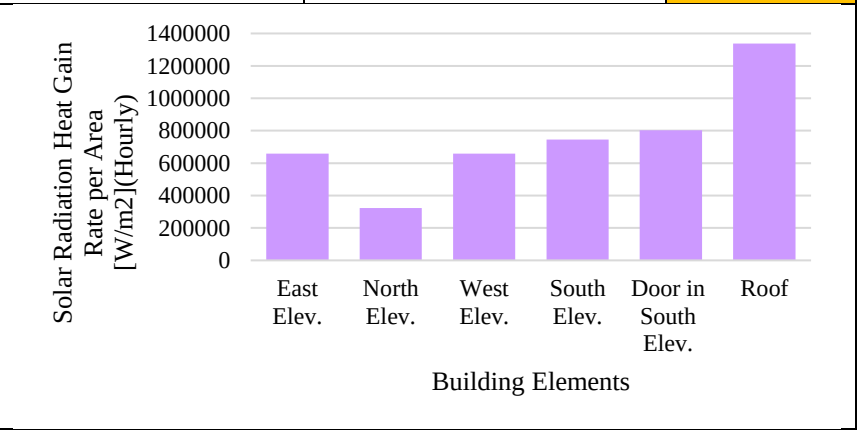
THERMAL ZONE SETTING	
No. of people	1 Person

DIFFERENCE BETWEEN THE OTHER CASES (FROM CASE (1) TO CASE (7)

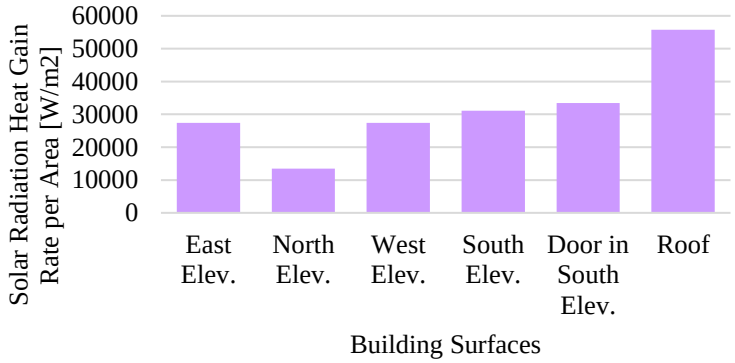
Cases	Wall	Roof	Floor	Windows (Dimension/Single or Double glazed)
Base - Case (1)	Stone 0.45m	Without Insulation	Without Insulation	Window (2m x 2m) Single Glazed
Case (2)	Stone 0.45m	**Expanded polystyrene (0.04 m)**	**Expanded polystyrene (0.04 m)**	Window (2m x 2m) Single Glazed
Case (3)	Stone 0.45m	Expanded polystyrene **(0.10 m)**	Expanded polystyrene **(0.10 m)**	Window (2m x 2m) **Double** Glazed
Case (4)	Stone 0.45m	Expanded polystyrene (0.10 m)	Expanded polystyrene (0.10 m)	Window (2m x 2m) Double Glazed **WITH Shading device 0.8m x 2.5m**
Case (5)	Stone 0.45m West, East, and south elevations are **Adiabatic**	Expanded polystyrene (0.10 m)- **Adiabatic**	Expanded polystyrene (0.10 m)	**Window (1.5mx1.5m)** Double Glazed WITH Shading device 0.8m x 2.5m
Case (6)- Best	**Stone 0.30m** West, and East elevations are **Adiabatic**	Expanded polystyrene (0.10 m)- **Adiabatic**	Expanded polystyrene (0.10 m)	**2 Windows in North and South elevations (1.5mx1.5m)** Double Glazed WITH Shading device 0.8m x 2.5m
Case (7)- Best	Stone 0.30m West, and East elevations are **Adiabatic**	Expanded polystyrene **(0.20 m)- Adiabatic**	Expanded polystyrene (0.10 m)	**2 Wind. in North and South elevations (1mx1 m)** Double Glazed WITH Shading device 0.8m x 2.5m

BUILDING PARAMETERS OF DIFFERENT CASES

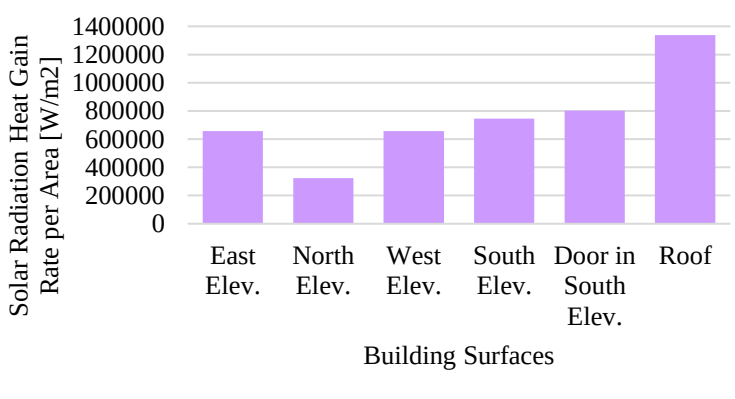
8- Case (1)

Building Parameters	Abbrev.	Equation	Calculation	Inquires
Surface Floor Area	S.F.A	Length x Width	5*5=**25m^2**	
Volume	Vol.	Length x Width x Height	5*5*4.5(Hight)= **112.5m^3**	
Window to Wall Ratio	WWR	WWR=Window area/Gross external wall area	*East= No windows *West= No windows * South= No windows * North= (2m*2m)/(4.5m*5m)= **0.17**	Should I do the same method in the South elevation that has a door?
Wall to Floor Ratio	W/F	Total Area of the walls/ Floor area	W/F=4*(4.5*5)/25=**3.6**	Should I calculate the North elevation without window area?
Surface Area to Volume Ratio	S/V	(Area of 4 walls + Area of floor and roof) / Volume	140/112.5=**1.24**	
Total Heat Gain [J]	Q		**748800 J**	Why it is constant number in all cases?
Total Solar Radiation heat gain W/m^2	U= **4524674 W/m^2**			

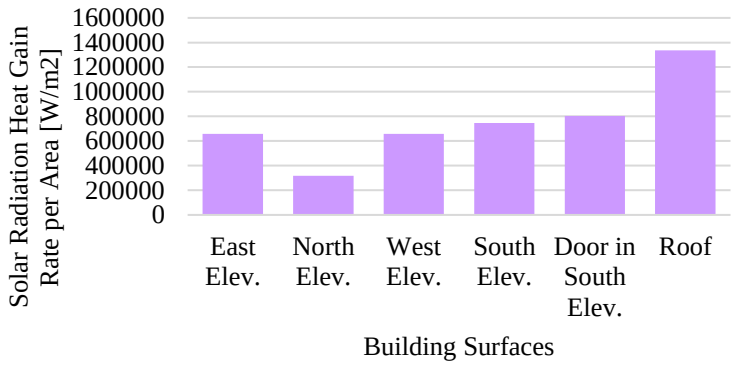
9- Case (2)

Building Parameters	Abbrev.	Equation	Calculation	Inquires
Surface Floor Area	S.F.A	Length x Width	**25m^2**	
Volume	Vol.	Length x Width x Height	**112.5m^3**	
Window to Wall Ratio	WWR	WWR=Window area/Gross external wall area	North= **0.17**	
Wall to Floor Ratio	W/F	Total Area of the walls/ Floor area	**3.6**	
Surface Area to Volume Ratio	S/V	(Area of 4 walls + Area of floor and roof) / Volume	**1.24**	
Total Solar Radiation heat gain W/m^2	U = **188528.1 W/m^2**			

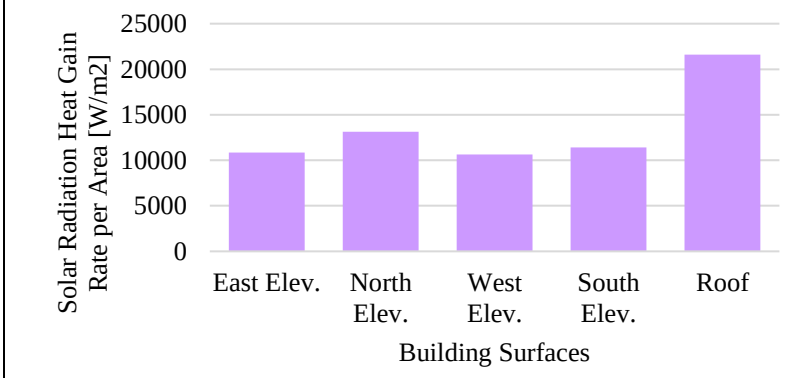
10- Case (3)

Building Parameters	Abbrev.	Equation	Calculation	Inquires
Surface Floor Area	S.F.A	Length x Width	5*5=**25m^2**	
Volume	Vol.	Length x Width x Height	**112.5m^3**	
Window to Wall Ratio	WWR	WWR=Window area/Gross external wall area	* North= **0.17**	
Wall to Floor Ratio	W/F	Total Area of the walls/ Floor area	**3.6**	
Surface Area to Volume Ratio	S/V	(Area of 4 walls + Area of floor and roof) / Volume	140/112.5=**1.24**	
Total Solar Radiation heat gain W/m^2	U= **4524674 W/m^2**			

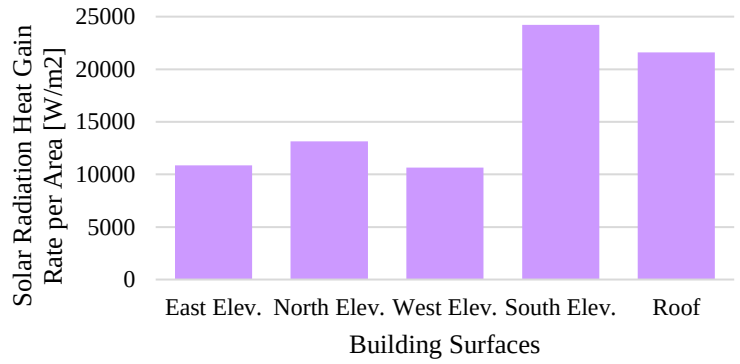
11- Case (4)

Building Parameters	Abbrev.	Equation	Calculation	Inquires
Surface Floor Area	S.F.A	Length x Width	5*5=**25m²**	
Volume	Vol.	Length x Width x Height	**112.5m³**	
Window to Wall Ratio	WWR	WWR=Window area/Gross external wall area	* North= **0.17**	
Wall to Floor Ratio	W/F	Total Area of the walls/ Floor area	**3.6**	
Surface Area to Volume Ratio	S/V	(Area of 4 walls + Area of floor and roof) / Volume	140/112.5=**1.24**	
Total Solar Radiation heat gain W/m²	U= **4518276 W/m²**			

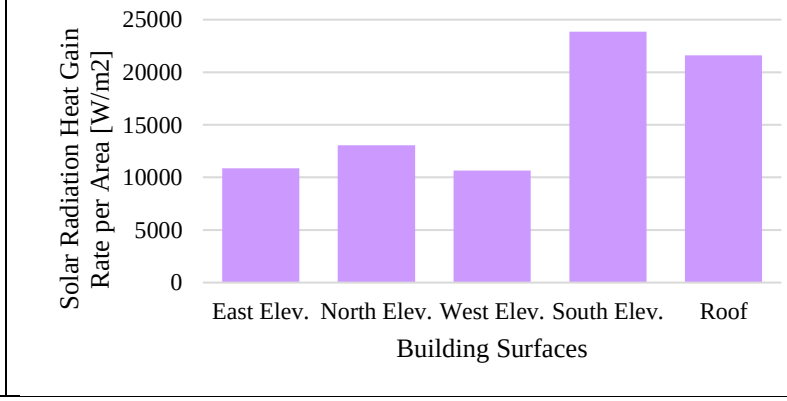
12- Case (5)

Building Parameters	Abbrev.	Equation	Calculation	Inquires
Surface Floor Area	S.F.A	Length x Width	5*5=**25m²**	
Volume	Vol.	Length x Width x Height	**112.5m³**	
Window to Wall Ratio	WWR	WWR=Window area/Gross external wall area	*** North= (1.5m*1.5m)/22.5 = 0.1**	
Wall to Floor Ratio	W/F	Total Area of the walls/ Floor area	**3.6**	
Surface Area to Volume Ratio	S/V	(Area of 4 walls + Area of floor and roof) / Volume	140/112.5=**1.24**	
Total Solar Radiation heat gain W/m²	U= **67661.27 W/m²**			

13- Case (6)

Building Parameters	Abbrev.	Equation	Calculation	Inquires
Surface Floor Area	S.F.A	Length x Width	5*5=**25m^2**	
Volume	Vol.	Length x Width x Height	**112.5m^3**	
Window to Wall Ratio	WWR	WWR=Window area/Gross external wall area	* **North= 0.1** * **South= 0.1**	
Wall to Floor Ratio	W/F	Total Area of the walls/ Floor area	**3.6**	
Surface Area to Volume Ratio	S/V	(Area of 4 walls + Area of floor and roof) / Volume	140/112.5=**1.24**	
Total Solar Radiation heat gain W/m^2	U= **80449.07 W/m^2**			

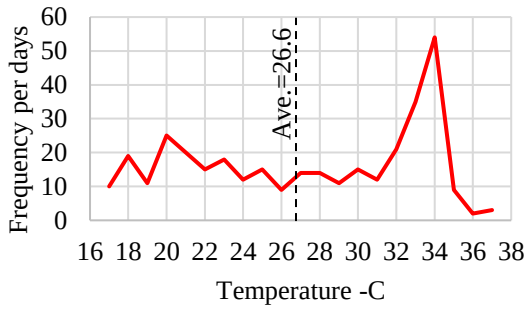
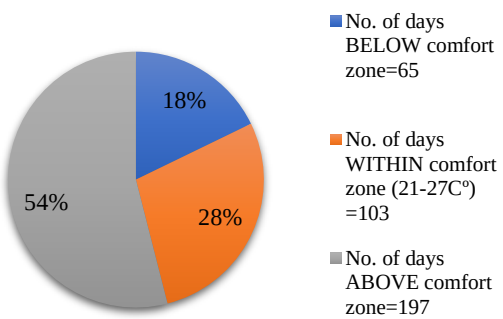
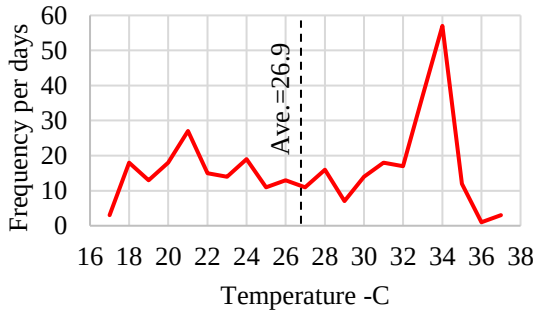
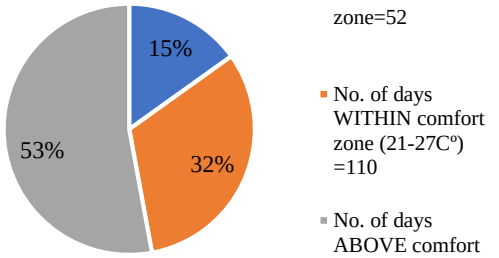
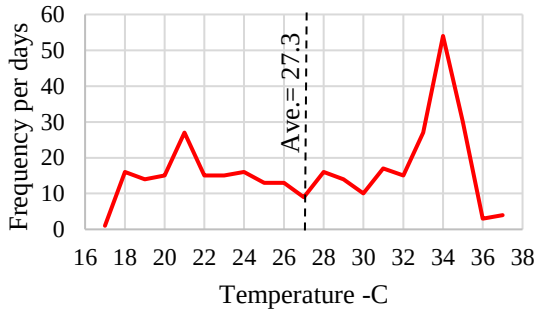
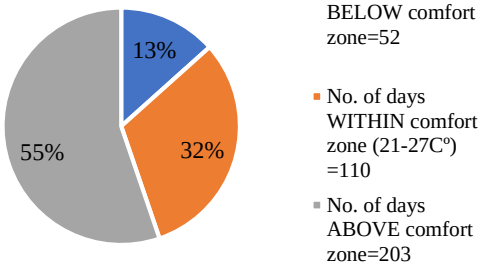
14- Case (7)

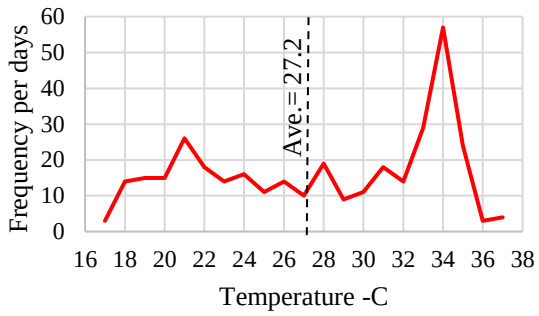
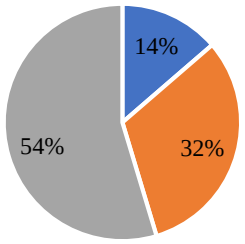
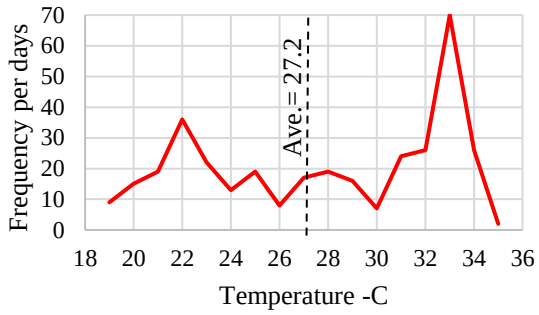
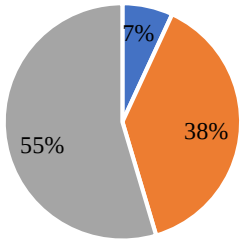
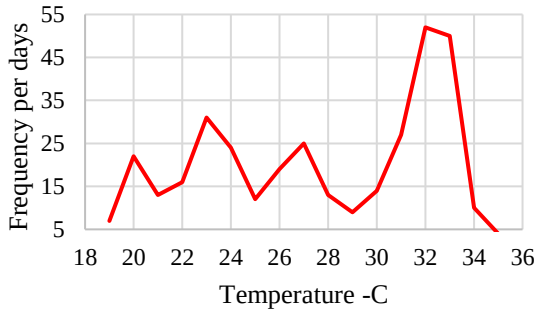
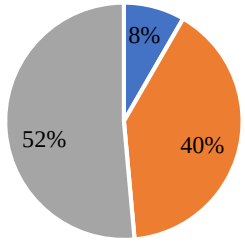
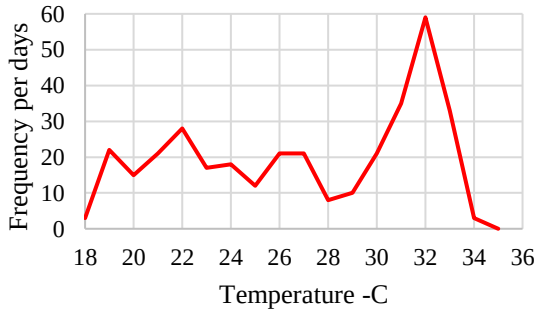
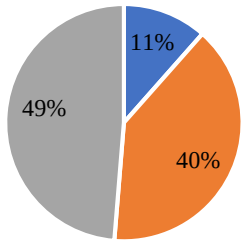
Building Parameters	Abbrev.	Equation	Calculation	Inquires
Surface Floor Area	S.F.A	Length x Width	5*5=**25m^2**	
Volume	Vol.	Length x Width x Height	**112.5m^3**	
Window to Wall Ratio	WWR	WWR=Window area/Gross external wall area	* **North= 0.04** * **South= 0.04**	
Wall to Floor Ratio	W/F	Total Area of the walls/ Floor area	**3.6**	
Surface Area to Volume Ratio	S/V	(Area of 4 walls + Area of floor and roof) / Volume	140/112.5=**1.24**	
Total Solar Radiation heat gain W/m^2	U= **80020.55 W/m^2**			

COMPARISON BETWEEN DIFFERENT CASES IN TERMS OF INDOOR AIR TEMPERATURE- (Cº)

Cases	Climatic parameters	Periods	Ranges				Day Hours Overheated- (Dh_h)= SUM (21-Ta Cº)	Day Hour Cold- (Dh_c) = SUM (Ta-26 Cº)
			Average	Average Cycle variation		Average Standard Deviation		
				Absolute MIN	Absolute MAX			
Case (1)	Indoor Air Temp.– (Cº)	Annual	26.687	16.21	36.82	5.88	-2075.67	250.67
Case (2)	Indoor Air Temp.–	Annual	26.98	16.73	36.57	5.74	-2184.34	359.34
Case (3)	Indoor Air Temp.– (Cº)	Annual	27.34	16.88	36.98	5.80	-2315.36	490.36
Case (4)	Indoor Air Temp.– (Cº)	Annual	27.25	16.78	36.85	5.79	-2281.92	456.92
Case (5)	Indoor Air Temp.– (Cº)	Annual	27.21	18.56	34.34	4.86	-2268.73	443.73
Case (6)	Indoor Air Temp.– (Cº)	Annual	27.15	18.08	34.66	4.63	-2247.8	422.8
Case (7)	Indoor Air Temp.– (Cº)	Annual	26.49	17.61	34.11	4.78	-2004.99	179.99

IMPACT OF ADDING DIFFERENT TEQUNIQUES ON THE ENHANCEMENTS OF THE INDOOR AIR TEMPERATURE (Cº) FOR THE SAME MODLE

	Frequency plot of Indoor Ta-(Cº)	No. of days Above, Within, and Below Comfort zone
Case (1)		
Case (2)-Insulation		
Case (3)- Double Glazed		

Case (4)- Shading		 No. of days BELOW comfort zone=47 No. of days WITHIN comfort zone (21-27Cº) =109 No. of days ABOVE comfort zone=188
Case (5)- Adiabatic		 No. of days BELOW comfort zone=52 No. of days WITHIN comfort zone (21-27Cº) =134 No. of days ABOVE comfort zone=190
Case (6)- Thermal mass		 No. of days BELOW comfort zone=29 No. of days WITHIN comfort zone (21-27Cº) =140 No. of days ABOVE comfort zone=179
Case (7)-Ventilation		 No. of days BELOW comfort zone=40 No. of days WITHIN comfort zone (21-27Cº) =138 No. of days ABOVE comfort zone=169