CME LIVE OPEN ACCESS

Journal of
Advances in Civil and Mechanical Engineering

Research Article

Projections of Greenhouse Heating and Ventilation Requirements in the New Valley Under Climate Change Scenarios

Mahmoud A Medany[1*], Ghada U Radwan[2] and Milad H Zaki[1]

[1]*Horticulture Research Institute, Agricultural Research Center, Egypt.*

[2]*Central Laboratory for Agricultural Climate, Agricultural Research Center, Egypt.*

Corresponding Author: Mahmoud A Medany, Horticulture Research Institute, Agricultural Research Center, Egypt.

Received: 2024 Aug 01 **Accepted:** 2025 Feb 18 **Published:** 2025 Feb 28

Abstract

Egyptian greenhouse megaproject is expanding all over the country in the recent years. Vegetable optimum growth under greenhouses requires temperature range from 15-32 °C. This study was conducted in Kharga Oasis, the New Valley Governorate, Egypt, in order to investigate the heat requirements and number of mechanical ventilation hours needed for vegetable production under greenhouses during the reference year of 2023-2024, compared to historical period of 1995-2014, and under climate change projections. Four future scenarios were used: SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) according to the IPCC sixth Assessment Report, with four projection intervals: 2020-2039, 2040-2059, 2060-2079, and 2080-2099. Hourly data was used for the estimation of heat requirements (kwh) when temperatures were lower than 15°C, in a greenhouse of 8.5m width, and 40m length and for the number of hours needed for ventilation if temperatures exceed 28, 30, 23 and 35 °C. The results indicated that total heating requirements decreased gradually from 755.1 kCal (≈0.88 kWh) for the actual estimated (2023-2024) down to 66.1 (≈0.07 kWh) kCal by the years 2080-2099 under SSP5-8.5 scenario. Seasonally, winter months required heating, while the rest of the year minimum temperatures were above 15°C set point. Ventilation hours increased to reach 3564 hours/year under the SSP5-8.5 scenario for the projected time intervals 2080-2099. These results indicate the need for vital attention in constructing new greenhouses, and to find the best cultivation dates for coping with climate change temperature rise till the end of the century.

Keywords: Heat Estimation, Downscaling, Smart Management, Climate Modification

1. Introduction

The location of Egypt among the driest areas of the globe with the highest solar intensities that attributed to its proximity to the globally latitudinal belt of the arid nature of its climate according to the Köppen classification [1]. With the implementation of mega greenhouse project of 100k Feddan that the country adopted in, the anticipated climatic conditions for the future may alter the ventilation needs and heating requirements as of hotter conditions [2,3]. Climate change will have a wide range of negative impacts in all activities, including agriculture, with high cost of adaptation, with stronger negative effects on developing countries [4,5]. There are two approaches for greenhouse cultivation: high-tech controlled greenhouses, and simple construction without control or with minimum controlled screenhouse [6]. As climate change will be associated with generally higher temperatures, it is to assume that this trend of increasing areas of simple greenhouses will continue in countries with mild winter climates [6]. Unpredictable climatic conditions and the consumer expectations for all year-round fresh vegetables will enhance the trend of intensive cultivation in temperate areas as well [7,8].

The most grown species in greenhouses are vegetables with medium thermal requirements (tomato, pepper, cucumber, melon, watermelon, marrow, green bean, eggplant); the aim is to extend the growing calendars beyond the conventional open-air cultivation season [9]. The indicated species, traditionally grown in the warm season, are adapted to average ambient temperatures ranging from 17 to 28 °C, with limits of 12 ºC (minimum) and 32 ºC (maximum). They are sensitive to the cold and suffer irreversible damage with frosts [9,10]. Most of the studies related to adaptation to high or low temperatures under greenhouses are conducted in Northern Mediterranean countries, with high-tech capabilities [6]. There are different determining factors leading to different environmental footprints compared to the existing greenhouse vegetable production management scenarios. Climate change stresses and potential adaptation and mitigation measures are mentioned to be a new thrust and direction [11]. Therefore, this study was conducted to investigate greenhouse heat requirements as well as the number of ventilation hours needed for vegetable production in greenhouses under climate change conditions in Kharga, New Valley, compared to the actual year of 2023-2024.

2. Materials and Methods

2.1 Methodology

The work examined the greenhouse heating requirements and ventilation hours needed in a prolonged high temperature during the day most of the days, and low temperatures during nights of winter season in Kharga Oasis, New Valley Governorate. The study aims to explore the changes in heating or ventilation needs in relation to the anticipated climate change compared to the current conditions. This involved the examination of historical climate data covering the years 1995-2014, as a reference period, and projected data from 2020 up to 2099, considering monthly minimum, average and maximum air temperatures. The actual hourly data for the same parameters covered the period from June 2023 to May 2024, were obtained from automatic weather station of the Central Laboratory for Agricultural Climate, and data were updated and downloaded remotely using FieldClimate® platform. Projected data were downscaled to hourly data using Microsoft® Excel® (Version 2406). for the four projected time intervals, under the four scenarios. The four different climate scenarios used are: SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5 w/m2 that were based on ensemble of 15 global general circulation models. The basic spatial datasets for current and future climate are implemented on a global scale using a resolution of 0.25° by 0.25° downloaded from the World Bank Knowledge Portal [12].

2.2 Study Area

The study area is in North of Karga Oasis Airport, The New Valley Governorate, Southwestern Egypt, at 25° 29' 53.448'' N and 30° 35' 42.216'' E. The area is surrounded by a typical Saharan desert, with aridity, high summer daytime temperature, large diurnal temperature variation, low relative humidity and high solar radiation [13]. As a capital of the New Vally Governorate, with great potential for newly land reclamation projects since it occupies more than 44% of Egypt. The location has ten greenhouses for vegetable production, with similar numbers in the neighboring farms. The greenhouse used was 8.5 x 40m, with photo voltaic (PV) solar panels installed on the roof that was conducted as part a project "Climate-smart Agriculture for Enhancing the Sustainability of Greenhouses Under Climate Change" funded by the Science, Technology & Innovation Funding Authority (STDF) in Egypt. The PV panels were made of different arrangements and structure as well as the commercial type. The total power produced by the system was six kWh, that could run fans, cooling pads, and irrigation during the day [14].

2.3 Actual Air Temperature

Two automatic weather stations, belonging to the Central Laboratory for Agricultural Climate, Agricultural Research Center, were installed in the study location. The stations read and store hourly data of air and soil temperature, relative humidity, solar radiation, wind speed, total rainfall and leaf wetness. The sensors make the measurement each minute and store the 60 readings to process the average or the total of the hour for hourly retrieval. Hourly data, with the date and time of the beginning of each hour. Hourly data were downloaded remotely using FieldClimate® platform. Minimum, average, and maximum hourly data were used in this study for the period from beginning of June 2023 to end of May 2024. The monthly averages of hourly data are illustrated in Table (1).

Month	Minimum Air Temp (°C)		Average Air Temp. (°C)		Maximum Air Temp. (°C)	
	Open	GH	Open	GH	Open	GH
Jan-24	4.0	2.2	13.9	15.1	27.3	29.6
Feb-24	2.8	2.3	15.1	16.6	31.1	34.0
Mar-24	8.1	8.1	20.7	22.3	36.1	41.5
Apr-24	11.7	12.2	25.4	27.7	42.1	47.6
May-24	14.8	14.9	27.0	28.3	41.7	46.2
Jun-23	20.1	20.5	32.6	34.5	47.0	50.7
Jul-23	21.0	21.3	32.9	34.9	44.0	48.3
Aug-23	21.6	23.9	33.3	34.8	45.9	50.4
Sep-23	19.7	17.9	30.5	32.5	45.8	48.5
Oct-23	15.7	16.0	25.2	28.0	37.2	42.6
Nov-23	8.0	7.9	21.3	23.6	34.4	39.2
Dec-23	7.9	5.9	16.2	18.0	28.0	31.4

Table 1: Monthly Minimum, Average, and Maximum Air Temperatures in the Open Field (open) and Greenhouse (GH) from June 2023 to May 2024

2.4. Projected Air Temperatures

Previous set of climate projections was based on those suggested in the Fifth Assessment Report (AR5) of the Intergovernmental Pannel for Climate Change (IPCC). The AR5 drew four main scenarios, known as Representative Concentration Pathways [15-17]. The RCPs were identified by their radiative forcing reached at the year 2100, going from 2.6, 4.5, 6.0 to 8.5 W/m2. The latest IPCC report (IPCC AR6, 2021) presented model simulations from Coupled Model Intercomparison Project using a new range of scenarios based on Shared Socio-economic Pathways [18,19]. The set of SSPs scenarios established a matrix of global forcing levels and socio-economic storylines [19]. Climate projection data is modeled data from, overseen by the World Climate Research Program. Data presented is CMIP6, derived from the Sixth phase of the CMIPs. The CMIPs form the data foundation of the IPCC Assessment Reports. CMIP6 supports the IPCC's Sixth Assessment Report. Data is presented at a 0.25º x 0.25º (25km x 25km) resolution. In this study, four climate projection scenarios were identified to be used for climate change studies [19,20]. SSP1-2.6 for sustainable pathways, SSP2-4.5 for middle-of-the-road, SSP3-7.0 for regional rivalry, and SSP5-8.5 for fossil fuel-rich development. A brief description of the nine is shown in Table (2).

Scenario	Description
SSP1-1.9	Holds warming to 1.5°C above 1850–1900 in 2100 and implied net zero CO2 emissions around the middle of the century.
SSP1-2.6	Stays below 2.0°C warming relative to 1850–1900 in 2100 and implied net zero CO2 emissions in the second half of the century.
SSP2-4.5	CO2 emissions remaining around current levels until the middle of the century. The SR1.5 assessed temperature projections for NDCs to be between 2.7°C and 3.4°C by 2100.
SSP3-7.0	CO2 emissions roughly double from current levels by 2100. SSP3-7.0 has particularly high non-CO2 emissions, including high aerosols emissions.
SSP4-3.4	A scenario between SSP1-2.6 and SSP2-4.5.
SSP4-6.0	The end-of-century nominal radiative forcing level of 6.0 W m–2.
SSP3-7.0	A variation of the intermediate-to-high reference scenario with mitigation of CH4.
SSP5-3.4	Unconstrained emissions growth in a fossil fuel-intensive setting until 2040 and then implements the largest net negative CO2 emissions to reach SSP1-2.6.
SSP5-8.5	CO2 emissions roughly double from current levels by 2050.

Table 2: Brief description of the Nine SSP Scenarios, Developed for the Sixth Assessment Report of the IPCC (IPCC AR6, 2021)

The projection data were downloaded from the World Bank Knowledge Portal, with the following specifications [12].

- Area of focus: Middle East and North Africa.
- Collection: cmip6-x0.25.
- Data type: climatology.
- Variables: Average Mean Surface Air Temperature, Average Maximum Surface Air Temperature, and Average Minimum Surface Air Temperature.
- Product: Anomaly.
- Aggregation: Monthly.
- Time Interval: 2020-2039, 2040-2059, 2060-2079, and 2080-2099.
- Percentile: Median or 50th Percentile of the Multi-Model Ensemble.
- Scenario: SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5.
- Model: Multi-Model Ensemble.
- Model Calculation: All.
- Download: Excel.

After downloading air temperature data for the four time-projection intervals, and four scenarios, all data were downscaled to hourly data in reference to the actual hourly data for 2023/2024 using Microsoft® Excel® (Version 2406). Monthly minimum and maximum air temperature anomalies are shown in Tables 3 and 4.

Season	Projection Scenario				Projection Scenario			
	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
	2020/2039				2060-2079			
January	0.78	0.81	0.86	0.82	1.18	1.78	2.40	2.96
February	0.93	0.98	0.77	0.92	1.22	1.96	2.38	2.99
March	0.89	0.93	0.82	0.86	1.21	1.86	2.29	3.00
April	0.82	0.73	0.74	0.81	1.26	1.90	2.35	2.88
May	0.93	1.00	1.07	1.17	1.44	2.10	2.76	3.40
June	0.99	1.09	1.06	1.19	1.62	2.22	3.05	3.79
July	1.11	1.20	1.17	1.36	1.68	2.50	3.41	4.32
August	1.21	1.43	1.38	1.51	1.85	2.80	3.79	4.72

September	1.06	1.23	1.18	1.34	1.69	2.53	3.39	4.36
October	1.08	1.00	1.01	1.27	1.54	2.36	3.10	4.00
November	1.08	1.06	1.01	1.19	1.39	2.27	2.89	3.63
December	0.97	1.02	0.86	1.08	1.22	2.04	2.48	3.18
	2040-2059				**2080-2099**			
January	1.15	1.26	1.63	1.76	0.92	1.99	3.31	4.40
February	1.08	1.42	1.56	1.84	1.23	2.21	3.42	4.37
March	1.08	1.43	1.43	1.85	1.23	2.22	3.26	4.32
April	1.10	1.34	1.48	1.95	1.11	2.34	3.45	4.33
May	1.28	1.65	1.88	2.16	1.32	2.43	3.82	5.06
June	1.41	1.76	2.00	2.42	1.27	2.64	4.15	5.38
July	1.57	2.04	2.22	2.71	1.52	2.99	4.78	6.21
August	1.76	2.12	2.40	3.02	1.67	3.29	5.17	6.79
September	1.68	2.02	2.27	2.62	1.59	2.99	4.72	6.17
October	1.54	1.71	2.01	2.43	1.21	2.87	4.31	5.56
November	1.39	1.59	1.89	2.37	1.21	2.64	4.04	5.53
December	1.33	1.53	1.63	2.08	1.10	2.38	3.76	4.97

Table 3: Minimum Monthly Air Temperature Anomalies Under Four Scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5) During Four Time-Intervals (2020-2039, 240-2059, 260-2079, and 2080-2099). This Represents the Projected Average Single-Day Minimum Value of the Daily Minimum Temperatures Over the Data Aggregation Period

Season	**Projection Scenario**				**Projection Scenario**			
	SSP1-2.6	**SSP2-4.5**	**SSP3-7.0**	**SSP5-8.5**	**SSP1-2.6**	**SSP2-4.5**	**SSP3-7.0**	**SSP5-8.5**
	2020/2039				**2060-2079**			
January	0.70	0.74	0.77	0.73	1.18	1.64	2.29	2.76
February	0.91	1.00	0.72	0.92	1.17	1.93	2.28	2.83
March	0.89	0.86	0.84	0.84	1.23	1.82	2.27	2.95
April	0.82	0.73	0.71	0.82	1.28	1.91	2.30	2.70
May	0.94	0.96	1.09	1.19	1.40	2.14	2.67	3.36
June	0.99	1.05	1.05	1.20	1.62	2.26	3.05	3.74
July	1.13	1.24	1.19	1.40	1.76	2.56	3.46	4.41
August	1.20	1.40	1.38	1.49	1.84	2.80	3.73	4.59
September	1.08	1.19	1.13	1.29	1.69	2.47	3.29	4.19
October	1.08	0.97	0.93	1.18	1.51	2.29	3.01	3.79
November	1.06	1.00	1.01	1.15	1.34	2.26	2.69	3.38
December	0.97	0.96	0.76	1.00	1.15	1.91	2.28	2.95
	2040-2059				2080-2099			
January	1.11	1.19	1.49	1.61	0.97	1.93	3.16	4.26
February	1.05	1.36	1.53	1.78	1.24	2.21	3.37	4.29
March	1.05	1.43	1.39	1.88	1.27	2.23	3.22	4.23
April	1.07	1.30	1.46	1.96	1.15	2.34	3.31	4.20
May	1.26	1.62	1.86	2.13	1.37	2.40	3.74	5.00
June	1.42	1.74	2.02	2.38	1.31	2.61	4.11	5.28
July	1.64	2.01	2.27	2.79	1.63	3.11	4.92	6.22
August	1.80	2.09	2.32	2.96	1.74	3.30	5.17	6.69
September	1.62	1.99	2.22	2.52	1.61	2.93	4.62	5.92
October	1.51	1.57	1.92	2.33	1.21	2.76	4.12	5.29

November	1.36	1.50	1.78	2.30	1.24	2.50	3.80	5.18
December	1.30	1.49	1.56	1.98	1.11	2.29	3.52	4.67

Table 4: Maximum Monthly Air Temperature Anomalies Under Four Scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5) During Four Time-Intervals (2020-2039, 240-2059, 260-2079, and 2080-2099). This Represents the Projected Average Single-Day Maximum Value of the Daily Maximum Temperatures Over the Data Aggregation Period

2.5. Heating requirement calculations

Most undesired heat loss from a greenhouse occurs by conduction (Qc) and infiltration (Qi) [21]. The greenhouse heat loss by conduction, Qc, (Watts) is estimated by the following equation:

Qc = UA (Ti- To) (1)

Where :

U =overall heat transfer coefficient, w/m^2 = 6.8 for polyethylene plastic;

A =exposed surface area, m^2; [A = area of front and rare faces + area of greenhouse cover. Front and rare faces = 56.75m^2. Area of greenhouse cover = Greenhouse length (40 m) x arch length (12m)= 40 x 12 = 480m^2. Accordingly, A = 56.75+480= 536.75m^2].

Ti =inside air temperature, °C [the desired temperature set point for most greenhouse crops is 15°C];

To =outside air temperature, °C;

Equation (1), using the previous inputs, could be rewritten as follows.

Qc =6.8 x 536.75 (14- To)

= 3649.9 X (14-To) Watts/greenhouse (2)

According to the hourly temperatures, Qc is calculated for the year 2023 hourly temperatures, as ell as projected temperatures under four projection scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) for the four time-intervals 2023-2039, 2040-2059, 2060-2079, 2080-2099.

The second major heat transfer made is air exchange between inside and outside the greenhouse.

Heat is transferred in both sensible and latent forms. The sensible heat is transferred by increasing the temperature of incoming air. The latent heat is removed as water vapor from evaporation and transpiration. For night heating calculation, heat used in evaporating water could be ignored. Infiltration heat loss, (Qi), can be estimated by the following equation.

Qi = 0.5 VN (Ti- To) (3) [10].

Where;

Qi = Heat loss by infiltration, watts;

V =Greenhouse internal volume, [V= face area (56.75/2=28.4m2) x length (40) = 1134.9 m3];

N =Number of air exchanges per hour = 4 for plastic house.

Ti = Inside air temperature, °C;

To = Outside air temperature, °C;

Equation (3) could be rewritten as follow:

Qi = 0.5 x 1134.9 x 4 (14- To)

= 2269.8 (14- To) watts/greenhouse (4)

The total heat requirements to compensate total heat loss will be the sum of Qc and Qi, as follows.

Total heat requirements = Qc + Qi (5)

= 3649.9 X (14-To) + 2269.8 (14- To)

= 5919.7 (14-To) watts/greenhouse (6)

The equations were used for the actual hourly maximum temperatures for 366 days (24 x 366 = 8784 hours), as well as the downscaled projected hourly maximum temperatures of four SSP scenarios and four projected intervals. Annual and seasonal heating requirements are then tabulated as shown in Tables 5 and 6. The season included December, January and February (DJF) months for winter, March, April, and May (MAM) for spring, June, July, and August (JJA) for summer, and September, October, and November (SON) for autumn.

Time interval	Actual 2023/2024	Projection scenario			
		SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
2020/2039	755.1	522.4	513.3	529.2	515.2
2040-2059	755.1	456.8	414.3	366.4	328.5
2060-2079	755.1	445.5	320.1	239.3	170.6
2080-2099	755.1	477.3	282.1	134.6	66.1

Table 5: Actual and Projected Annual Heat Required up to 15°C (Kilo Calory) for the Four Time-Intervals (2020-2039, 2040-2059, 2060-2079, & 2080-2099) for Four Scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, & SSP5-8.5)

Season	Actual 2023/2024	2020/2039			
		SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
DJF (winter)	734.6	515.8	507.0	521.9	508.3
MAM (Spring)	18.1	6.6	6.3	7.3	6.9
JJA (Summer)	0.0	0.0	0.0	0.0	0.0

Season	Actual 2023/2024	2040-2059			
SON (Autumn)	2.4	0.0	0.0	0.0	0.0
Total / annum	755.1	522.4	513.3	529.2	515.2
Season	**Actual 2023/2024**	**2040-2059**			
		SSP1-2.6	**SSP2-4.5**	**SSP3-7.0**	**SSP5-8.5**
DJF (winter)	734.6	451.8	411.1	363.2	326.7
MAM (Spring)	18.1	5.0	3.2	3.2	1.8
JJA (Summer)	0.0	0.0	0.0	0.0	0.0
SON (Autumn)	2.4	0.0	0.0	0.0	0.0
Total / annum	755.1	456.8	414.3	366.4	328.5
Season	**Actual 2023/2024**	**2060-2079**			
		SSP1-2.6	**SSP2-4.5**	**SSP3-7.0**	**SSP5-8.5**
DJF (winter)	734.6	441.3	318.3	238.6	170.6
MAM (Spring)	18.1	4.2	1.8	0.8	0.0
JJA (Summer)	0.0	0.0	0.0	0.0	0.0
SON (Autumn)	2.4	0.0	0.0	0.0	0.0
Total / annum	755.1	445.5	320.1	239.3	170.6
Season	**Actual 2023/2024**	**2080-2099**			
		SSP1-2.6	**SSP2-4.5**	**SSP3-7.0**	**SSP5-8.5**
DJF (winter)	734.6	473.3	281.1	134.6	66.1
MAM (Spring)	18.1	4.1	0.9	0.0	0.0
JJA (Summer)	0.0	0.0	0.0	0.0	0.0
SON (Autumn)	2.4	0.0	0.0	0.0	0.0
Total / annum	755.1	477.3	282.1	134.6	66.1

Table 6: Actual and Projected Seasonal Heat Required up to 15°C (Kilo Calory) for the Four Time-Intervals (2020-2039, 2040-2059, 2060-2079, & 2080-2099) for Four Scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, & SSP5-8.5)

2.6. Ventilation Hours Estimation

Hourly data for the current period (2023/2024), and monthly maximum daily temperatures anomalies were used to estimate the number of hours needed to run mechanical ventilation. The projected data obtained under the four scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5) for the four projection time intervals from 2020-2039, 2040-2059, 2060-2079, and 2080-2099) were used to downscale the daily data to hourly data using Microsoft® Excel® (Version 2406). Four set points were examined to estimate the number of hours needed if temperatures exceed 28, 30, 32, and 35°C. The daily required hours were obtained from the sum of hourly units of one, if the temperature value was higher than the set point. Monthly, seasonally, and annual sum up was the estimated. The season included December, January and February (DJF) months for winter, March, April, and May (MAM) for spring, June, July, and August (JJA) for summer, and September, October, and November (SON) for autumn. The monthly and seasonal ventilation hours needed were estimated from the actual hourly minimum temperatures for 366 days (24 x 366 = 8784 hours), as well as the downscaled projected hourly minimum temperatures of the four SSP scenarios and four projected intervals, for the temperature set pint higher than 35, 32, 30 and 28°C. Annual and seasonal ventilation hours needed requirements are then tabulated as shown in Tables 7-11.

Time intervals	**Actual 2023/2024**	**Projection scenario**			
		SSP1-2.6	**SSP2-4.5**	**SSP3-7.0**	**SSP5-8.5**
	Total hours >35°C				
2020/2039	1514	1727	1715	1721	1729
2040-2059	1514	1832	1884	1941	1943
2060-2079	1514	1874	2019	2141	2152
2080-2099	1514	1849	2110	2336	2365
	Total hours>32°C				
2020/2039	2130	2303	2306	2302	2295
2040-2059	2130	2368	2412	2456	2471

2060-2079	2130	2393	2519	2588	2636
2080-2099	2130	2387	2571	2757	2862
	Total hours>30°C				
2020/2039	2470	2622	2616	2608	2627
2040-2059	2470	2679	2726	2759	2804
2060-2079	2470	2694	2826	2880	2974
2080-2099	2470	2688	2867	3061	3228
	Total Hours >28°C				
2020/2039	2796	2950	2948	2945	2954
2040-2059	2796	3003	3032	3067	3132
2060-2079	2796	3014	3136	3220	3315
2080-2099	2796	2997	3202	3397	3599

Table 7: Actual and Projected Annual Ventilation Hours Needed (Hours/Year) Under Four Scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, & SSP5-8.5) for Set Point Temperatures of 35, 32, 30 and 28°C, During Four Time-Intervals (2020-2039, 240-2059, 260-2079, and 2080-2099)

Season	Actual 2023/2024	Projection Scenario			
		SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
		2020/2039			
DJF	0	0	0	0	0
MAM	218	268	264	267	276
JJA	949	1020	1022	1025	1006
SON	347	439	429	429	447
		2040-2059			
DJF	0	0	0	0	0
MAM	218	288	307	310	337
JJA	949	1065	1087	1118	1060
SON	347	479	490	513	546
		2060-2079			
DJF	0	0	0	0	0
MAM	218	297	334	370	406
JJA	949	1097	1143	1180	1105
SON	347	480	542	591	641
		2080-2099			
DJF	0	0	0	3	9
MAM	218	296	360	425	474
JJA	949	1095	1177	1240	1142
SON	347	458	573	668	740

Table 8: Actual and Projected Seasonal Ventilation Hours (Hours/Season) Needed Under Four Scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, & SSP5-8.5) During Four Time-Intervals (2020-2039, 240-2059, 260-2079, & 2080-2099) if Set Temperature was Above 35°C

Season	Actual 2023/2024	Projection Scenario			
		SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
		2020/2039			
DJF	0	6	6	4	6
MAM	404	444	444	445	445
JJA	1141	1198	1200	1202	1181

SON	585	655	656	651	663
		2040-2059			
DJF	0	7	8	8	10
MAM	404	454	479	487	512
JJA	1141	1228	1235	1248	1211
SON	585	679	690	713	738
		2060-2079			
DJF	0	7	10	15	30
MAM	404	469	512	522	551
JJA	1141	1238	1261	1274	1225
SON	585	679	736	777	830
		2080-2099			
DJF	0	7	16	40	68
MAM	404	465	523	574	633
JJA	1141	1241	1273	1288	1227
SON	585	674	759	855	934

Table 9: Actual and Projected Seasonal Ventilation Hours (Hours/Season) Needed Under Four Scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, & SSP5-8.5) During Four Time-Intervals (2020-2039, 240-2059, 260-2079, & 2080-2099) if the Set Temperature was Above 32°C

Season	**Actual 2023/2024**	**Projection Scenario**			
		SSP1-2.6	**SSP2-4.5**	**SSP3-7.0**	**SSP5-8.5**
		2020/2039			
DJF	11	30	32	26	31
MAM	510	545	541	542	548
JJA	1233	1266	1267	1267	1251
SON	716	781	776	773	797
		2040-2059			
DJF	11	36	40	43	49
MAM	510	560	582	587	617
JJA	1233	1276	1280	1286	1262
SON	716	807	824	843	876
		2060-2079			
DJF	11	38	51	56	81
MAM	510	567	616	630	669
JJA	1233	1281	1286	1288	1262
SON	716	808	873	906	962
		2080-2099			
DJF	11	37	56	101	155
MAM	510	566	627	688	753
JJA	1233	1280	1288	1288	1262
SON	716	805	896	984	1058

Table 10: Actual and Projected Seasonal Ventilation Hours (Hours/Season) Needed Under Four Scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, & SSP5-8.5) During Four Time-Intervals (2020-2039, 240-2059, 260-2079, and 2080-2099) if the Set Temperature was Above 30°C

Season	Actual 2023/2024	Projection Scenario			
		SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
		2020/2039			
DJF	51	82	84	79	83
MAM	616	662	659	661	662
JJA	1279	1287	1287	1287	1282
SON	850	919	918	918	927
		2040-2059			
DJF	51	93	101	106	116
MAM	616	674	691	696	725
JJA	1279	1288	1288	1288	1282
SON	850	948	952	977	1009
		2060-2079			
DJF	51	94	122	143	179
MAM	616	685	722	753	784
JJA	1279	1288	1288	1288	1282
SON	850	947	1004	1036	1070
		2080-2099			
DJF	51	93	143	217	326
MAM	616	682	746	802	858
JJA	1279	1288	1288	1288	1282
SON	850	934	1025	1090	1133

Table 11: Actual and Projected Seasonal Ventilation Hours (Hours/Season) Needed Under Four Scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, & SSP5-8.5) During Four Time-Intervals (2020-2039, 240-2059, 260-2079, and 2080-2099) if Set Temperature was Above 28°C

3. Results and Discussions

3.1. Current and Projected Heat Requirements

The actual estimated heat requirement for the greenhouse size of 8.5 x 40m in Kharga, New Valley Governorate, was found to be 755.1 kilo calories (≈0.88 kWh) for the period from June 2023-end of May 2024 using a set point temperature of 15°C (Table 5). The current power produced by the solar panels installed over the greenhouse (6.0 kWh) could be sufficient for heating one greenhouse during night if suitable batteries were installed [14]. The daily number of hours below 15°C was found ranged from 1-7 hours, for a period of 126 days, mainly in winter (Figure 1). The unheated greenhouses with the actual air temperatures during winter months (Table 1) are not appropriate for growing sweet pepper and cucumbers [7,22-25].

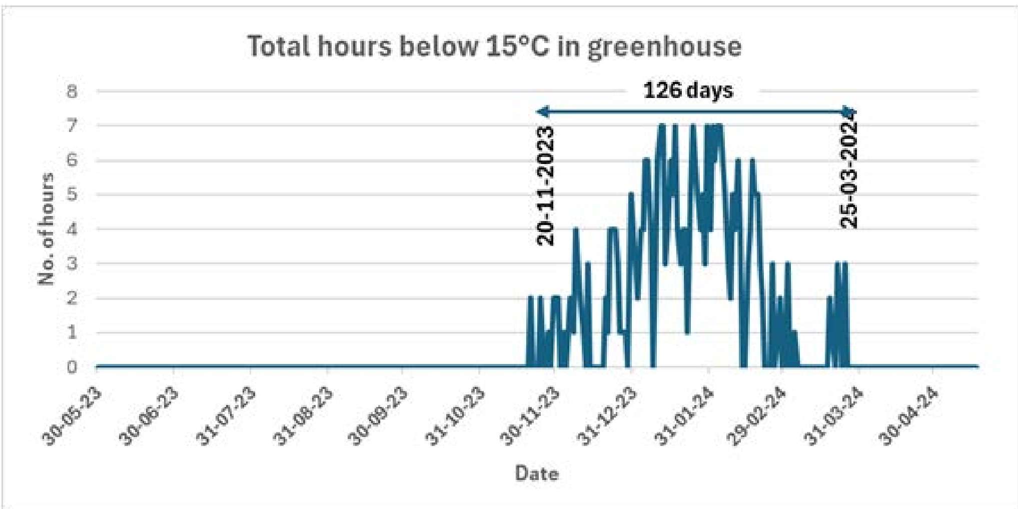

Figure 1: Number of Hours below 15°C in Kharga Oasis, 2023-2024

The annual projected heating requirements under the four SSP scenarios for the time intervals 2020-2039, 2040-2059, 2060-2079, and 2080-2099 clearly showed a general decrease over time under different scenarios (Table 5). The heat requirements projected for SSP1, SSP2, SSP3, and SSP5 were 69.2, 68.0, 70.1 and 68.2% of the actual requirements for the projected interval 2020-2039, respectively, while were 63.2, 37.4, 17.8, and 8.8% of the actual requirements for the projected interval 2080-2099, respectively. These results clearly indicate the effect of increased temperatures under climate change conditions on the greenhouse heating requirements. The trend of increased night temperatures (Table 3) suggests the need for smart production management for greenhouse vegetables such as modifying planting dates, cultivation of different crops or cultivars, or apply efficient environmental control systems [9,26].

For specific seasonal actual and projected heat requirement (Table 6), the results indicated that 79.3 to 98.7% of the annual heat requirements were for the current and projected winter months of December, January and February of the time interval 2020-2039. The percentage continues to increase up to 100% for SSP3 and SSP5 for the projection time interval 2080-2099. Vegetable fruit quality, e.g. cucumber, sweet pepper, and tomato, are reported to be decreased by low night temperatures [9,10,27]. Modifying the minimum set point below 15°C may reduce the number of hours and duration for heating requirements (Figure 2). This emphasizes the importance of managing greenhouse environmental control with more economically feasible alternatives, with smart utilization of energy [9,28].

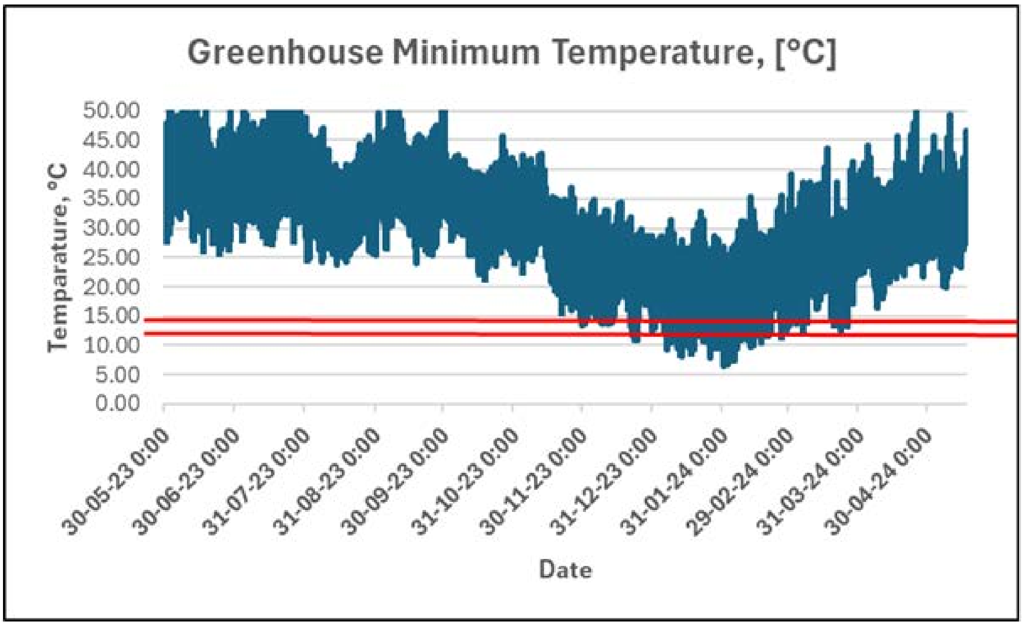

Figure 2: Greenhouse hourly minimum temperature in Kharga Oasis, 2023-2024

3.2. Current and Projected Ventilation Needs

Greenhouse ventilation is an important necessity for vegetable production, either natural or mechanically. Natural Ventilation requires a greenhouse opening of about 20% of ground area, which is generally difficult to attain is simple structure greenhouses, such as the type commercially used in the country [29,30]. Ventilation is required in the greenhouse for several reasons including replenishment of carbon dioxide consumed by green leaves, reduction of relative humidity, removal of condensed water vapor, and most importantly evacuation of excessive heat loads, and hence reduce internal temperature [31].

Actual (2023/2024) and projected annual ventilation hours needed (hours/year) under four scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, & SSP5-8.5) for set point temperatures of 35, 32, 30 and 28°C, during four time-intervals (2020-2039, 240-2059, 260-2079, and 2080-2099) are presented in Table (7). The number of hours above 35°C increased over the time intervals till 2080-2099 between 14-22%, 14-40%, 14-55% and 14-57% for the SSP1, SSP2, SSP3, and SSP5 scenarios, respectively. This represents up to about 15% additional number of hours higher than 35°C compared to the actual measurements of 2023/2024. The additional number of hours above the control was considerably reduced compared to the actual hourly temperatures of 2023/2024 with a range of 8.2-35.0, 6.2-31.0 and 5.5-29.0 for set temperatures of 32, 30, and 28°C, while the total annual number was increasing be lowering set point temperatures. Compared to the 35°C set point of the actual temperatures, the number of hours increased by 41, 64, and 85% for the 32, 30, and 28°C, respectively. Compared to the 35°C set point temperature of the actual values. The SSP1, SSP2, SSP3, and SSP5 incremental hours ranges were 0.14-0.57, 0.52-0.90, 0.74-1.14 and 0.96-1.38 folds for 35, 32, 30, and 28°C, respectively. Consequently, the set point temperature for running mechanical fans could reach three times the actual conditions of the study under SSP-5 during the time interval 2080-2099. As described by, greenhouse design and ventilation equipment should consider the ventilation needs, as poor ventilation may lead to lower yield and quality of major crops [29,30,32]. Enrichment of CO2 could be an additional management tool [33].

Concerning the seasonal projections, data presented in Tables 8, 9, 10, and 11 show the actual and projected seasonal ventilation hours (hours/season) needed under four scenarios (SSP1-2.6, SSP2-4.5, SSP3-7.0, & SSP5-8.5) during four time-intervals (2020-2039, 240-2059, 260-2079, & 2080-2099) assuming set temperature was above 35, 32, 30, and 28°C, respectively. For set point temperature 35°C, the distribution of hours among the four seasons (winter, spring, summer, and autumn) was the highest in summer with 57-60% of a total annual hour of all time intervals ranged from 1514 to 2365, followed by autumn (25-27%), then spring (15-17%), with 0% for winter, throughout all SSP scenarios. As for the 32°C set point, the distribution of hours among the four seasons was the highest in summer with 49-52% of a total annual hour of all time intervals ranged from 2130 to 2862, followed by autumn (28-30%), then spring (19-20%), with 0% for winter, throughout all SSP scenarios. Similar trend was found for the 30°C set point, as the highest number of hours was found in summer with 45-49% of a total annual hour of all time intervals ranged from 2470 to 3228, followed by autumn (30-31%), then spring (21-22%), with 0% for winter, throughout all SSP scenarios.

The highest annual number of hours obtained from a set point of 28°C ranged between 2796 hours under SSP1 in the closest time interval (2020-2039) to 3599 hours under SSP5 under the furthest time interval (2080-2099). Seasonal distribution of the hours using this set point was also the highest during summer (40-44%), followed by autumn (31-32%), then spring (22-23%), with 3-4% for winter, throughout all SSP scenarios. Those results indicated that ventilation of greenhouses under the environmental conditions of the study area of Kharga Oasis requires acute attention throughout the year, especially in summer and autumn. The dramatic increase of the number of hours above 35°C from 1514 in the actual measured period to 2365 hours under SSP5 for the 2080-2099 time-interval. The latter number of hours could reach 3599 hours for more heat sensitive crops (above 28°C). Accordingly, the greenhouse construction and design should be revisited in order to find more appropriate covering materials, smarter ventilation options, with adequate crop production management [9,17,18,31].

Acknowledgement

This paper is based upon work supported by the Science, Technology & Innovation Funding Authority (STDF) under grant number 46908.

References

1. Belda, M., Holtanová, E., Halenka, T., & Kalvová, J. (2014). Climate classification revisited: from Köppen to Trewartha. *Climate research, 59(*1), 1-13.
2. Egypt State Information Service (2018). Egypt Greenhouse Mega Project.
3. Change, I. P. O. C. (2007). Climate change 2007: the physical science basis. *Agenda, 6*(07), 333.
4. Nelson, G. C., Rosegrant, M. W., Koo, J., Robertson, R., Sulser, T., Zhu, T., ... & Lee, D. (2009). *Climate change: Impact on agriculture and costs of adaptation* (Vol. 21). Intl Food Policy Res Inst.
5. Bosello, F., Campagnolo, L., Cervigni, R., & Eboli, F. (2018). Climate change and adaptation: the case of Nigerian agriculture. *Environmental and Resource Economics, 69,* 787-810.
6. Montero, J. I., Van Henten, E. J., Son, J. E., & Castilla, N. (2009, June). Greenhouse engineering: new technologies and approaches. *In International Symposium on High Technology for Greenhouse Systems: GreenSys2009 893* (pp. 51-63).
7. Bisbis, M. B., Gruda, N., & Blanke, M. (2018). Potential impacts of climate change on vegetable production and product quality–A review. *Journal of Cleaner Production, 170,* 1602-1620.
8. Gruda, N., Bisbis, M., & Tanny, J. (2019). Impacts of protected vegetable cultivation on climate change and adaptation strategies for cleaner production–a review. *Journal of Cleaner Production, 225*, 324-339.
9. Baudoin, W., Nono-Womdim, R., Lutaladio, N., Hodder, A., Castilla, N., Leonardi, C., ... & Duffy, R. (2013). Good agricultural practices for greenhouse vegetable crops: Principles for mediterranean climate areas.
10. Medany, M. A., Mahmoud, M. H., Gaafer, S. A., & Abou-Hadid, A. F. (1990). Effect of cultivation in heated and non-heated plastic houses on quality and shelf life of sweet pepper fruit. *Egypt J Hort, 17*(1), 57-67.
11. Parajuli, R., Thoma, G., & Matlock, M. D. (2019). Environmental sustainability of fruit and vegetable production supply chains in the face of climate change: A review. *Science of the Total Environment, 650,* 2863-2879.
12. World Bank (2024). Climate Change Knowledge Portal.
13. Khalil, M. H. (2012). Bio-Climatic Analysis and Thermal Performance of Upper Egypt A Case Study Kharga Region.
14. MEDANY, M., Radwan, G., & Zaki, M. H. (2024). Projections of Greenhouse Heating and Ventilation Requirements in the New Valley Under Climate Change Scenarios.
15. Meinshausen, M., Smith, S. J., Calvin, K., Daniel, J. S., Kainuma, M. L., Lamarque, J. F., ... & van Vuuren, D. P. (2011). The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. *Climatic change, 109,* 213-241.
16. Van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., ... & Rose, S. K. (2011). The representative concentration pathways: an overview. *Climatic change, 109*, 5-31.
17. Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2012). An overview of CMIP5 and the experiment design. *Bulletin of the American meteorological Society, 93*(4), 485-498.
18. Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., & Taylor, K. E. (2016). Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geoscientific Model Development, 9*(5), 1937-1958.
19. O'Neill, B. C., Tebaldi, C., Van Vuuren, D. P., Eyring,

V., Friedlingstein, P., Hurtt, G., ... & Sanderson, B. M. (2016). The scenario model intercomparison project (ScenarioMIP) for CMIP6. *Geoscientific Model Development, 9*(9), 3461-3482.

20. Allan, R. P., Arias, P. A., Berger, S., Canadell, J. G., Cassou, C., Chen, D., ... & Zickfeld, K. (2023). Intergovernmental panel on climate change (IPCC). Summary for policymakers. *In Climate change 2021: The physical science basis. Contribution of working group I to the sixth assessment report of the intergovernmental panel on climate change* (pp. 3-32). Cambridge University Press.
21. Aldrich, R. A., & Bartok, J. W. (1989). Norteast Regional Agricultural Engineering Service. *Greenhouse engineering*. 3rd ed. Ithaca, NY, 212, 3-32.
22. Abou-Hadid, A. F., Medany, M. A., Khalifa, H., & El-Beltagy, A. S. (1990). Response of growth and development of cucumber and sweet pepper to heating effectiveness. *Egypt. J. Hort, 19*(1).
23. Abou-Hadid, A. F., El-Beltagy, A. S., & Medany, M. A. (1993, April). The effect of air temperature on fruit yield of sweet pepper (Capsicum annuum) grown under plastic houses in Egypt. In *II Symposium on Protected Cultivation of Solanacea in Mild Winter Climates 366* (pp. 93-98).
24. Abd-El-Baky, H. M., Ali, S. A., El Haddad, Z., & El Ansary, Z. A. (2010). Some environmental parameters affecting sweet pepper growth and productivity under different greenhouse forms in hot and humid climatic conditions. *Journal of Soil Sciences and Agricultural Engineering, 1*(3), 225-247.
25. Abed Elfattah, S., Mostafa, M. M., Elnono, M. A., & Kassem, A. M. (2014). Greenhouse heating and ventilation control system. *Misr Journal of Agricultural Engineering, 31*(2), 667-682.
26. Ayyogari, K., Sidhya, P., & Pandit, M. K. (2014). Impact of climate change on vegetable cultivation-a review. *International Journal of Agriculture, Environment and Biotechnology, 7*(1), 145-155.
27. Çaylı, A., Baytorun, A. N., Akyüz, A., & Üstün, S. (2020). An Investigation of Temporal Variability of Heat Requirements for Greenhouse Tomato Production in Turkey's Mediterranean Region.
28. Ullah, I., Fayaz, M., Aman, M., & Kim, D. (2022). An optimization scheme for IoT based smart greenhouse climate control with efficient energy consumption. *Computing, 104*(2), 433-457.
29. Wadid, M. M., Medany, M. A., Farag, A. A., Abou-Hadid, A. F., & El-Behairy, U. A. (1999). Effect of improved natural ventilation of plastic house on cucumber grown in Egypt.
30. Litago, J., Baptista, F. J., Meneses, J. F., Navas, L. M., Bailey, B. J., & Sánchez-Girón, V. (2005). Statistical modelling of the microclimate in a naturally ventilated greenhouse. *Biosystems Engineering, 92*(3), 365-381.
31. Ghoulem, M., El Moueddeb, K., Nehdi, E., Boukhanouf, R., & Calautit, J. K. (2019). Greenhouse design and cooling technologies for sustainable food cultivation in hot climates: Review of current practice and future status. *Biosystems Engineering, 183*, 121-150.
32. Bournet, P. E., Brajeul, E., Truffault, V., Chantoiseau, E., & Naccour, R. (2018, August). Impact of heating location, forced ventilation and screens on the energy efficiency and condensation risks inside a cucumber greenhouse. In *XXX International Horticultural Congress IHC2018: III International Symposium on Innovation and New Technologies in Protected 1271* (pp. 25-32).
33. Sánchez-Guerrero, M. C., Lorenzo, P., Medrano, E., Castilla, N., Soriano, T., & Baille, A. (2005). Effect of variable CO2 enrichment on greenhouse production in mild winter climates. *Agricultural and forest meteorology, 132*(3-4), 244-252.