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RESEARCH ARTICLE

REDUCING CO_2EMISSIONS IN GREENHOUSES REGARDING HEAT EFFICIENCY INCREASE.

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Abstract

Heat requirements in greenhouses change according to the climate of the region, type of plant cultivated in the greenhouse and the technical equipment of the greenhouse. In Antalya, a city in West Mediterranean Region of Turkey where there is intensive green housing, heat requirement of a single pane PE covered 2400 m^2greenhouse (A_H/A_G=1.57) with temperature 17/18°C night/day throughout the production period is 156.6 kWh m^{-2} a^{-1}. In a greenhouse of the same size, in which technical precautions are taken to increase heat efficiency, heat energy requirement can be reduced to 68.4 kWh m^{-2} a^{-1}. Reducing heat energy requirement also reduces CO_2emissions into the atmosphere. When thermal curtains are used for heat conservation in greenhouses, it is possible to achieve a heat saving of 30-45% depending on the texture quality of the thermal curtain, number of curtain panes and insulation. In the case that covering surfaces with heat losses are covered with multi-pane covering materials, energy saving rates can reach as high as 55%. However, multi-pane covering materials may lead to photosynthetic active radiation (PAR) losses and thus a decrease in efficiency. This study aims to estimate heat savings in different combinations of covering materials as well as CO_2 emissions into the atmosphere.

Introduction:-

Heat requirements in greenhouses changeaccording to greenhouse types, available equipment in the greenhouse, the climate of the region and temperature requirements of the cultivated plant. Greenhouses installed in cold climate regions need to be heated during longer periods. In temperate climate regions, heating is required in the winter months and heating periods are shorter. In hot climate regions like Israel, heating is required only at night in the winter months. Heat energy requirement in greenhouses installed in Mediterranean regions is lower than that of greenhouses in cold European countries. According to De Pascale and Maggio (2005), heat energy requirement for a 1 ha cut flower greenhouse is estimated to be 5200–6800 GJ $year^{-1}$ while this value is 16000 GJ $year^{-1}$in the Netherlands. Despite their low energy requirements, greenhouses in the Mediterranean climate zone are mostly heated with simple methods by making use of environmentally hazardous fossil energy sources and without taking or implementing proper heat conservation precautions.

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Table1:- Energy budgets of the greenhouses installed in Northern and Southern Europe.

Fuel requirement kgm^{-2}a^{-1} (Fuel oil)	
Southern Europe	Northern Europe
5 – 6	60 - 80
Greenhouse heat energy requirement	
2.0–3.0 kWhm^{-2}day^{-1} (14/10^{o}C)	Northern Europe
0.5–1.0 kWhm^{-2}day^{-1} (12/10^{o}C)	Southern Europe

Energy requirements and fuel consumption of greenhouses installed in northern and southern countries including Israel are given in table 1. As can be seen from the chart, fuel consumption in greenhouses installed in northern and southern countries differs significantly. Fuel quantity required in greenhouses in northern European countries is 10 to 13 times the requirement in southern European countries (CampiottiandDondi. 2007).

Heat energy requirement for greenhouses installed in northern European countries is 1900 MJm^{-2}a^{-1} (528 kWhm^{-2}a^{-1}) while this value is 1500 MJm^{-2}a^{-1} (417 kWhm^{-2}a^{-1}) and 500 MJ m^{-2} a^{-1} (139 kWh.m^{-2} a^{-1}) for central European and southern European countries respectively. In northern European countries, 45 L m^{-2} of fuel oil is required for 1900 MJ m^{-2} a^{-1} heat energy requirement throughout the production period. This value is 35 Lm^{-2}in central European countries and 12 Lm^{-2} in southern European countries (Bot 2008).

Table 2 shows heat energy requirements calculated by Çanakçı at al. (2013) for greenhouses in different cities of the Mediterranean region where greenhousing is a common agricultural practice. Çanakçı et al. (2013) determined heat energy requirements in PE plastic greenhouses with16/18^{o}C as night/day temperatures taking into consideration the temperature desired in the greenhouse, the average temperature at night hours and the night hours of each month. As can be seen from the chart, the highest heat energy requirement is in Muğla (290.5 kWhm^{-2}a^{-1}).

Table2. Heat energy required in greenhouses in different cities of the Mediterranean region when the temperature is kept at 16^{o}C(kWh.m^{-2}.a^{-1}).

City	Antalya	Muğla	Mersin	Adana	Hatay
Heat energy kWh m^{-2} a^{-1}	147.1	290.5	99.8	156.2	159.9

Determining heat energy requirements in greenhouses based on hourly climate values gives optimum results (Zabeltitz 2011). Using the ISIGER-SERA specialized system developed by Baytorunet al. (2016), it is possible to calculate temperature increases depending on energy storage specifications of the greenhouse and required heat energy depending on the greenhouse equipment besides hourly climate values.

Significant amounts of heat energy can be saved when multi-pane covering materials and thermal curtains are used. In his study on low energy requiring greenhouse structures (ZINEG), Tantau (2012) concluded that a heat energy saving of upto 80% can be achieved if multi-pane covering materials and thermal curtains are used. In the same study, Meyer (2012) concluded that energy saving rates in plastic greenhouses in Germany could be increased to 90%.

In greenhouses installed in the Mediterranean region, where the climate is temperate, heating is definitely necessary in order to achieve required high efficiency rates. However, while heating provides the advantage of fast improvement and earliness, it becomes disadvantageous due to energy costs and CO_2 release unless proper energy saving precautions are taken.

This study aims to compare the heat energy requirements between the reference greenhouse with no heat conservation precautions and those of greenhouses with different technical equipment and to determine the saved heat energy and decrease in CO_2 release.

Material and Method:-

In this study, greenhouses of size 2400 m^{2}with 4 m sidewall height, 6.5 m roof ridge height and 1.57 A_H/A_G ratio were used. In order to make relevant comparisons, the calculations are based on a reference greenhouse with single-pane covering and without a thermal curtain. The technical precautions used for heat conservation in the greenhouses are given in Table 3.

Table 3:- The reference greenhouse used in the calculations and the technical precautions taken for heat conservation

Greenhouse	Roof	Side wall	Thermal curtain
Reference greenhouse	Single pane PE	Single pane PE	None
Greenhouses with heat conservation precaution	Single pane PE	Double pane PE	Single pane with little aluminum texture
	Single pane PE	Double pane PE	Double pane with more aluminum texture
	Double pane PE	Double panePE	Double pane with more aluminum texture

Heat requirement in greenhouses was calculated with ISIGER-SERA specialized system (Baytorunet al. 2016).The calculations of fuel quantities and costs were based on the values given in Table 4. In the study, 17/18^{o}C were taken as night/day temperatures and 15/18^{o}C for energy saving. In the calculations, long-term climate of Antalya (temperature, solar radiation, wind speed) was taken as reference.

Equation 1 was used to determine the fuel quantity required in the greenhouse (Tantau 1983).

$$B_y = \frac{q_H}{H_u * \eta_{ges}} \qquad [1]$$

In the equation:

B_y: Fuel quantity (kg m^{-2} or m^3 m^{-2}),

q_H: Heat energy requirement of the greenhouse at a certain temperature (kWh m^{-2} a^{-1}),

H_u: Lower heating value of fuel (kWh unit-1)

Table 4:- Cost comparison table for lower heating values (H_u), burning efficiency and heat energy of fuels used for heating greenhouses(with VAT exclusive unit prices set on September 16, 2015). http://www.tesisat.com.tr/yayin/yakit-fiyatlari/

Fuel type	Unit	Lower heating value kWh/Unit	16.09.2015 Price □/Unit	Average operating efficiency	Price □/kWh
Natural gas 300.001 m^3/year and above	m^3	9.59	0.805383	93%	0.090303
Native lignite 10-18 mm	Kg	5.74	0.457000	65%	0.122487
Coal imported from Siberia	Kg	8.14	0.728814	65%	0.137746
Fuel oil N. 6	Kg	11.12	1.338983	80%	0.150515
LNG –Liquefied Natural Gas	m^3	9.59	1.594356	93%	0.178766

In calculating CO_2 emissions of fossil fuels used for heating, the heat energy required in the greenhouse and losses in heat energy conduction were taken into consideration. Heat loss in conduction was accepted as 3% (Haaseet al. 2014).CO_2 release values of different fuel types used for heating green houses are given in Table 5. CO_2 emission in obtaining electrical energy was taken as 575 g/kWh$_{el}$ (Grebe et al. 2011).

Table 5:- CO_2 releases of the fuel types used in calculations (IWU 2014)

Fuel type	kg equiv. CO_2/kWh
Liquid gases	0.260
Natural gas (H)	0.239
Imported coal	0.421
Lignite coal	0.448
Fuel oil	0.313

CO_2 emissions of fuel types used for heating were calculated using Equation 2 (Yazıcıet al. 2012).

$$SEGM_y = B_y * Hu * FSEG \qquad [2]$$

In the equation:

$SEGM_y$: Annual CO_2 emission quantity (kg equiv. CO_2)

$FSEG$: CO_2emission conversion factor according to fuel type (kg equiv. CO_2/kWh).

Result and Discussion:-

Heat energy requirements (kWh m^{-2} a^{-1}) and heating duration (h) throughout the production period for a reference greenhouse and greenhouses with different temperatures and equipment were calculated using ISIGER-SERA specialized system. The results obtained are given in Table 6 and 7. As can be seen from Chart 6, under climate conditions of Antalya, heat energy required in a PE plastic greenhouse without any protection measures is 156.58 kWh m^{-2} $a^{-1}$when night/day temperature in the greenhouse is kept at 17/18°C. In order to provide this heat energy, 108 W $m^{-2}$of maximum heat powers and an annual heating duration of 2903 hours is needed. When the sidewalls of the greenhouse are covered with double-pane PE plastic to save heat and a single-pane thermal curtain with little aluminum texture is used to reduce heat losses, heat energy requirement throughout the production period can be decreased by 38% to 97.04 kWh m^{-2} a^{-1}. Maximum heat power required with these heat conservation precautions is reduced to 99 Wm^{-2}.This results in a decrease in the initial investment costs of heating.

Table 6. Heat energy, heat power, heating duration and fuel requirements and CO_2 releases in greenhouses with different equipment when night/day temperature and ventilation temperature are kept at 17/18°C and 25°C respectively.

	Reference greenhouse	Greenhouses with heat conservation equipment		
Roof covering	Single pane PE plastic	Single pane PE plastic	Single pane PE plastic	Double pane PE plastic
Side wall and facade	Single pane PE plastic	Double pane PE plastic	Double pane PE plastic	Double pane PE plastic
Thermal curtain	None	Single pane with little aluminum texture	Double pane with more aluminum texture	Double pane with more aluminum texture
Heat energy (kWh m^{-2} a^{-1})	156.58	97.04	74.75	68.42
Heating duration (h)	2903	2890	2889	2823
Heat power (W m^{-2})	108	99	99	76
Energy saving compared to reference greenhouse	-	38.0	52.3	56.3
	Fuel Requirement			
Natural gas(m^3 m^{-2})	18.08	11.21	8.63	7.90
Imported coal(kg m^{-2})	30.48	18.89	14.55	13.32
Native lignite(kg m^{-2})	43.23	26.79	20.64	18.89
Fuel oil (kg m^{-2})	18.13	11.24	8.65	7.92
LNG (m^3 m^{-2})	18.08	11.21	8.63	7.90
	CO_2Release(kg m^{-2})			
Natural gas	44.22	28.46	22.55	20.82
Imported coal	107.24	67.50	52.63	48.35
Native lignite	113.95	71.66	55.85	51.29
Fuel oil	65.88	41.89	32.88	30.28
LNG	44.22	28.46	22.55	20.82

When a double-thermal curtain with more aluminum texture is used, energy requirement of the greenhouse is 74.75 kWh m^{-2} a^{-1}, reflecting a 52.3% decrease compared to the reference greenhouse. Under these conditions, heating duration and maximum heat power required in the greenhouse is equal to the values required in the greenhouse with a single-pane thermal curtain. This is because maximum heat power is required in the early morning hours when the thermal curtain is opened. When a double-pane thermal curtain is used, double-pane roof covering provides an energy saving of 7% compared to a single-pane roof covering. In the event that double-pane roof covering is used in a greenhouse with a double-pane thermal curtain, maximum heat power required is 76 W m^{-2} while this value is 99 W m^{-2} if the roof is covered with single-pane PE plastic. This enables lowering the initial investment costs and reducing solar energy radiation that will reach the greenhouse during daytime.

One of the most important parameters affecting heatenergy requirement in the greenhouse is the temperature desired in the greenhouse. Vegetables grown in greenhouses have adapted to 17-27°C (Verlodt 1990, Krug 1991). However, in recent years a new control strategy has evolved due to the fluctuations in oil price and CO_2 emissions from fossil energy sources. Today, ventilation temperatures are kept high in order to save energy while night temperatures are dropped. Table 7 shows heat energy, heat power and heat durations required throughout the production period when ventilation temperature is kept at 25°C and night/day ambient temperature is kept at 15/18°C. As can be seen from the chart, lowering the greenhouse temperature at night hours results in significant decreases in heat energy requirements. Lowering the night temperature from 17°C to 15°C provides a 30% heat energy saving.

Table7:- Heat energy requirement, fuel requirement and CO_2 releases in greenhouses with different equipment for different night/day temperatures.

TemperatureNight/Day (°C)	Reference greenhouse	Greenhouses with heat conservation equipment		
	Single pane PE plastic, no thermal curtain	Roof single and side walls double pane PE plastic, thermal curtain single pane with little aluminum texture	Roof single and side walls double pane PE plastic, thermal curtain double pane with more aluminum texture	Double pane PE plastic, thermal curtain double pane with more aluminum texture
	Heat Energy Requirement kWh m^{-2} a^{-1}			
17/20°C	168.37	107.64	85.35	75.71
17/18°C	156.58	97.04	74.75	68.42
16/18°C	132.33	82.89	64.51	58.30
15/18°C	109.67	69.68	54.97	48.86
14/18°C	88.65	57.45	46.14	40.11
14/16°C	79.89	49.59	38.29	34.91
	Fuel requirement (Imported coal kg m^{-2} a^{-1})			
17/20°C	32.78	20.95	16.62	14.74
17/18°C	30.48	18.89	14.55	13.32
16/18°C	25.76	16.14	12.56	11.35
15/18°C	21.35	13.56	10.70	9.51
14/18°C	17.26	11.18	8.98	7.81
14/16°C	15.55	9.65	7.45	6.80
	CO_2Release (kg m^{-2} a^{-1})			
17/20°C	115.26	74.70	59.86	53.35
17/18°C	107.24	67.50	52.63	48.35
16/18°C	90.91	57.93	45.66	41.45
15/18°C	75.64	48.93	39.13	34.99
14/18°C	61.45	40.61	33.07	29.00
14/16°C	55.46	35.23	27.69	25.42

CO_2 emissions from fuels used for heating greenhouses change according to fuel type and quantity. Fuel types and relevant CO_2 emissions calculated for the sample greenhouses of this study are given in Charts 6 and 7. Working hours of the circulation pumps, burners of the heating boilers and feeding elevators used in CO_2 emission calculations were determined with the help of ISIGER-SERA specialized system. In the study, electrical energy required throughout the production period was calculated assuming that the power of the operating pumps is 4 kW. CO_2 release due to the electrical energy used throughout the production period has been added to the CO_2 release resulting from obtaining the required heat energy.

As can be seen from Chart 6, the highest CO_2 release occurs when native lignite is used in the greenhouse. Using imported coal for heating results in a 5.8% decrease in CO_2 release. When fuel oil is used, decrease in CO_2 emission will be as high as 40-42%. As can be seen from Charts 6 and 7, the most appropriate fuel types in terms of CO_2 release are natural gas and liquefied natural gas (LNG). When the night temperature in the greenhouse is dropped from 17°C to 15°C, the decrease in CO_2 emission into the atmosphere is 30%.

Energy conservation measures taken to increase energy efficiency in the greenhouse provide a decrease in CO_2 emission into the atmosphere. In Mediterranean climate conditions, in a greenhouse where no heat conservation measures are taken, night/day temperature is kept at 17/18°C and native lignite is used for heating, 113.95 kg m^{-2} of

CO_2 is released into the atmosphere throughout the production period. On the other hand, when a double-pane thermal curtain is used and the side walls of the greenhouse are covered with double-pane PE plastic, the CO_2 release into the atmosphere drops to 51.29 kg m^{-2}, reflecting a 50% decrease. As can be concluded from the calculations, technical measures taken for heat conservation have a significant influence on CO_2 emissions.

When choosing the fuel type to be used in the greenhouse, besides the CO_2 released into the atmosphere, the cost of fuel throughout the production period is also important. Fuel costs calculated for sample greenhouses with 17/18°C as night/day temperature are given in Table 8.

Table8:- Fuel costs throughout the production period when night/day temperature is kept at 17/18°C

	Reference greenhouse	Greenhouses with heat conservation equipment		
Roof covering	Single pane PE plastic	Single pane PE plastic	Single pane PE plastic	Double pane PE plastic
Side wall and facade	Single pane PE plastic	Double pane PE plastic	Double pane PE plastic	Double pane PE plastic
Thermal curtain	None	Single pane with little aluminum texture	Double pane with more aluminum texture	Double pane with more aluminum texture
Natural gas (₤ m^{-2})	14.56	9.03	6.95	6.36
Imported coal (₤ m^{-2})	22.21	13.77	10.60	9.71
Native lignite (₤ m^{-2})	19.76	12.24	9.43	8.63
Fuel oil (₤ m^{-2})	24.28	15.05	11.58	10.60
LNG (₤ m^{-2})	28.83	17.87	13.76	12.60

Conclusion:-

In terms of CO_2 releases and costs, natural gas is evidently the most favorable fuel type to be used for heating greenhouses when fuel prices in Turkey are taken into consideration. However, natural gas cannot be used for heating, as there is no natural gas infrastructure in areas with greenhouse installations. The second cost effective fuel is native lignite. However, as can be seen from the results of the study, native lignite is the least favorable fuel in terms of CO_2 emission. Although it is 11% less costly than imported coal, it is important that transportation be taken into account as larger quantities are used.

When fuel oil is used for heating greenhouses, the cost difference between fuel oil and imported coal is between 0.89 ₤ and 2.07 ₤ per unit greenhouse area. If heat conservation measures are taken in the greenhouse, cost difference between the two fuel types will decrease. In the event that the boiler providing the basic heat requirement works with coal and the boiler providing the heat required under extreme conditions works with fuel oil, not only will CO_2 emission into the atmosphere decrease but also it will be possible to save energy.

In conclusion, in choosing the fuel type to be used for heating greenhouses, both fuel costs and CO_2 release into the atmosphere should be evaluated. It is highly important for the environment that CO_2 release is decreased while energy efficiency in heated greenhouses is increased. However, it should be noted that energy savings should meet the cost of technical measures to be implemented in the greenhouse. For these reasons, the feasibility studies should cover investment costs besides the energy saved with technical measures.

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