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THE DETERMINATION OF HEATING AND COOLING DAY VALUES USING DEGREE-DAY METHOD: TOMATO PLANT EXAMPLE

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Summary

Based on the amount and duration of external temperature, degree day values are determined according to whether the selected equilibrium temperature is lower or higher than the air temperature. Degree day values are calculated according to the fluctuations in ambient temperature. It can be understood whether heating or cooling systems are necessary within the calculated periods. In this study, the meteorological data of Antalya region dating back many years and the temperature values suggested according to the cultivation periods of tomato in greenhouse environment have been used as material. The daily average temperature values recorded for many years have been compared with the equilibrium temperature values selected for the tomato plant thereby calculating the heating and cooling day values for each cultivation period. Tomato cultivation in greenhouses is carried out in 2 periods in the region in spring and autumn. At the end of these two periods, it was determined that the heating degree days in autumn were determined to be higher than that in spring. Whereas cooling degree days were determined to be greater for autumn cultivation in comparison with that of spring cultivation. Information regarding the energy consumption of an agricultural structure can be obtained beforehand via the heating and cooling degree day values. It has been surmised that such studies will help in making estimations regarding the energy need of various agricultural structures as well as gaining insight in the planning of the design stages that are directly related to the energy consumption of the building such as heating, cooling and ventilation.

Keywords: Antalya, Degree day, Greenhouse, Tomato

INTRODUCTION

Greenhouses are structures in which plant cultivation can be carried out during periods when climate conditions are not suitable by controlling climate factors such as heat, light and moisture. Greenhouse cultivation in our country has started in 1940s at the city of Antalya and has rapidly gained popularity in the 1970s due to the suitable climate conditions of the Mediterranean beachfront along with the advancement in plastic technology (Ozkan et al., 2011). The greatest number of greenhouses is in the city of Antalya. Tomato is ranked top among the plants cultivated in greenhouses. The total greenhouse area of Antalya is 220.000 decares. Tomato cultivation is carried out on 44 % (96.800 da) of the total greenhouse area. According to 2011 data, the total cultivation is calculated as 2 million tones (TUIK, 2012).

Since cultivation is carried out all year long in greenhouse cultivation, the climate suitable for tomatoes should be provided by heating and cooling when the climate is not suitable. Tomato is a mild climate plant. The ideal temperature average for tomatoes ranges between 18°C and 27°C. Temperatures below 10°C have negative effects on flowering and night frosts can cause severe damages on the products. Defloration occurs when pollen viability decreases dramatically due to dryness that occurs at temperature higher than 35°C and low moisture conditions. It has been determined that at well balanced nutrition conditions, defloration is less than imbalanced nutrition conditions (Anonymous, 2012).

Heating, cooling and ventilation systems in greenhouses are subject to external weather conditions. The use of climate information summarizing the long period values of the region instead of one or several years during the design and performance simulation of these systems will ensure that results will be more accurate and realistic (Ileri and Uner, 1999).

Degree-day values are one of the simplest measurement units used in the estimation of the annual energy requirement of a structure in a certain place and location. When used with the average heat transfer coefficient of outer shell elements, the annual energy requirement of the structure can easily be calculated (Bayram and Yesilata, 2009).

The objective of this study is to gain insight about the energy consumption of agricultural production in agricultural structures using degree day method similar to residences. Thus, it is aimed to contribute to the design and planning of the parts of these structures that are directly related to energy consumption such as insulation, ventilation, heating and cooling.

MATERIAL AND METHOD

In this study, 22 year daily temperature data for the city of Antalya has been selected as material. These temperature data have been examined along with the equilibrium temperature values given in Table 1 suggested with a basis on the development of the tomato plant to determine the heating and cooling degree day values for tomato cultivation in the region. Greenhouse cultivation is carried out in two periods during spring and autumn in the Antalya region. Therefore long term temperature data have been handled separately for periods when spring and autumn cultivation was carried out.

Table 1. Suggested temperature and production times for the spring and autumn cultivation of tomato plant (Seniz, 1992).

The spring cultivation	**Temperature**	**Date**	**Period**
Greenhouse planting	18-22 °C	1st of February week	1. week
Flower formation, pollination, insemination	18-20 °C	The end of February-Beginning of March	2. week
Fruit ripening	15-25 °C	Beginning of April – Beginning of May	4. week
Harvest	18-35 °C	Beginning of May – Beginning of July	8. week
The autumn cultivation	**Temperature**	**Date**	**Period**
Greenhouse planting	18-22 °C	2nd of September week	1. week
Flower formation, pollination, insemination	18-20 °C	1st of October – 3rd of October week	2. week
Fruit ripening	15-25 °C	3rd of November week – 3rd of December week	4. week
Harvest	18-35 °C	3rd of December week – 3rd of February week	8. week

Degree-Day (DD) Method: In general, a degree-day value is stated as a temperature that is added to ambient temperature. These values are determined based on the quantity and duration of temperature and according to whether the selected equilibrium temperature is lower or higher than the ambient temperature (Matzarakis and Balafoutis, 2004). Whereas equilibrium temperature is defined as the ambient temperature at which no heating or cooling is required in a structure (Bulut et al., 2000). In this study, the temperature values suggested in Table 1 according to the greenhouse cultivation weeks of tomato plant have been selected as equilibrium temperatures. According to these values, it has been determined that greenhouse temperature for suggested for tomato plants requires heating for values below the ambient temperature and cooling for those that are higher.

Heating Degree-Day (HDD) Method: Each temperature difference when the daily average external temperature decreases below the equilibrium temperature selected for the greenhouse is expressed as a Heating Degree-Day (HDD) (Yalcinkaya and Satman, 1999). In general, HDD can be calculated via this equation (Gultekin, 1995).

$$\text{For } (T_O < T_b),\ HDD = \sum_{i=1}^{n} (T_b - T_O) \tag{1}$$

Here; HDD is the cumulative sum of the heating degree-days for n days, n is the total number of days in the period, T_b is the greenhouse equilibrium temperature suggested for the tomato plant and T_0 is the average external temperature.

Cooling Degree-Day (CDD) Method: Cooling degree-day (CDD) values are mathematically defined as the difference between the external temperature value and the equilibrium value and are defined as the equilibrium temperatures above the external temperature values (Krese et al., 2012).

$$\text{For } (T_O > T_b),\ CDD = \sum_{I}^{n} (T_O - T_b) \tag{2}$$

Here; CDD is the cumulative sum of the cooling degree-days for n days, n is the total number of days in the period, T_b is the greenhouse equilibrium temperature suggested for the tomato plant in Table 1 and T_0 is the average external temperature.

Heating Degree-Day Value (HDDV) Method: Heating degree-day values are defined as the difference between the equilibrium temperature and air temperature for each day. Many methods and approaches have been given in literature for the calculation of degree day values (Baskerville and Emin, 1969; Floyd and Braddock, 1984; Yang et al., 1995; McMaster and Wilhelm, 1997; Martinaitis, 1998, Matzarakis and Balafoutis, 2004). It is calculated as the number of days for which the average external temperature values are below the equilibrium temperature values suggested for the tomato plant for the cultivation period (HDDN) in a certain time frame. Heating Degree-Day Value (HDDV) values have been calculated using the equation 3 given below.

$$HDDN = \sum_{i=1}^{n} HDD \tag{3}$$

Here; n is the total number of days which were HDD during the selected period (Buyukalaca et al., 2001).

Cooling Degree-Day Value (CDDV) Method: In this method developed similar to HDDN values, the number of days during the cultivation period in which the average external temperature values for the Cooling Degree-Days (CDD) were higher than the equilibrium temperature values suggested for the examined tomato plants have been calculated via equation 4 given below.

$$CDDN = \sum_{i=1}^{n} CDD \tag{4}$$

Here; n is the total number of days in the selected period which were CDD (Buyukalaca et al., 2001).

RESULTS

In this study, the heating and cooling day values were calculated for each cultivation period using the 22 year average temperature values between 01.01.1990 and 30.11.2011 along with the suggested equilibrium temperature values suggested for the tomato plant. Cultivation is carried out in 2 periods in the region as spring and autumn cultivation. The temperature data between the start and end times of both periods were examined with regards to the cultivation periods of the tomato plant.

Spring Cultivation

Spring cultivation starts in the first week of February in the region and continues until the end of July. The plantation process of the seedlings covers a period of one week. When the temperature values at these dates are examined, this one week period was determined as a heating day value completely both for the suggested temperature values (18-22 ^{o}C) for the heating day value and for the average temperature value (20 ^{o}C) for the tomato plant in the greenhouse (Table 2).

Table 2. Heating and cooling day values during the sowing and plantation period of spring cultivation

	Desired temperature in the greenhouse (^{o}C)	Heating number day	Cooling number day	That should not be heating and cooling number of days	Sowing and plantation period (Day)
Mean	18	7	0	0	7
	19	7	0	0	7
	20	7	0	0	7
	21	7	0	0	7
	22	7	0	0	7

The heating and cooling day values for flowering and pollination which is another period of spring cultivation have been given in Table 3. This period was also determined as one week and all the examined days actualized as heating day values.

Table 3. Heating and cooling day values during the flowering and pollination period of spring cultivation

	Desired temperature in the greenhouse (°C)	Heating number day	Cooling number day	That should not be heating and cooling number of days	Flowering and pollination period (Day)
Mean	18	14	0	0	14
	19	14	0	0	14
	20	14	0	0	14

When the next stage of spring cultivation which is fruit ripening is examined, it is observed that this period covers a time frame of one month (Table 4). It has been determined that the values of cooling days increased with the increase in temperature during this period. However, it has been determined that heating day values increased once again for values exceeding 18 °C in this period when heat demand is high.

Table 4. Heating and cooling day values during the fruit ripening period of spring cultivation

	Desired temperature in the greenhouse (°C)	Heating number day	Cooling number day	That should not be heating and cooling number of days	Ripening period (Day)
Mean	15	8	22	0	30
	16	10	20	0	30
	17	22	8	0	30
	18	30	0	0	30
	19	30	0	0	30
	20	30	0	0	30
	21	30	0	0	30
	22	30	0	0	30
	23	30	0	0	30
	24	30	0	0	30
	25	30	0	0	30

When our data for harvesting, which is the last period of spring cultivation, are examined we observe that this period covers a time frame of 2 months (Table 5). It has been determined that cooling day values increased and that even at average temperature value the cooling day value was 13.

Table 5. Heating and cooling day value during the harvesting period of spring cultivation

	Desired temperature in the greenhouse (°C)	Heating number day	Cooling number day	That should not be heating and cooling number of days	Harvesting period (Day)
	18	4	56	0	60
	19	9	51	0	60
	20	12	48	0	60
	21	22	38	0	60
	22	31	29	0	60
	23	34	26	0	60
	24	36	24	0	60
	25	40	19	1	60
	26	46	14	0	60
Mean	**26,5**	47	13	0	60
	27	52	8	0	60
	28	58	2	0	60
	29	60	0	0	60
	30	60	0	0	60
	31	60	0	0	60
	32	60	0	0	60
	33	60	0	0	60
	34	60	0	0	60
	35	60	0	0	60

Autumn Cultivation

Autumn cultivation in the region starts in the second week of September and continues until the end of February. When the temperature values in this period are examined, temperature values for the tomato plant in greenhouse have been determined as cooling day values for almost all the suggested temperatures (18-22 °C) and the average temperatures (20 °C). In contrast to spring cultivation, cooling day values have been determined throughout the autumn cultivation in the study area (Table 6).

Table 6. Heating and cooling day values during the sowing and plantation period of autumn cultivation

	Desired temperature in the greenhouse (°C)	Heating number day	Cooling number day	That should not be heating and cooling number of days	Sowing and plantation period (Day)
	18	0	7	0	7
	19	0	7	0	7
Mean	**20**	0	7	0	7
	21	0	7	0	7
	22	0	7	0	7

When the next stage of autumn cultivation which is flowering and pollination is observed, it can be seen as in Table 7 that in contrast with spring cultivation cooling day values have been determined throughout the examined period.

Table 7. Heating and cooling day values during the flowering and pollination period of autumn cultivation

	Desired temperature in the greenhouse (°C)	Heating number day	Cooling number day	That should not be heating and cooling number of days	Flowering and pollination period (Day)
	18	0	14	0	14
Mean	**19**	0	14	0	14
	20	0	14	0	14

When the fruit ripening period of autumn cultivation in the study area is examined, it has been determined that there has been a decrease in the number of cooling day values obtaining a cooling day value of only 15 °C for a period of five days due to the fact that the period coincides with the later stages of cultivation and that in contrast the temperature decreases.

When Table 9 which is related to the harvesting period of autumn cultivation is examined, we see that it covers a time period of 2 months. It has been determined that due to the decrease of heating day values with a decrease in temperature, the need for heating day values has increased for the whole period.

When heating and cooling day values are examined for both the autumn and spring cultivation periods of tomato plant according to only the average temperature value (Figures 1 and 2), we observe that the average temperature values intersect the graph only for a one day period. Hence, it is observed that both the heating and cooling day values provide the ideal temperature values for only one day in the greenhouse environment during the autumn and spring cultivation of tomato plant. We can safely state that heating and cooling systems will be required in these cultivation periods.

Table 8. Heating and cooling day values for the fruit ripening period of autumn cultivation

	Desired temperature in the greenhouse (°C)	Heating number day	Cooling number day	That should not be heating and cooling number of days	Ripening period (Day)
Mean	15	25	5	0	30
	16	30	0	0	30
	17	30	0	0	30
	18	30	0	0	30
	19	30	0	0	30
	20	30	0	0	30
	21	30	0	0	30
	22	30	0	0	30
	23	30	0	0	30
	24	30	0	0	30
	25	30	0	0	30

Degree day method has an important advantage when compared with other simple methods used in energy calculations. Since degree day values are calculated according to the fluctuations in external temperature, we can understand whether heating and cooling systems are required during these periods based on these fluctuations. Thus, degree day methods enables us to make reliable energy consumption estimations especially during mild temperature periods. In other words, degree days provide a simplified method for energy estimations with less data requirement and can be used in the planning stage of basic design decisions that directly influence energy consumption such as cooling, ventilation, heating and thermal heat capacity of buildings (Anonymous, 2006).

Table 9. Heating and cooling day values for the harvesting period of autumn cultivation

	Desired temperature in the greenhouse (°C)	Heating number day	Cooling number day	That should not be heating and cooling number of days	Harvesting period (Day)
	18	60	0	0	60
	19	60	0	0	60
	20	60	0	0	60
	21	60	0	0	60
	22	60	0	0	60
	23	60	0	0	60
	24	60	0	0	60
	25	60	0	0	60
	26	60	0	0	60
Mean	**26,5**	60	0	0	60
	27	60	0	0	60
	28	60	0	0	60
	29	60	0	0	60
	30	60	0	0	60
	31	60	0	0	60
	32	60	0	0	60
	33	60	0	0	60
	34	60	0	0	60
	35	60	0	0	60

CONCLUSIONS

In this study, Heating and Cooling Degree-Day values that best reflect the heating and cooling period for the greenhouse cultivation of tomato plant have been calculated using long term meteorological data of the Antalya region. Long term annual daily average temperature values of the central air conditioning station related to the General Directorate of State Meteorology have been used as temperature data. HDDV and CDDV were calculated according to the equilibrium temperature values required by the tomato plant during the greenhouse cultivation periods along with the daily average temperature values of the city of Antalya. Greenhouse tomato cultivation is carried out in two periods in the Antalya region namely the spring and autumn periods. At the end of these two periods, the heating day values in the autumn period were determined to be greater than that in the spring period. Whereas cooling day values were determined to be greater for spring period in comparison to that of the autumn period. Information regarding the agricultural energy consumption of a region can be obtained beforehand using the heating and cooling degree day method. Knowledge of the heating and cooling degree day values is important for the calculation of the energy required to heat or cool buildings (Ulupinar et al., 2012). Thus, it has been determined that cooling energy requirement is greater in spring cultivation and heating energy requirement is greater in autumn cultivation. Ulupinar et al. (2012) state that such studies may be used to increase estimations regarding the future when the consistency ratio of these seasonal estimations increases.

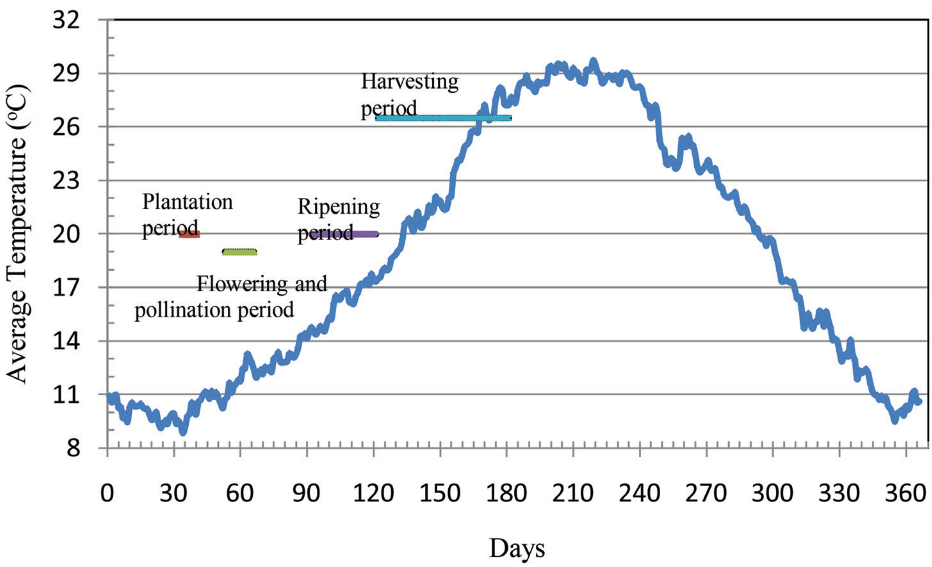

Figure 1. Graphical view of heating and cooling day values related to the average temperature demands of tomato plant during spring cultivation

Climate studies state that due to the climate changes that will occur in the future, heating requirements will decrease and cooling requirements will increase (Santos et al., 2002). The study carried out regarding our country estimates that until 2030, there will be a decrease of 10 % in the heating requirements in the Southeastern Mediterranean Region and an increase of 28 % in the cooling requirements. Intensive use of air conditioners during the summer months due to cooling requirement will result in an increase in the electricity energy demand (Valor et al., 2001). If we know the climate condition of today and determine its difference with that of the past, we can make estimations regarding the future energy demands when making an agricultural structure plan for a specific region (Ulupinar et al., 2012).

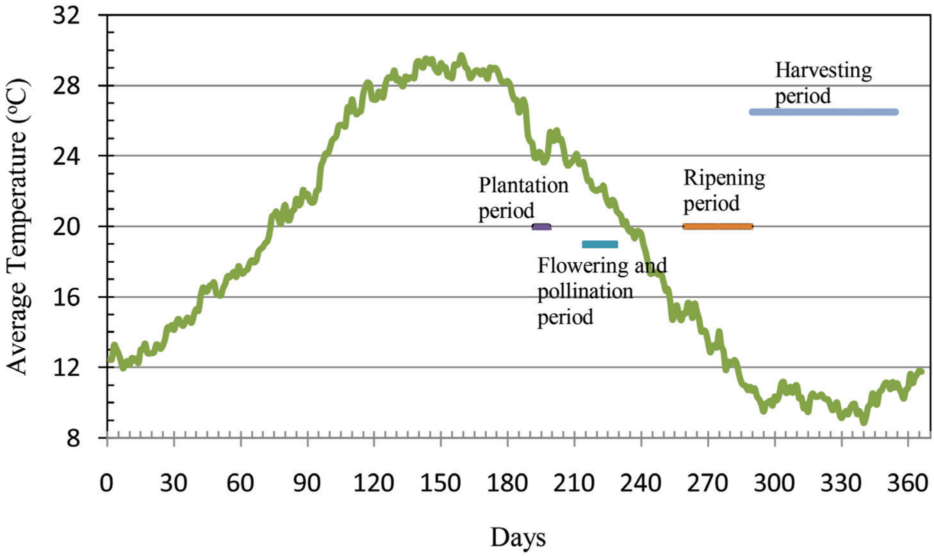

Figure 2. Graphical view of heating and cooling day values related to the average temperature demands of tomato plant during autumn cultivation

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