

The Effect of Relative Humidity on Daily Temperature Range

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Introduction

The daily range of temperatures is an important characteristic of any climate. It impacts other aspects of the area, such as vegetation, and affects human life as well - for instance, whether and when crops can be planted without the fear of freezing overnight. The purpose of this experiment is to determine whether humidity is one of the factors influencing daily temperature fluctuations.

There are several reasons to believe that humidity affects the daily temperature range (meaning the difference in temperature between the nighttime low and daytime high). Humidity's relation to the formation of dew is the simplest. When water changes to water vapor (evaporation), it stores energy as latent heat. 600 calories, the latent heat of vaporization, are required to turn water to water vapor or back (Tarbuck and Lutgens, 388). In theory, therefore, humidity should moderate the daily range of temperatures because heat will be transformed into latent heat and re-radiated when the temperature drops (through condensation during the formation of dew) instead of changing the temperature. In this experiment, measurements of the relative humidity and temperature allow calculation of the dew point (see Appendix 2), which is the temperature at which, for given absolute humidity, the air is saturated with water vapor and the water vapor begins condensation. Combining this information with the overnight low temperature, it is possible to tell whether dew was formed overnight, and then to compare daily temperature ranges when the dew point was reached and when it was not.

Differences in the specific heat of water vapor and of air account for another similarly mitigating effect of humidity on temperature range. Water vapor (H_2O), because it is made up of molecules with more atoms than the nitrogen (N_2) and oxygen (O_2) that make up 99% of air, has a higher specific heat - that is, more energy is required to raise its temperature a certain amount than is required to raise the temperature of air. This is because energy goes not only into "exciting" the electrons (moving them farther from the nucleus) but also into the bonds between atoms. Water vapor has a specific heat of 1996 kilojoules per kilogram per degree Kelvin, meaning that it requires 1996 kilojoules to raise one kilogram of water vapor one degree Kelvin (at standard temperature). Air has approximately half (1158 kJ/kg K) the specific heat of water vapor. This means that when the atmosphere is exposed to radiation, water vapor will absorb more energy than air for the same temperature increase, and temperature changes will be smaller for the same changes in energy - mitigating the daily temperature variation. Overall, this effect might be expected to be negligible, since water vapor is only up to 4% of the atmosphere by volume (Scott).

However, water vapor also absorbs a disproportionate amount of radiation it is exposed to compared to air. An understanding of how an atom absorbs and reradiates (scatters) energy is necessary to understand why this is. An atom is made up of electrons in concentric shells around a nucleus. Each shell corresponds to a different energy level - meaning that when energy is added, electrons can "jump" up to the next level. Any "jump" - either up (away from the nucleus), which absorbs energy, or down (toward the nucleus), which emits energy in the form of a photon in a random direction - requires or produces a very specific amount of energy. This amount of energy corresponds to a

specific wavelength of light. When the sun emits radiation, most of it passes through the atmosphere without being absorbed, because there are very few leaps an electron can make from level to level requiring such short-wavelength (high-energy) radiation. However, when the Earth absorbs the solar radiation, it reradiates energy at longer wavelengths. These are absorbed efficiently by water vapor, because there are many "jumps" between energy shells that the electrons can make using these wavelengths. This means that radiation from the Earth is absorbed and scattered (because when an electron drops down one or more shells, a photon is emitted with a wavelength specific to the electron's jump, but not with any particular direction) by water vapor. Normal air (mainly nitrogen and oxygen), on the other hand, is not a good absorber of Earth's radiation (Scott, Pidwirny ch. 7). Thus, the effect of differing specific heats is magnified because water vapor absorbs more radiation than air does for its volume.

World climates may demonstrate the mitigating effect discussed here of humidity on temperature range, although among so many variables it is hard to tell which are responsible for moderating temperature variation. Deserts, for instance, are known for low humidity and precipitation and for their striking daily variations in temperature. Could the striking contrast between day and night temperatures be due to their extremely low (under 20%) relative humidity (Missouri Botanical Garden)? Perhaps, but there are many other differences between deserts and other climates - less cloud cover, less vegetation, less water in the soil, and (in sandy areas) higher reflectivity, or albedo (Tarbuck and Lutgens, 378).

To measure the effect of humidity on daily temperature range, measurements of relative humidity (defined as the fraction of its water vapor capacity the air contains), daily temperature range, cloud cover (estimated as a percentage) and light, are collected in a fixed location. From the relative humidity, absolute humidity is determined through knowledge of air's capacity to hold water vapor at various temperatures. (See Appendix 3.) It is important to use absolute humidity rather than relative humidity, because the amount dew formation and the different specific heats will affect the temperature range has to do with the actual amount of water in the air.

The reason for measuring cloud cover and light is to ensure that relative humidity is not confused with cloud cover as the cause of reduced temperature ranges. Clouds have high albedo, or reflectivity, because they are made up of water droplets (Scott) and thus reduce the amount of radiation reaching Earth's surface during the day. At night, though, they absorb and scatter the longer-wavelength radiation from Earth's surface, slowing the loss of heat (Tarbuck and Lutgens, 382-283). (See Appendix 4.) Cloud cover is estimated, and the light meter measurements provide more information about how much light is getting through the clouds (an important measurement beyond estimation of cloud cover, because thin clouds covering 100% of the sky may not reflect as much light as thicker clouds covering 50% of the sky).

The thermometer measuring the temperature variation is set up over a small, raised concrete garden in a parking lot, raised approximately six feet off the ground to reduce the amount of interference from re-radiation of heat very close to the ground. The temperature probe is shaded so as not to receive direct sunlight and skew the temperature measurement (Chester), but air can freely reach it.

Hypothesis

Higher humidity will correspond to smaller daily variations in temperature, because water vapor will absorb and release energy as latent heat.

Materials

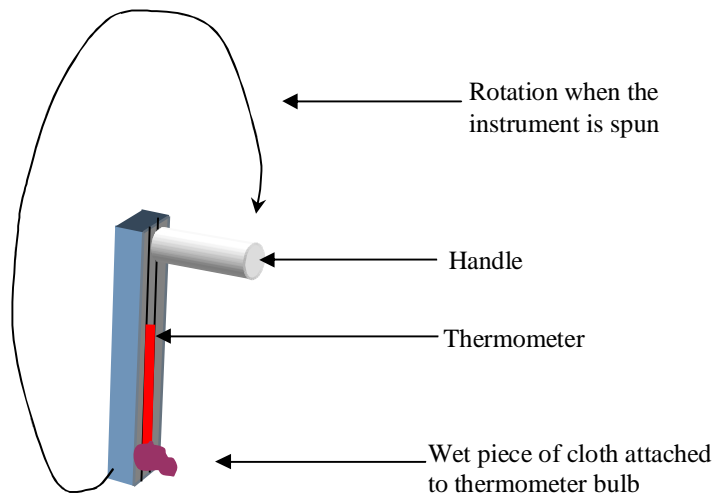
1. (1) Thermometer that records daily max/min temperatures, mounted on a stick with the thermometer probe shaded by a waterproof cardboard and duct-tape structure; see Figure 1.

Figure 1: Thermometer Structure



2. (1) Sling psychrometer for measuring relative humidity. See Figure 2.

Figure 2: Use of a Sling Psychrometer

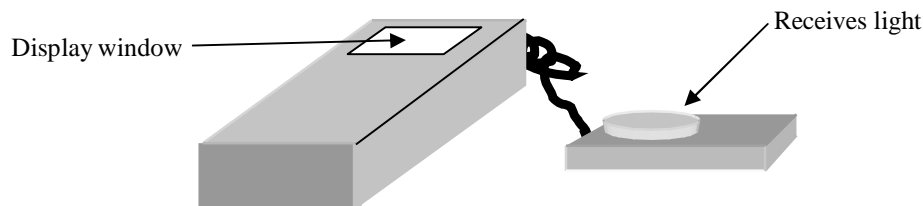


A sling psychrometer has two thermometers, one standard and one with a piece of wet cloth attached to the bulb. It works on the principle that more water will evaporate from this piece of cloth if the relative humidity is lower (Tarbuck and Lutgens, 394). The depression of the wet bulb, or the difference in wet- and dry- bulb temperatures (because of the heat used to evaporate water on the cloth, the latent heat of evaporation) along with the dry-bulb temperature are used to look up the relative humidity and dew point on a table (see Appendix 1 and Appendix 2). Since warmer air has a higher capacity to hold

water vapor, both temperature and relative humidity are necessary to find absolute humidity (for instance, in grams of water vapor per cubic meter air) on a table (see Appendix 3).

3. (1) Light meter. See Figure 3.

Figure 3: Light Meter



A light meter uses a semiconductor that produces a small amount of electricity when a photon, or “light particle,” hits it. Since the current will increase with the rate at which photons are hitting the semiconductor, measuring this current yields a measurement of light (“Measuring Light”). Light was measured in a unit of illumination called LUX, or lumens per square meter.

Procedure

1. Set up the thermometer structure in the Wellesley High School parking lot: $42^{\circ}15'40''N$, $71^{\circ}16'45''W$. See Figure 4 and Figure 5.

Figure 4: Setup of Thermometer



Figure 5: Location of Thermometer in Relation to School



2. Each day measurements are taken,
 - § record maximum and minimum temperatures from thermometer (minimum being the previous night, and maximum at midday)
 - § record wet bulb/dry bulb sling psychrometer temperatures
 - § Estimate percentage of cloud cover.
 - § Record light meter readings every ten seconds for two minutes.

Data

Table 1: Daily Readings of Light, Cloud Cover, Humidity, and Temperature Range

Date	Time	LUX readings (x100) ²	LUX avg. (x100) ¹	Cloud cover	Dry bulb (Temp)	Wet bulb	Relative humidity ¹	Dew point ¹ (°C)	Low (°F)	Low (°C) ¹	High (°F)	High (°C) ¹
4/28	2:00 PM	318 326 793 282 271 263 266 282 274 272 274 274	325	50%	12.5	8.0	57%	1	no data	no data	no data	no data
4/29	2:00 PM	834 835 835 825 824 823 824 824 824 824 824 823	827	10%	24.7	15.5	36%	8	36.9	2.7	83.7	28.7
5/2	8:00 AM	no data ³	no data ³	100%	17.0	14.0	80%	13	62.3	16.8	72.9	22.7
5/4	1:30 PM	295 322 1126 1267 1071 368 337 327 326 334 464 704	578	60%	13.5	10.0	65%	6	42.3	5.7	60.8	16.0
5/6	1:30 PM	1129 1109 1077 1109 801 899 996 729 1026 1096 1052 992	1001	30%	21.8	16.5	58%	14	41.9	5.5	81.7	27.6
5/7	1:30 PM	968 967 970 970 970 969 970 971 970 964 959 950	967	15%	27.0	18.1	40%	14	52.9	11.6	91.1	32.8
5/12 ⁴	1:30 PM	988 985 986 981 981 978 981 981 983 981 982 981	982	10%	32.3	20.0	34%	13	55.3	12.9	93.8	34.3
5/18 ⁴	2:10 PM	no data	no data	100%	23.5	20.8	74%	20	54.7	12.6	85.3	29.6
5/19 ⁴	1:30 PM	678 648 681 665 653 647 652 656 669 694 652 647	661	95%	23.0	20.7	84%	21	62.5	16.9	85.1	29.5
5/26	2:00 PM	188 180 188 180 183 182 181 182 181 183 184 187	183	100%	14.0	10.1	60%	6	47.0	8.3	59.0	15.0
5/27	2:30 PM	893 900 892 894 881 874 878 876 871 867 877 880	882	5%	21.9	18.0	68%	16	50.8	10.4	75.6	24.2

¹ calculated value. See Appendix 1 for relative humidity table and Appendix 2 for dew point table.

² LUX: a unit of illumination equal to one lumen per square meter

³ LUX measurements at 8:00 AM would not be helpful for comparison against measurements at 1:30-2:30, and later in the day, it was raining.

⁴ Consistent sling psychrometer

Data Analysis

Table 2: Absolute Humidity, Dew Formation, and Temperature Range

Date	Humidity (g/m ³) *	Dew point reached overnight? **	Temperature Range, °C (starting previous night)
4/28	6.5	No data	No data
4/29	8.3	Y	26.0
5/2	11.7	N	5.9
5/4	7.9	Maybe ***	10.3
5/6	11.4	Y	22.1
5/7	10.4	Y	21.2
5/12	11.7	Maybe ***	21.4
5/18	16.2	Y	17.0
5/19	17.4	Y	12.6
5/26	7.3	N	6.7
5/27	13.3	Y	13.8

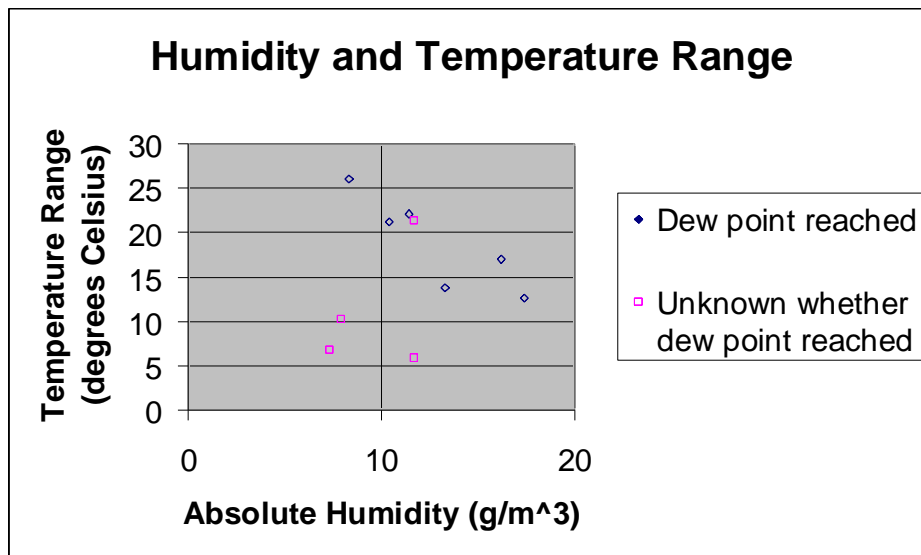
*Calculated as relative humidity times capacity of air to hold water vapor (see Appendix 3).

**From dew point and overnight low; see Table 1.

***Measurements of dew point and overnight low were too close to be certain whether the dew point was reached.

The days when the dew point was not reached overnight corresponded to the two smallest temperature ranges by far; however, the relative humidity was low, implying that another factor (such as cloud cover) was responsible for the small temperature range on these days.

Graph 1:

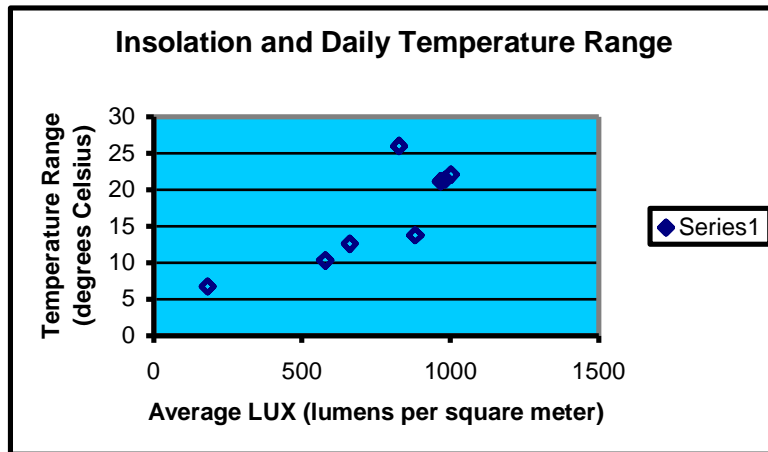


On first glance, it appears that Graph 1 shows no correlation between humidity and temperature range. However, the data points where the dew point was reached show a fairly clear negative correlation – temperature range decreases with humidity. This is explained by the fact that when dew forms, latent heat is released; the more water vapor in the air, the more energy can be emitted as latent heat without the temperature changing. One point where the

creation of dew was unknown also fit this pattern well, suggesting that the dew point was reached.

There is not enough data from days when the dew point was not reached to find a clear pattern for the temperature range versus humidity on these days. However, temperature ranges were generally low, likely because not reaching the dew point meant having a lower overall range.

Graph 2:

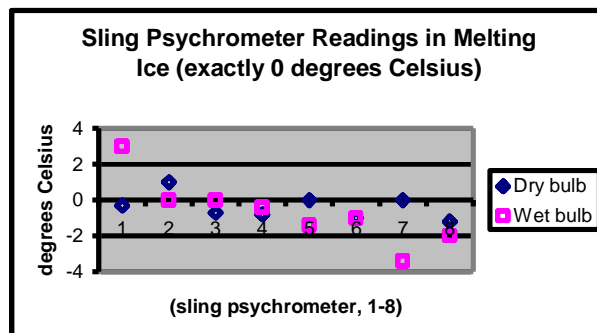


Graph 2 shows a clear positive correlation between solar insolation (radiation or light received at Earth’s surface) and daily temperature range. This supports the idea that cloud cover would insulate the atmosphere (see Appendix 4) because more light reaching the surface corresponds to less cloud cover.

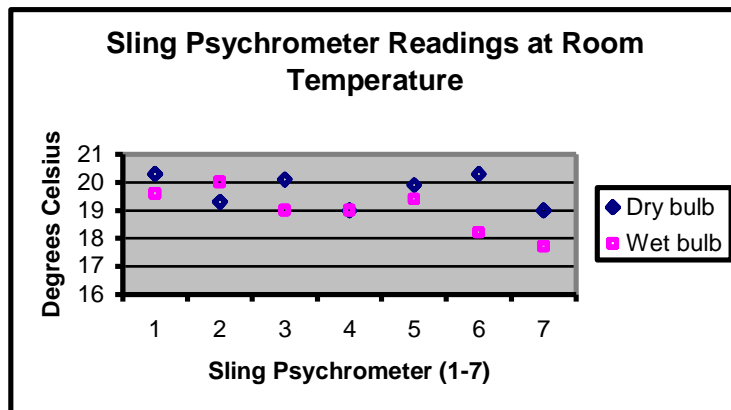
Sources of error

- ◇ Rainfall was not noted. Like dew on the ground in the morning, rain provides water to be evaporated. Energy is converted to latent heat instead of raising the temperature when water is evaporated, so rainfall might have been lowering daytime high temperatures without being recorded.
- ◇ Inaccurate values from the sling psychrometer may have skewed relative humidity calculations. See Graph 3 and Graph 4.

Graph 3:



Graph 4:



Although a few degrees' difference between the wet and dry bulbs is a small percentage at room temperature, it can make a large difference in the calculated relative humidity. To minimize this problem the same psychrometer was used once the problem was noted, starting May 12th. Both wet and dry bulbs read 20.8 degrees Celsius at room temperature; in melting ice, the dry bulb read -0.4 degrees and the wet bulb -0.5 degrees. However, the marked sling psychrometer was missing after May 19th, so very few measurements of relative humidity are known to a high degree of accuracy. One standard deviation for a sling psychrometer measurement (wet bulb or dry bulb), calculated as

$$\sqrt{\frac{1}{16} \sum_{i=1}^6 (\bar{x} - x)^2}$$

where \bar{x} is the average temperature measured and x is a temperature measurement, is 1.3 degrees Celsius. If the wet and dry bulbs are each one standard deviation away from the actual temperature, the relative humidity can easily be 15% more or less than the actual relative humidity.

- ◇ Cloud cover and light were only measured at one point in the day, which could have been during a period of unusually clear or cloudy sky for the day.
- ◇ 12 data points is an exceptionally small sample size; more data would be needed to provide more statistically significant results.

Conclusion

The negative correlation between absolute humidity and daily temperature range when the dew point is reached (see Graph 1) is consistent with the hypothesis that higher humidity would correspond to smaller daily variations in temperature. However, the data is inconclusive because of the small number of data points and large uncertainty in relative humidity.

Using a consistent sling psychrometer with greater precision and accuracy to measure relative humidity, measuring cumulative insolation rather than light at a particular time, and taking data for a longer period of time would result in more conclusive data.

The finding that water vapor decreases the daily temperature range would be of use to farmers for predicting safe times to start planting crops - since an early frost can kill plants, it is crucial not to plant too early, but at the same time, an early start gives plants more time to grow. Relative humidity could be used to predict the best time to plant. Also, the daily temperature

range is important for various other species that cannot live above or below certain temperatures; being able to predict the temperature range would allow biologists to assess the impact of human activity that changes the humidity (for instance, in predicting climate change because of global warming) on animal populations.

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