Global Journal of Researches in Engineering: J
General Engineering
Volume 19 Issue 2 Version 1.0 Year 2019
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Urban Heat Island Effect on Building Electricity use

By Menglin S. Jin & Rebecca Huff
University of Maryland

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GJRE-J Classification: FOR Code: 580799

URBANHEATISLANDEFFECTONBUILDINGELECTRICITYUSE

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Urban Heat Island Effect on Building Electricity use

Menglin S. Jin α & Rebecca Huff σ

Abstract- The campus-wide electricity use in University of Maryland, College Park (UMCP) is highly correlated with the outdoor 2-meter surface air temperature, at hourly, daily, and monthly scales, with the correlation coefficients normally > 0.70 in 2014 and 2015. Nevertheless, 2-meter surface air temperature has evident spatial heterogeneity, determined by underlying surface types and surrounding vegetation fraction, with up-to 6 °F difference between a roof on campus and a vegetation-covered airport for the clear days on Julys 2014 and 2015. Such urban heat island effect (UHI) signal suggests that urban local surface air temperatures, instead of those in an nearby airport, may be needed in order to accurately forecast the electricity use for a given urban community. In addition to outdoor weather conditions, campus electricity use amount is also affected by other factors such as human behavioral pattern, for example, weekdays vs weekends. Therefore, interdisciplinary effort from weather system, society, and mechanical engineering is needed to fully understand and thus forecast electricity use.

I. INTRODUCTION

Electricity is needed to power heating, ventilation and air conditioning (HVAC). An average of 41% of the consumed electricity in the U.S. is used by HVAC systems [Goetzler *et al*. 2014], which is widely implemented on buildings to maintain human comfortable level. In addition, lightings and lab equipment such as computers also need electricity. Accurately forecasting electricity need for a building, a community, or a city is critical for the facility management to plan the resources in advance for sustainable development and electricity savings. Various natural weather factors, in particular, the ambient air temperature and humidity, affect the amount of electricity used in buildings [Jin 2018]. In addition, the configuration of the building structure such as the materials of the roof and exterior walls, the shape of the building, the slope of the roof and the number and size of the windows affect building energy use [DOE 2015, Wei *et al.,* 2016]. Various studies assess building contributions to the Urban heat island effect (UHI) and vice versa. For example, Shahmohamadi *et al.* [2011] showed that the lack of impervious surface materials in the city Tehran, Iran forced "an evaporation deficit in the city which is caused intensity of urban heat island." If the city continues to build structures using "waterproof and low albedo" materials, the surface air temperature there would further rise. UHI is mainly caused by reduced surface albedo [Jin et al. 2005], less vegetation coverage in the city, less soil moisture, and reduced heat capacity in urban surfaces [Table 1]. Specifically, for vegetation surface, the heat capacity is 1300J/g/K while the asphalt parking lot and roof are only 1000 J/g/K and 837 J/g/K, respectively. Therefore, with the same amount of solar radiation absorbed, vegetative covered airport would have less ground temperature increase than the parking lot and roof since part of the solar radiation absorbed in the airport is redistributed as latent heat flux. Furthermore, parking lot and roof surface albedo differs from vegetation- covered airport, as shown in Table 1, and results in UHI (Jin et al. 2005).

Via evapotranspiration, soil moisture affects atmospheric humidity, another parameter important for HVAC control on building environment. Urban regions have less soil moisture for evaporation, a natural physical process that cools down the surface [Zhao *et al.* 2013]. Dickinson [1992] concluded that "presence or absence of vegetation is significant", which can be revealed through the diurnal temperature and humidity variations between urban and rural surfaces. Humidity affects electricity use similarly to how outdoor temperatures do. The specific heat capacity of water, as expressed by Perlman, is defined as "water has to absorb 4.184 Joules of heat for the temperature of one gram of water to increase 1 degree Celsius (°C)." Therefore, it takes electricity to make the air drier just as ground water needs absorption of solar radiation to evaporate. According to Byrd Heating and Air Conditioning, "air conditioners cool homes by removing heat and moisture from the air. When humidity levels are excessive, they need to work a lot harder." As HVAC systems work through high humidity levels, more electricity is needed to power moisture off the room and cool a building. Nevertheless, due to the limited availability of humidity data, this study only studies the air temperature effect on building electricity use.

This study compares 2-meter surface air temperatures measured from various urban surfaces with that in a local airport, College Park, MD. Temperature heterogeneity throughout a small city like

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Author α σ: Oceanic Science, University of Maryland – College Park, MD. e-mail: mjin1@umd.edu

College Park, MD of 30,000 population, namely, apparently indicate the UHI1 [1]

signal,a well known phenomena that city surface is hotter than non-urban region. More importantly, the electricity use on the University of Maryland, College Park (UMCP) campus has high correlation coefficients with outdoor 2-meter air temperatures. In addition, the airport 2- meter surface air temperature, which is traditionally used in energy industry, is less related to UMCP building electricity use than other surfaces in a city environment. Airport 2 meter surface air temperature, in general, is lower than urban surfaces at night as well by 2-6 °F. The electricity use on UMCP campus showed a high-correlation relationship (coefficient ~0.81)with the 2-meter surface air temperature. Nevertheless, abrupt electricity use may occur for currently unclear reasons and forecasting such abrupt change is a key need in current energy industry. Correlation coefficient could be as low as 0.1-0.5 when abrupt electricity use appears. The section below discusses the data used in this work. Section 3 briefs the methodology of this study as well as uncertainty discussion, followed by the results analyses in Section 4. A final remark is given in Section 5.

II. Data

To study the urban heterogeneity and UHI signals, six surface types were analyzed, including a roof located on the top of the UMCP Atlantic Building (ATL) which is 50 feet tall red brick research and lab building (Figure 1b), two roofs in the National Aeronautics and Space Administration Goddard Space Flight Center (NASA GSFC) campus that is ~2.5 miles away in direct distance from the UMCP campus, an asphalt parking lot and a grass field at GSFC (Figure 1a), and College Park airport which is 1.5 miles away from UMCP. In UMCP, the 2- meter surface air temperatures was measured by Earth Networks SM(EN) weather station located 5 feet above the roof surface. This weather station records the temperature on a 24 hours/7 days a week basis with 15-minute interval in order to assess the diurnal, daily, monthly and seasonal variations. The ATL roof is comprised of a rough stone surface and has a tan coloration. Field experiment was conducted at NASA GSFC campus by the NASA Climate Adaption Science Investigation group(M. Carroll, personal communication, 2016).The temperature equipment used in GSFC field experiment was the "HOBO U23 Pro v2 External Temperature/Relative Humidity Data Logger-023-002" at 2 meters above each surface. During the time of collection in October 2013 - November 2015, the NASA Climate Adaption Science Investigation group programmed the loggers to record the temperature in 15-minute intervals beginning at the start of each hour and the data are sampled to hourly for use. The logger includes a radiation shield to minimize sunlight influence on the temperature. In addition,two-meter surface air temperatures recorded by an Automated Weather Observing System (AWOS) station at the College Park Airport located 1.5 mile away from the UMCP campus is also used. The temperature sensor is approximately 5 feet above the ground and also includes a radiation shield to minimize sunlight influence, as standard requirement by WMO.

The hourly, campus-wide electricity data used in this analysis was provided by UMCP facility management (Susan Curry, personal communication, 2016). The electricity use was measured in Kilowatt Hours (kWh) on six different accounts for the campus and these accounts have been summed to represent the entire campus electricity use.

III. Methodology

The diurnal, seasonal, and inter-annual variations of the 2-meter surface air temperature measured at the five different urban surfaces, together with College Park airport weather station measurements, are compared with the electricity use on the UMCP campus, via correlation coefficient calculation, Box-and-Whisker Plot analysis, and regression analysis. Five urban surfaces (parking lot, one grass field, too roofs) located at the NASA GSFC are only approximately 2.5 miles away from the UMCP campus and normally have the same atmospheric and bounder-layer conditions. These GSFC sites are used to study the different urban surfaces impacts under the same solar insolation and wind conditions in 2014 and 2015.

a) Uncertainty Analysis

Uncertainties of the results may exist on the *in-situ* 2-meter surface air temperature measurements. While other surfaces remained similar relative features in 2014 and 2015, ATL roof was colder than the airport during the daytime and warner than the latter in 2015. Two possible reasons are for such a big difference: inter-annual weather variation in city or calibration error. The 2-meter surface air temperatures data from the ATL roof need to be further validated to understand this two-year variations.Unfortunately, without other UMCP sites to cross-validate, we cannot determine what is the reason for the difference. This is also the reason that GSFC observations are included to across-check the UHI and electricity use relations. Nevertheless, a 2.5 km

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[1] Urban heat island effect (UHI) originally is observed from 2-meter surface air temperature (Landsberg, 1975, Oke 1982). On this weather field, UHI is most evident at night and therefore is called as "nocturnal phenomenon". Nevertheless, UHI has also been identified from the satellite-based land surface skin temperature (Jin et al. 2005, Zhang et al. 2017). On skin temperature, UHI signal is apparent during both daytime and nighttime. Skin temperature and 2-meter surface air temperature have different physical meaning and thus magnitude, as discussed by Jin (2010, 2012). During daytime, mixing in boundary transfers heat from the surface to 2-meter air level, and thus reduces UHI signal during the day at 2-meter air level. Given the focus of this study, only 2-meter air temperature is analyzed.

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away might lead to different atmospheric conditions sometimes, which is another uncertainty source.

The field experiment of GSFC, although well documented and calibrated, covered only two years from late October 2013 through early November 2015. This limits the capability to understand the relationship between surface air temperatures and the electricity use. A statistical analysis with longer observation duration would be insightful.

Last, and most importantly, in order to reach a better understanding of the electricity use, in particular, extreme electricity use, individual building electricity usage data is needed. The electricity data used in this study is a sum of about 200 buildings on the UMCP campus. Each building, nevertheless, has unique requirement of energy use and people behavior pattern. This analysis only reveals an integrated sense of the relation between 2-meter air temperature and campus wide electricity use.

IV. RESULT DISCUSSION

UHI signal is evident on the monthly diurnal cycle of the 2-meter surface air temperatures measured at the College Park airport and UMCP Atlantic Building roof (ATL, Figure 2a), with the ATL roof temperature higher than the airport by 2-3 °F at night but less than 1 °F during the day for July 2015. The UHI is significant at night when more longwave radiation emitted from the building walls and campus roads heated up the 2-meter air than in CA airport. In addition, more water-proof surfaces in UMCP than in airport led to less soil moisture evaporation thus nighttime temperature. The CP airport is surrounded by grassy surfaces and therefore soil moisture underlying led to higher specific heat capacity and evaporation, which redistributed part of the absorbed radiative radiation into latent heat flux and thus slowed down the warming process. Specifically, the general patterns of the diurnal cycle for both surfaces were similar: temperatures decreased after sunset and the cooling continued until sunrise in the next morning. As daylight began, 2-meter air temperatures raised because of the absorption of solar radiation at the ground surfaces and then gradually warmed up the air above the ground. Maximum temperature was reached in the mid-afternoon hours (4 p.m. in summer time which is one hour after the real local time). Nevertheless, temperature peaked at different time for these two surfaces - ATL roof at 4:00 p.m. and the CP airport at 5:00 p.m. (summer time). After the peak, a decreasing continued when the sunlight gradually diminished.

During 10:00 a.m. to 7:00 p.m., ATL roof outdoor surface air temperature was close to CP airport with only 0-0.5 °F difference. Such a feature on monthly-average scale might be that the average process smoothed large day by day variation. Specifically, in July 2014 (Figure 2b), the box-and-whisker plot revealed that larger day-by-day variations occurred in CA airport, in particular, at night and during the noon, than in campus roof. In addition, CA airport was hotter than ATL roof from 1-7 PM. Nevertheless, ATL roof was still warmer than the airport during the nighttime hours. The CP airport surface air temperature had a wider range of readings possibly due to the effects of soil moisture changes. Although both surfaces may receive approximately the same amount of solar radiation, the underlying surface albedo of the mastic asphalt roof material is 5-7% while the dry vegetation albedo varies from 1-25% (Table 1), therefore on dry July days the airport had larger variations at absorbing surface insolation, leading to the larger 2- meter air temperature variations than ATL roof did. On the other hand, at night, the observed large variation on 2-meter surface air temperature at the airport was probably due to clouds cover and soil moisture variations.

This inter-annual variations of Julys 2014 (Figure 2b) and 2015 (Figure 2a) proves a well-studied UHI phenomenon previously revealed by Oke (1982): UHI is most significant at night on 2-meter surface air temperature variable. During the daytime, the UHI signal could be well mixed by boundary-layer convection and thus had reduced magnitude or even no signal at all. Note that in July 2015, ATL roof temperature was close or higher than that in airport around noon to early afternoon (Figure 2a) while in July 2014, it was lower than the airport (Figure 2b). Such a big 2-year difference may be due to two reasons: inter-annual variations in weather conditions or measurement uncertainty. The ATL roof temperature records were not well validated since there were no other roof data at UMCP available. To gain more understanding, field experiment data conducted at 2.5 miles away in GSFC campus were analyzed in this study.

All six surfaces showed similar seasonal variations on the 2-meter surface air temperatures (Figure 3a-c). In April 2014, at nights (Figure 3a), cooling of each surface was a result of reduced longwave radiation emitted from the underlying ground. ATL roof was warmer than the airport between 12:00 a.m. and 7:00 a.m., a UHI signal of 1.5-2 °F. At night from 8:00 p.m. and 11:00 p.m. UHI signal gradually increased since heat absorbed by building walls and roads in daytime was re-emitted in form of longwave radiation to heat up surface-layer atmosphere. Furthermore, urban temperature heterogeneity is evident. In April 2014, UMCP ATL roof had the lowest diurnal range compared with NASA GSFC campus surfaces and CP airport. The roof 2 of NASA GSFC had the highest monthly-average surface air temperature (66 °F). ATL roof also had the lowest daytime peak among all these surfaces, with difference by as much as 4 °F from roof 2 at early afternoon. Such a large difference may be partly due to the relatively condensed urban building blocks on UMCP campus than on GSFC and partly due to

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uncertainty of roof measurements. Nevertheless, different part of urban area having different temperature and thus different UHI magnitude is a well-known, physically sound feature in urban system. How such a feature can be used in electricity use forecast is an important question to be addressed.

A clear bell-curve was observed for UMCP campus-wide electricity use with the lowest value occurring at 3:00 a.m. and the maximum occurring at 2:00 p.m. This electricity use pattern followed the temperature diurnal cycle pattern. A 3:00 a.m. minimum was reasonable since people left campus and students rest after nighttime studies. At sunrise, the electricity use began to increase, resulting from heating each building before students and faculty arrival as well as turning on lab equipment, lighting, classroom tools, etc. for the day. Less heating was needed in the afternoon hours, followed the maximum at 2:00 p.m. due to warm ambient air temperatures outside the buildings.

In July 2014, electricity use pattern and 2-meter surface air temperatures had similar diurnal cycles as in April 2014 (Figure 3b). The monthly averaged minimum temperatures were observed around sunrise due to radiative cooling at night. Again, ATL roof had the highest 2- meter surface air temperature during the nighttime hours than other surfaces, suggesting the most significant UHI effect on the UMCP campus. Nevertheless, the electricity use amount differed from April. With fewer students and faculty on campus in July, the electricity use decreased from April, although still high during most of the daylight hours with the maximum occurring at 2:00 p.m. just before the average surface air temperature maximum. Specifically, the maximum in April was 20700 kWh and in July was only 16500 kWh, a 20% decrease even though the outdoor air temperature had a 21 °F increase (April maximum 66 °F while July maximum 87 °F). July is one of the hottest months of the year in Maryland and thus many buildings on campus use air conditioning to accommodate for the warm temperatures outdoors. Between 11:00 a.m. and 300 p.m. the electricity use amounts were very similar, showing almost constant high el ectricity use between 16,000 kWh and 16,500 kWh.

November 2014 was a cold month with the averaged 2-meter surface air temperature minimum below 40 °F and maximum around 52 °F (Figure 3c). Again, ATL roof continued to show strong nighttime UHI signal by comparing with the CP airport. The averaged 2-meter surface air temperatures at the NASA GSFC campus, on the other hand, were similar in July and the roof 2 topped out with the highest temperature at 4:00 p.m.. In addition, the averaged electricity use followed the surface air temperatures with the minimum occurring at 3:00 a.m. and the maximum occurring at 4:00 p.m., which is after the maximum temperature of 3 p.m. This 4:00 p.m. maximum may be not only due to needed heat for decreasing solar radiation in winter, but also to the need of turning on lights in buildings. Further, the absolute amount of electricity use in November was less than in April and July because in winter a lot of buildings used steamed water to warm the building, a different mechanic approach instead of electricity-based AC and thus less electricity used.

To study inter-annual variations, April and July 2015 are analyzed (Figure 4). First, the diurnal cycle of 2-meter air temperatures were very similar in April 2015 (Figure 3a) and in April 2014 (Figure 4a) with the maxima both occurred at 4:00 p.m. Roof 2 of NASA GSFC campus was still the warmest among all 6 surfaces during daylight hours. Although the field data was missing for this month, comparisons were still meaningful. ATL roof continued to show UHI effect during the nighttime hours up until the sunrise at 7:00 a.m., with the maximum UHI at 12:00 a.m. and 6 a.m. of approximately 4 °F. However, the ATL Roof remained the coolest during the daylight hours in this month among the 6 surfaces.

Similar to 2014, the monthly averaged electricity use peaked before the maximum temperature in April 2015 while the minimum at 3:00 a.m. Having a minimum at 3 a.m. for each analyzed month may suggest that there could be a regulated amount of electricity use during the nighttime hours on the UMCP campus before a large jump in electricity need after sunrise. The electricity use quickly increased after sunrise due to the influx of students and faculty arrival on campus and thus needed both lightning and heat in the buildings. Therefore, human behavior pattern, together with air temperature condition, affects campus electricity use.

The maximum 2-meter surface air temperature in July 2015 occurred at 4:00 p.m. with the roof 2 surface being the warmest among the 6 surfaces (Note this is summer time, Figure 4b).However, UMCP ATL roof stayed warmer than CP Airport in both daytime as well as nighttime, which was different from that in July 2014, indicating a daytime and nighttime UHI. The GSFC field surface had the lowest averaged hourly 2-meter surface air temperature during the nighttime in July 2015. Furthermore, the electricity use showed the inter-annual similarities in July 2015 to July 2014. The maximum electricity use had a leveling period between the hours of 10:00 a.m. to 3:00 p.m. In addition, the actual kWh values were much greater in 2015 than in 2014 by 3,000 kWh, which was consistent with the daytime UHI occurring in July 2015 on campus.

High correlation coefficient(>0.75) between hourly electricity use and 2-meter surface air temperature for the week of August 1-5, 2015 occurred for all urban surfaces (Figure 5 a-c, other surfaces not shown). The maximum correlation was approximately 0.80 for the field of GSFC, with 0.75 for roof 2 and 0.77 for parking lot. In this week, in particular, the field seems to be a better index for electricity use than the parking lot or roof 2. On each day, the campus electricity use had clear diurnal cycle, following the 2-meter surface air temperature. Since August was the month when many students and faculty were not on campus for summer break and thus few events scheduled on campus, the electricity use was likely only geared towards HVAC and lighting for buildings. Nevertheless, daily variations in electricity use were evident and, in particular, there was an abrupt decrease on August 5morning. Reasons for this sudden decrease and then jump back were unidentified. From all the two-year data analyzed, such an abrupt change in electricity use occurred not rarely. Unfortunately, reasons for such abrupt change were unidentified due to the limited data availability. Such abrupt change could lead to power outrage and a significant jump on electricity bills, but forecasting such an electricity abrupt change is challenge if reasons unknown. The only conclusion one can draw so far is that such an abrupt change in electricity use may not be induced by weather.

People behavioral pattern affected the electricity use. For example, the campus electricity use differed on weekday and weekend. During the weekdays, electricity was more predictable due to the daily electricity use routine on the UMCP campus, specifically, August 3, 4, and 5 except for its abrupt change for a short period of time in the morning. On the contrary, August 1st and 2nd, 2015 were Saturday and Sunday, respectively, and had significant decrease in electricity use due to a lower energy demand on the campus. This suggests that when forecasting electricity use, weekday and weekends should be separately simulated.

The correlation coefficients between UMCP campus electricity use and 2-meter surface air temperatures for parking lot, roofs, grass field and CA airport on each days of August 2015 showed heterogeneous surface impacts on electricity use (Figure 6). First, although August 10th was missing due to the lack of data, correlation coefficients were in general more than 0.75, indicating a possible relationship between surfaces and the electricity. Specifically, more than 1/3 days, the coefficients were above 0.90. Second, the lowest correlation occurred on August 28th, 2015 which was below 0.27 for all surfaces. August 28th was one of the first days when students moved into their dormitories on the UMCP campus, which may need for more electricity to meet the demand of students and their families coming onto campus. Since August 29th (a Saturday) correlation coefficients recovered, the university likely adjusted the electric load need to accommodate the influx of students. Third, differences in correlation were detectable, suggesting that different surface was related to electricity use differently. The field surface, again, had in general the largest coefficients in August 2015. The correlation for field on August 9th and August 14th were almost 1.0, indicating almost a 100% correlation between surface air temperatures and electricity used. On days such as August 17th, 21st and 27th much smaller correlations were shown for all surfaces, due to sudden change on electricity use field with unidentified reasons. The ATL roof data were not reliable to be included in this specific analysis.

Extreme electricity use, for example, August 5th 2015, is most needed to be forecasted since the facility management needs to foresee the needs so that they can arrange strategies in advance to save electricity bills. Energy price normally soars on extreme use hours and if too much electricity use might lead to blackout. Nevertheless, forecasting extreme electricity use is a challenge since it depends not only outdoor weather but also many known or unknown society factors and building facility configurations. In other worlds, simply use weather information cannot accurately forecast extreme electricity use since these two are not linearly related. For example, the maximum 2-meter surface air temperature for August 3rd , 4th , and 5th were 93 °F, 94 °F, and 90 °F, respectively, and the electricity use on these three days were 18000 kWh, 20000 kWh, and 23000 kWh, respectively (Figure 5). A 11% increase in electricity use for a 1 °F temperature increase, from August 3 to August 4.On August 5, however, although 2-meter surface air temperature decreased by 4 °F from August 4th, the electricity use in fact increased by 15%. The daily correlation coefficients for extreme day (August 5th) case was0.92 between field and electricity use, which was higher than all the rest surfaces studied (Figure 5). Nevertheless, this high correlation coefficient does not lead much ways to forecast the extreme temperature use on that day. More research, combined both natural, societal, and mechanical data, are urgently needed.

A random day (July 30th, 2014) was selected to show the UHI signals for a specific summer day (Figure 7). This day was chosen only because it represented typical diurnal variations of UHI. First, UHI signals were evident at night from 9 PM to 8 AM, a well-known nocturnal phenomenon which was also shown in monthly mean (Figure 3b). The UHI signal could be ~6 °F between UMCP ATL roof and College Park airport, at 6 AM, and could be relatively small for Roof 1 and Roof 2, with about ~5 °F. During the daytime, the UHI signals for all three roofs were not evident, partly because of strong convection rapidly exchanging heat at the lowest surface-layer. Clear nighttime UHI might be important for HVAC control strategy, for example, most of building HVAC has free cooling operation, which uses the outside fresh air to replace building inside air at night when weather conditions are proper. This is an important way to save HVAC energy. Free cooling threshold is a function of outside air temperature. For example, in UMCP, when 2-meter air temperature is 60-70 °F, it is set to do free cooling (Curry, UMCP facility manager, personal communication, 2016). Currently, airport air temperature forecast is used in energy use industry. As shown from Figure 7, airport temperature could be 5-6 °F lower than campus building outside temperature.If based on airport temperature, HAVC management may miss free cooling nights when airport coder than 60 °F but UMCP temperature within 60-70 °F. Therefore, forecasting building outside air temperature could be helpful for HVAC control planning.

Regression equations were derived based on hourly 2-meter surface air temperature of UMCP ATL measurements and campus-wide electricity use data for June 2014. Again, weekday and weekends had apparently different values, as previously discussed in Figure 5. The regression equation for weekdays is:

$$Y = -17374 + 402.5\ X,$$

where Y is hourly campus-wide electricity use amount and X is 2-meter building outside air temperature. Units of coefficient is 402.5kWh/°F and-17374kWh, respectively. For the weekends,the regression equation is:

$$Y = -3868.9 + 17885X,$$

Where the units of coefficients are -3868.9kWh and 17885 kWh/°F,respectively.

In addition to 2-meter air temperature, we also combined humidity information (dew point, relative humidity) and vegetation index from remote sensing to better interpret the spread of electricity use (results not shown). Nevertheless, neither humidity nor vegetation index can better explain why for the same outdoor air temperature, large differences on electricity use occur. Simple put, other factors in addition to weather conditions may be responsible for big increase in electricity use.

Most importantly, abnormal values of electricity use occurred for almost all surface air temperatures. For weekdays, for example, it could be 25000 kWH for air temperature of 80 °F. Even for weekends,when much fewer events and population, electricity use could extreme at 18000 kWh at 70 °F. Understanding such extremes in electricity use is most critical, but challenge, in order to forecast it. Our research showed that big values seems to be partly due to human behavioral such as football games on campus, building HVAC configurations, and building structure. Nevertheless, we are far from being able to weight the key reasons to a level to forecast such extremes. Interdisciplinary collaborations among HVAC engineering, facility data record, and weather information are needed for future research.

V. Conclusion

This study focused on addressing how different surface surfaces affect the electricity use on the UMCP campus. Analyses on the monthly averaged hourly surface air temperature for April, July and November 2014 as well as April and November 2015 show clear UHI signals for all urban surfaces (parking lot, ATL roof, roof 1, roof 2 and field), with relatively different magnitudes due to thermal and dynamical differences. ATL roof, in particular, shows strong, consistent UHI signals up-to 6 °F during the night hours but much less in the daylight hours. In addition, the surfaces such as the roof surfaces on the NASA GSFC campus were warmer than airport by as much as 4 °F, mostly during the daytime hours.

The diurnal cycle of electricity use, in general, follows the outdoor air temperature well. The correlation coefficients between 2-meter surface air temperatures among surfaces on the NASA GSFC campus, CP airport and the UMCP electricity use all showed similar, high correlation (>0.75) for most of the days. Nevertheless, extreme electricity use and abrupt changes may occur, from time to time, with unidentified reasons In addition, the field might be an adequate index to forecast electricity use since it had a correlation of above 0.80, while the other surfaces has correlation around 0,70-0.74 (Figure 6).

Outdoor air temperature is partly responsible for building electricity use. Therefore UHI has important use on electricity use management. Nevertheless, other factors, such as human behavior pattern, building mechanical configuration and thermal materials, also attribute to electricity use.

Weather system impact on the electricity use is an inter-disciplinary research. Observations and efforts from weather system, mechanical engineering, and society are essential in order to improve current knowledge to a level to forecast electricity use as functions of local weather, people behavior, and underlying land cover and economic factors.

Acknowledgements

This work is funded by NASA Precipitation Program (award NNX16AD87G) and NSF I-Corps Program (award number 1639727). Thanks go to Mark Carroll of SSAI for providing us GSFC measurements. Study was part of the senior thesis of the co-author Huff.

References Références Referencias

1. Byrd Heating and Air Conditioning 2015: How does Humidity Affect Air Conditioning and Heating? https://byrdheatingandair.com/articles/how-does-humidity-affect-air-conditioning-anheating(Accessed November 24, 2017). IES Virtual Environment, Apache-Tables User Guide.
2. Department of Energy (DOE). September 2015: Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities Chapter 5: Increasing Efficiency of Building Systems and Technologies.
3. Dickinson, R. E., 1992: *Climate System Modeling: Land Surface*. K.E. Trenberth, Ed. Cambridge University Press, Cambridge.

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4. Duan, R., C. B. Fedler, and J. Borrelli, 2012: Comparison of Methods to Estimate Saturated Hydraulic Conductivity in Texas Soils with Grass. *Journal of Irrigation and Drainage Engineering*, 138, 322–327.
5. Goetzler, W., M. Guernsey, and J. Young, October 2014. *Research & Development Roadmap for Emerging HVAC Technologies*. Prepared by Navigant Consulting, Inc.
6. Jin, M., R. E. Dickinson, and D. Zhang, 2005: The Footprint of Urban Areas on Global Climate as Characterized by MODIS. *Journal of Climate*, 18, 1551–1565, doi:10.1175/jcli3334.1.
7. Jin, M. and R. E. Dickinson, 2010: Land Surface Skin Temperature Climatology: Benefitting from the Strengths of Satellite Observations. Environ. Res. Lett. 5, 044004.
8. Jin, M., 2012: Developing an Index to Measure Urban Heat Island Effect Using Satellite Land Skin Temperature and Land Cover Observations. *Journal of Climate*, **25**, 6193–6201,
9. Zhang, H. M. Jin, M. Leach, 2017: A Study of the Oklahoma City Urban Heat Island Effect Using a WRF/Single-Layer Urban Canopy Model, a Joint Urban 2003 Field Campaign, and MODIS Satellite Observations. Climate 2017, 5(3), 72.
10. Jin, M., 2018: The Relationship Between Surface Temperatures and Building Electricity Use: A Potential New Weather Application. Journal of Building and Sustainability, 2018, vol1.
11. Lang, J., S. Lyu, Z. Li, Y. Ma, and D. Su, 2018: An Investigation of Ice Surface Albedo and Its Influence on the High-Altitude Lakes of the Tibetan Plateau. *Remote Sensing*, **10**, 218.
12. Landsberg, H. E., 1975: Atmospheric changes in a growing community, Inst. Fluid Dynamic Appl. Math Note, University of Maryland (1975). No. BN 823
13. Markowski, P., and Y. Richardson, 2010: Mesoscale Meteorology in Mid-latitudes. Wiley- Blackwell, Chichester. 83-87.
14. Oke, T.R., 1982: The Energetic Basis of the Urban Heat Island. Quarterly Journal of the Royal Meteorological Society, 108, 1-24.
15. Oke, T. R., 1987: *Boundary Layer Climates*. Routledge, Taylor & Francis Group, London. 401.
16. Perlman, U. S. G. S. H., Specific Heat Capacity of Water. *Specific Heat Capacity of Water (Water Properties, USGS Water Science School*) https://water.usgs.gov/edu/heatcapacity.html(Accessed November 24, 2017).
17. Ramirez, A. Z., and C. B. Munoz, 2012: Albedo Effect and Energy Efficiency of Cities. *Sustainable Development - Energy, Engineering and Technologies - Manufacturing and Environment*, doi:10.5772/29536.
18. Shahmohamadi, P., A. Che-Ani, I. Etessam, K. Maulud, and N. Tawil, 2011: Healthy Environment: The Need to Mitigate Urban Heat Island Effects on Human Health. *Procedia Engineering*, 20, 61–70.
19. Standfuss, C., M. Viollier, R. S. Kandel, and J. P. Duvel, 2001: Regional Diurnal Albedo Climatology and Diurnal Time Extrapolation of Reflected Solar Flux Observations: Application to the ScaRaB Record. *Journal of Climate*, 14, 1129–1146.
20. Touchaei, A. G., M. Hosseini, and H. Akbari, 2016: Energy savings potentials of commercial buildings by urban heat island reduction strategies in Montreal (Canada). *Energy and Buildings*, 110, 41– 48.
21. U.S. Environmental Protection Agency, 2008: Cool Roofs."In: Reducing Urban Heat Islands: Compendium of Strategies .https://www.epa.gov/Heat-islands/heat-island-compendium.
22. Wei, L., W. Tian, J. Zuo, Z.-Y. Yang, Y. Liu, and S. Yang, 2016: Effects of Building Form on Energy Use for Buildings in Cold Climate Regions. *Procedia Engineering*, **146**, 182– 189.
23. Weng, Q., D. Lu, and J. Schubring, 2004: Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies. *Remote Sensing of Environment*, **89**, 467–483, doi:10.1016/j.rse.2003.11.005.
24. World Urbanization Prospects. 2014 ed. United Nations Department of Economic and Social Affairs.
25. Zhao, L., J. Xia, C.-Y. Xu, Z. Wang, L. Sobkowiak, and C. Long, 2013: Evapotranspiration estimation methods in hydrological models. *Journal of Geographical Sciences*, **23**, 359- 369.

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TABLES AND FIGURES

Table 1: Typical values for urban surfaces [Dobos 2005, Duan *et al.* 2012, IES, Ramierez *et al.* 2012,U.S. EPA 2008].

Surface Qualities	Dry Vegetation	Parking Lot (Asphalt)	Mastic Asphalt Roof Material	Bare Soil	Water
Albedo	1-25%	2-10%	5-7%	25-45%	10%
Emissivity	75-99%	90-98%	92-97%	55-75%	90%
Heat Capacity	1300 J/g K	1000 J/g K	837 J/g K	837 J/g K	4175 J/g K
Hydraulic Conductivity	2.03 W/m K	0.500 W/m K	1.150 W/m K	1.729 W/m K	N/A

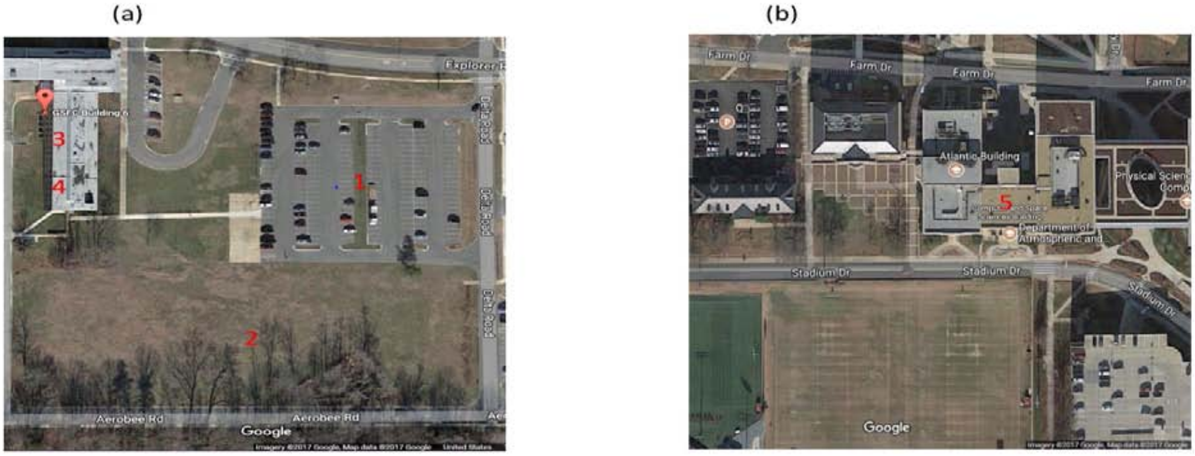

Figure 1: Maps of the locations and surrounding land cover for (a) NASA GSFC campus field experiments 1 is parking lot, 2 is grass field, 3 and 4 are roof 1 and roof 2, respectively; and (b) UMCP Atlantic Building roof site from Earth Network. The weather station in College Park airport is not shown since it is a standard weather station locating above grass, as required by WMO standard

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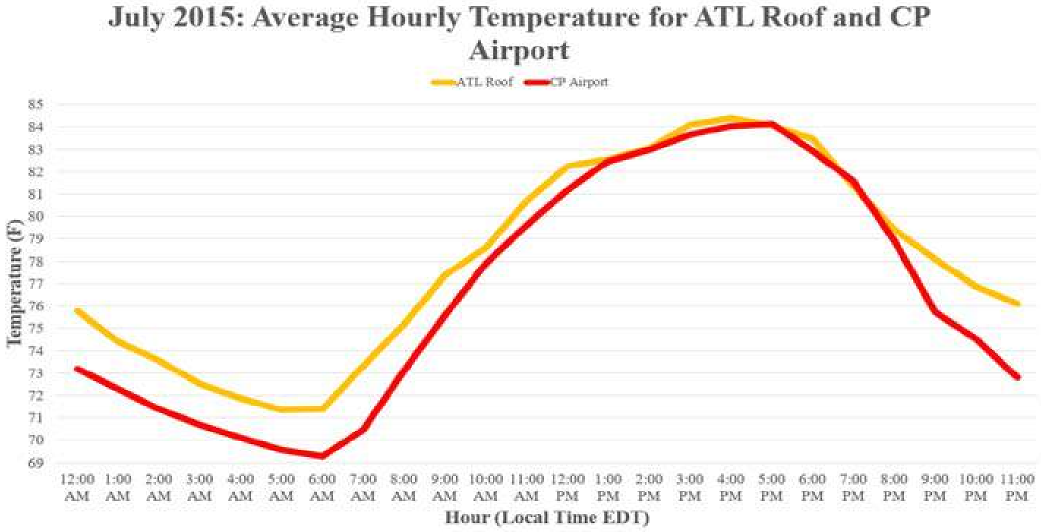


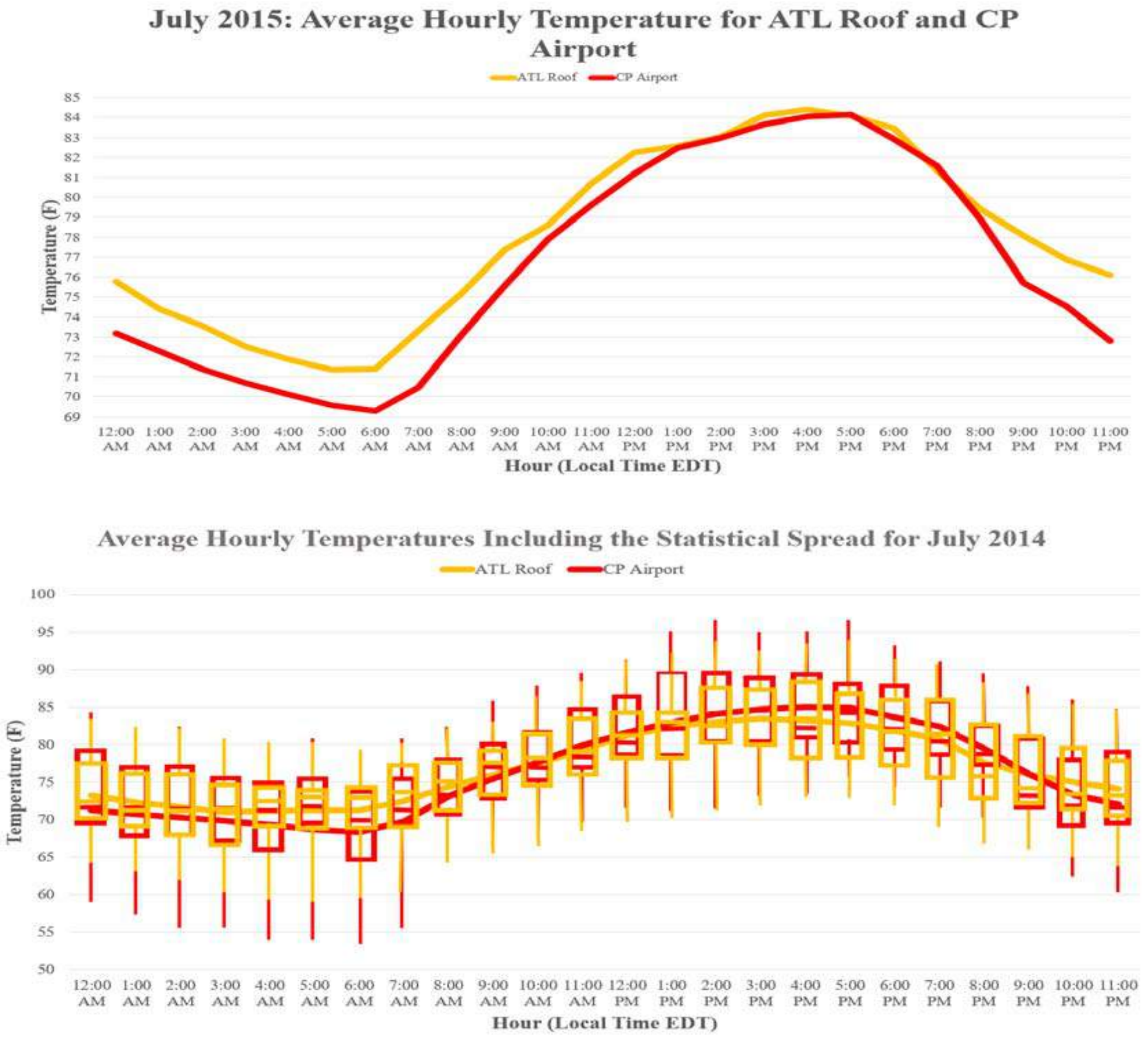
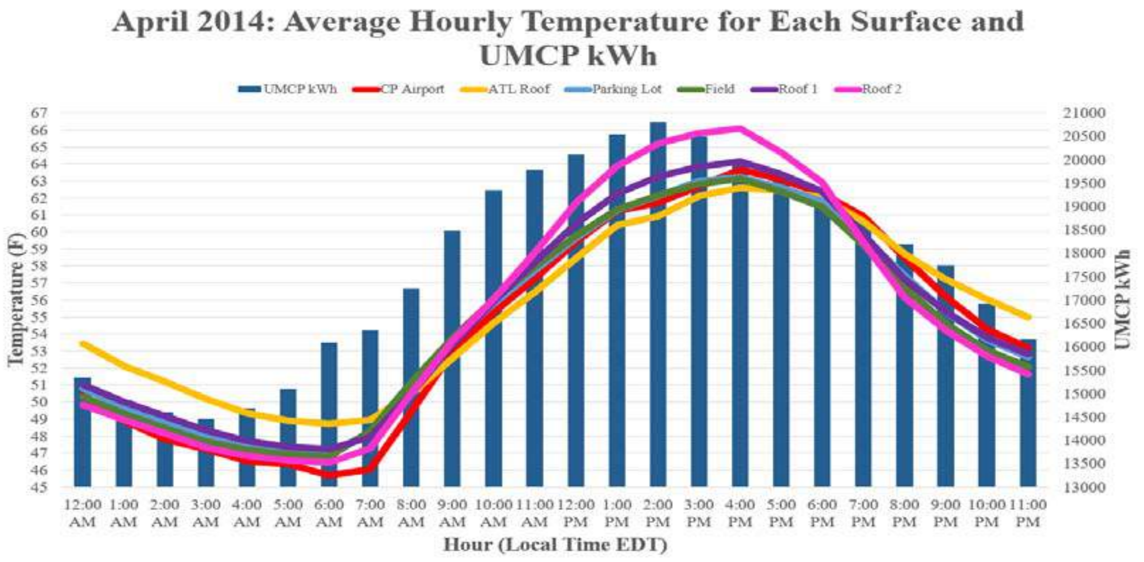


Figure 2: (a). Monthly averaged hourly 2-meter surface temperatures for University of Maryland College Park (UMCP) Atlantic Building roof (ATL Roof) and College Park airport (CP Airport) for July 2015. (b). Same as (a) except for July 2014 including a Box-and Whisker plot analysis showing the spread of temperatures for each hour.



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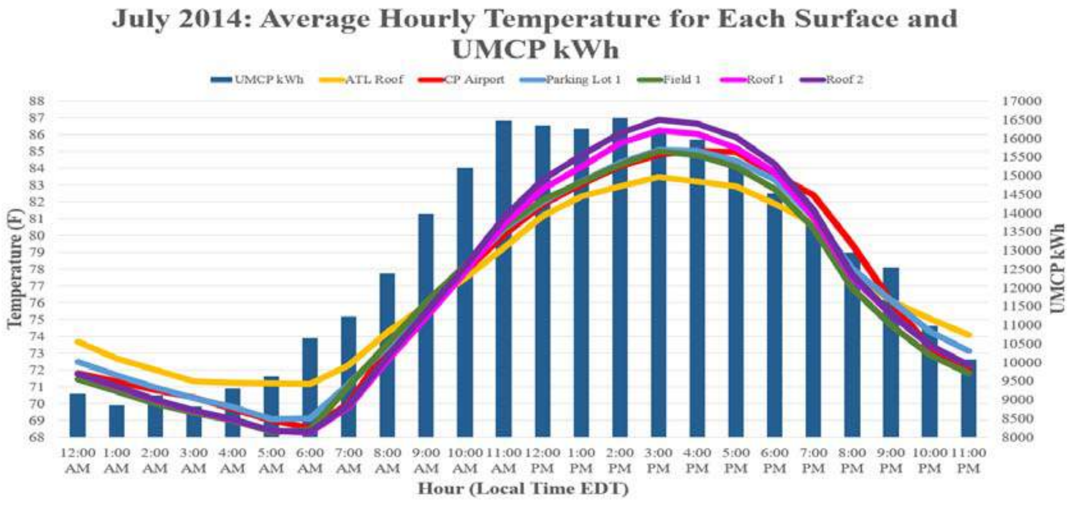


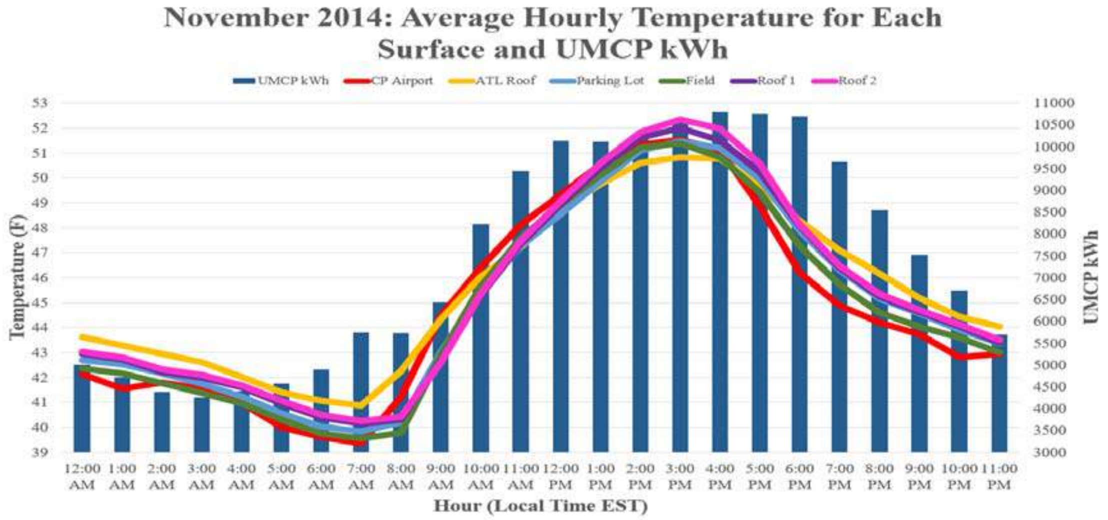
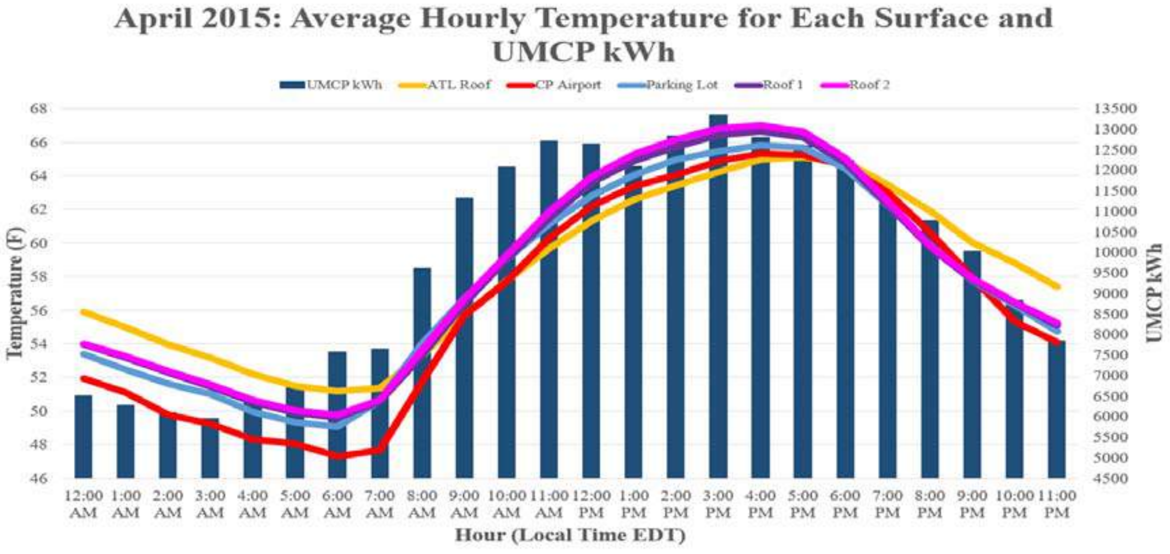


Figure 3: (a). The monthly averaged hourly 2-meter surface air temperature (unit: °F) in April 2014 for CP Airport, ATL Roof, Parking Lot, Field, Roof 1 and Roof 2 with the UMCP campus- wide average hourly electricity use (unit: kWh). (b). Same as (a) except for July 2014. (c). Same as (a) except for November, 2014



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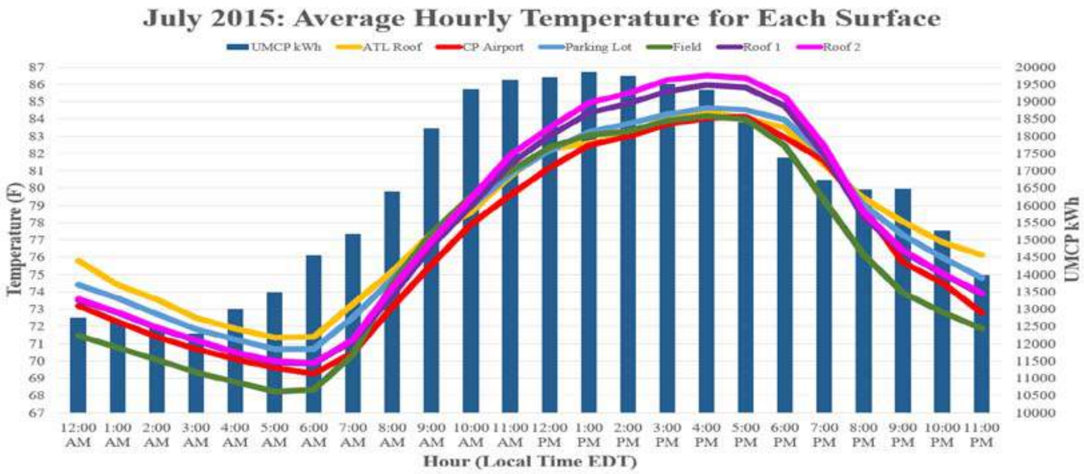

Figure 4: (a). Same as Figure 5 except for April, 2015. (b). Same as (a) except for July, 2015.

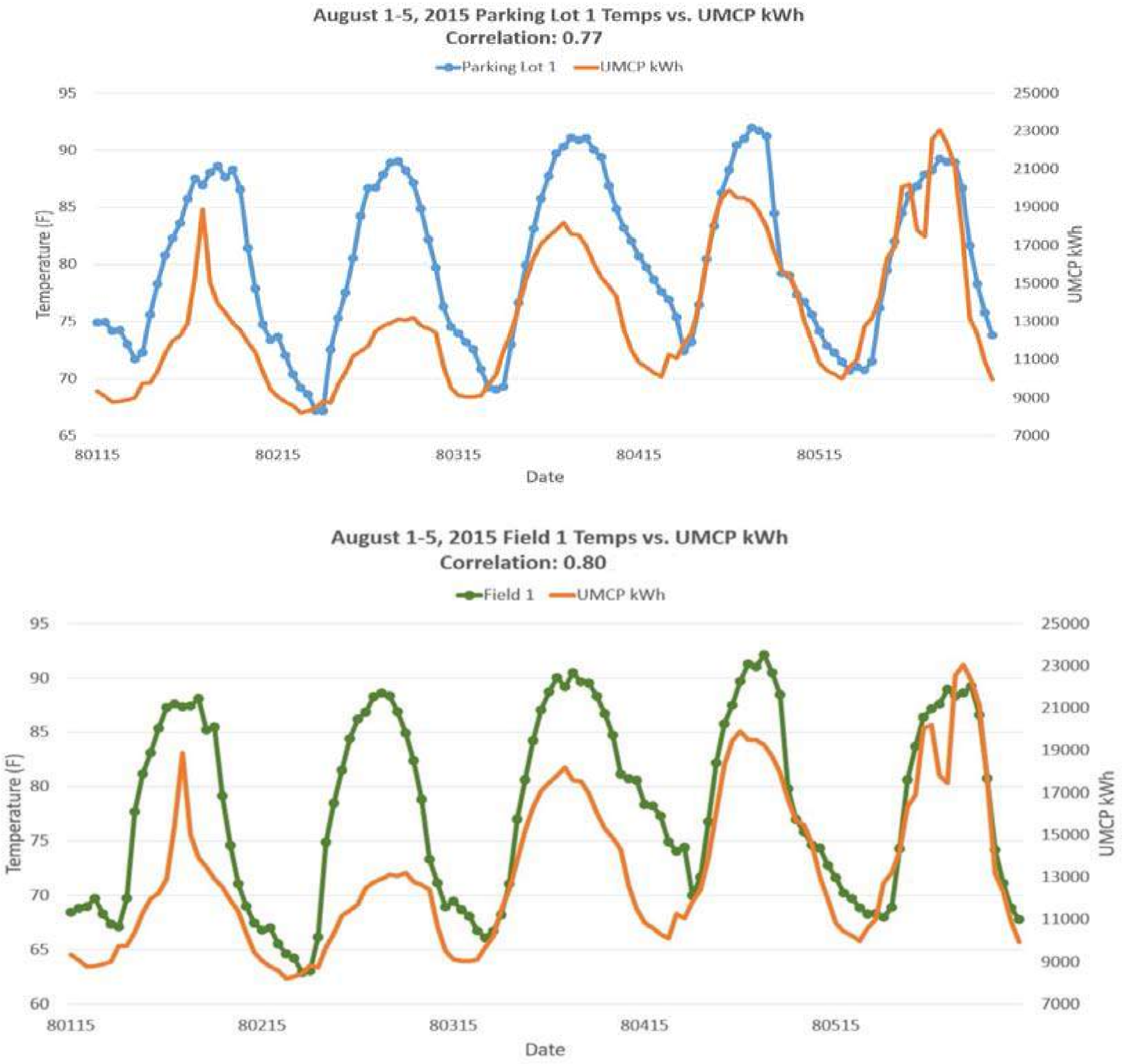

Figure 5: Weekly variations of UMCP campus electricity (unit: kWh) use with the 2-meter surface air temperature measured at (a) Parking Lot, (b) Field, and (c) Roof 2 August 1 – 5, 2015. Correlation coefficients between surface air temperature and electricity-use have been calculated.

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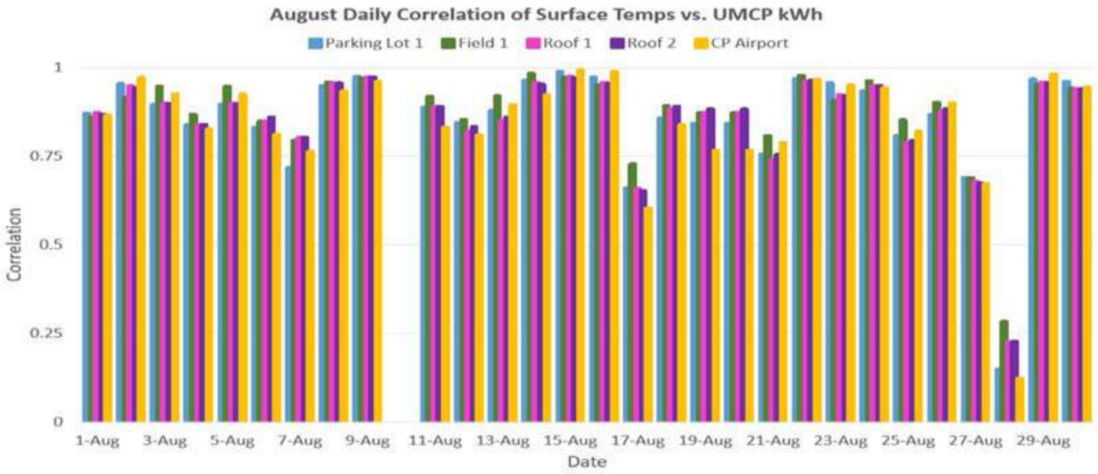

Figure 6: Daily correlation coefficients between surface air temperature and the UMCP campus electricity use in August 2015.August 10 is not included due to missing data.

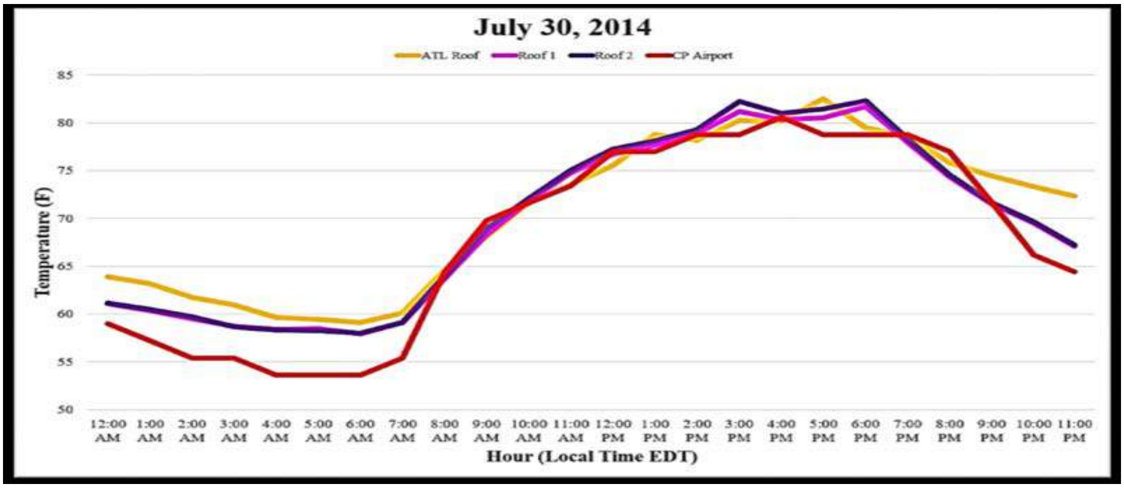

Figure 7: Daily diurnal cycle of 2-meter surface air temperature for the roofs in UMCP campus (ATL Roof),GSFC (Roof 1 and Roof 2) and Collage Park airport (CP Airport).

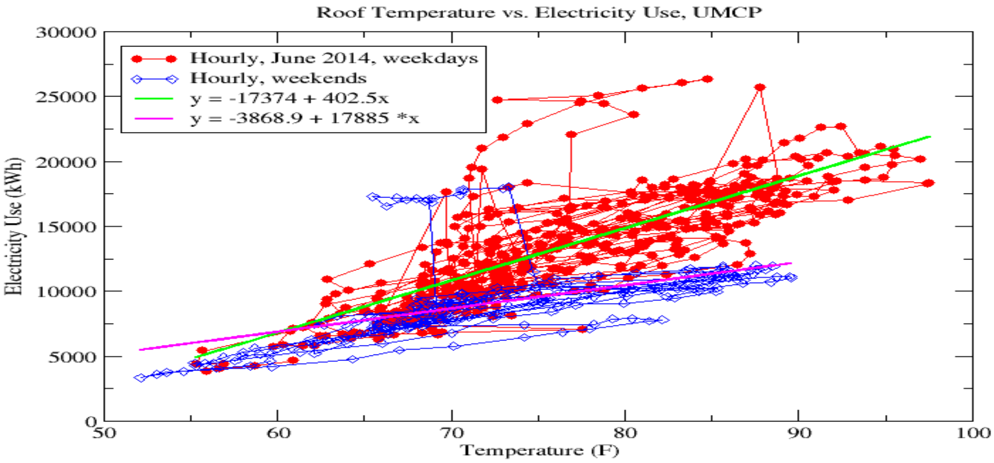

Figure 8: Regression model for UMCP campus wide electricity use based on hourly 2-meter surface air temperature measurements and electricity use data. Data is for June 2014. Weekday and weekends are analyzed differently.