The Relationship Between Surface Temperatures and Building Electricity Use: A Potential New Weather Application

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**ABSTRACT**

Building electricity that is used for heating and cooling is a function of weather conditions, in particular, temperature, humidity, and wind. Nevertheless, a study that compares weather condition and electricity use from building scale, city grid scale, to state scale is new. Currently, communities calculate their energy use efficiency using the 2-meter air temperature measured from a nearby airport. Because of the high heterogeneity in urban regions, an airport air temperature could be >10 degrees different than the downtown canyon region, in particular, during clear summer days. This paper shows the temperature differences measured at a local airport, at a parking lot, at a grass field, and on a building roof in and around College Park, Maryland. Results indicate an up-to daily-averaged 5 °C difference between the airport and roof temperatures. The latter is classified as the building envelop temperature. Furthermore, the correlation between envelop temperature and electricity use on University of Maryland, College Park campus is much larger than that between the local airport temperature and building electricity use (for example, 0.73 vs. 0.43 in July, 2014). Evidently, local temperature information is critical for accurately assessing electricity use. On a state scale, land surface skin temperature ($T_{\text{skin}}$) measured from the National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) observations, at 1 km and 4 times/day, also shows a strong correlation to residential energy use in three different states including California, New York, and Arizona. California and New York have energy use peaks during both summer and winter. Nevertheless, climate conditions and population evidently refine the relation between $T_{\text{skin}}$ and energy use. Therefore, accurate information of building and urban surface temperatures using high spatial and temporal temperature measurements is a new, interdisciplinary, and practical method to helping the energy community better assess the energy use efficiently and rapidly predict the electricity needs. In conclusion, forecasting the residential and commercial energy by $T_{\text{skin}}$ may be a new direction in weather data application. This new application would be most appropriate for green building and smart city developments around the world.

Keywords: urban system, surface temperature, electricity use, building energy efficiency, satellite remote sensing

1. Introduction

Urban heat island effect (UHI) is a critical human-activity-induced phenomenon that has proved the urban regions hotter than the surrounding rural regions. UHI, traditionally detected from the 2-meter air temperature ($T_{\text{air}}$) observed by weather stations, was considered to be only a nocturnal phenomenon (Landsberg 1970. Oke 1982). Nevertheless,
recent studies using satellite remotely-sensed skin temperature \(T_{\text{skin}}\) data have found that the daytime UHI is, in fact, more intense than that at nighttime on a clear day for most of the urban regions due to the reductions of vegetation coverage, changed surface albedo and emissivity of underlying, water-proofed human-made surfaces, and building walls (Jin et al. 2005, Jin 2012). The differences in UHI in terms of \(T_{\text{air}}\) and \(T_{\text{skin}}\) are due to the different physical processes at skin- and 2-meter air levels (Jin and Dickinson 2002, 2010). \(T_{\text{skin}}\), a radiometric surface temperature, is not only related to surface heat, but also to soil moisture, rainfall, and urban human-induced heat fluxes. This variable more rapidly responds to land-atmosphere interactions than the traditional 2-meter \(T_{\text{air}}\) does and therefore \(T_{\text{air}}\) normally has a phase lag after \(T_{\text{skin}}\) on its diurnal range (Jin et al. 1997). Since urban regions distort the surface energy balance and increase surface layer temperature, more energy or electricity is demanded to keep the buildings at comfortable living or working conditions. However, the human induced anthropogenic release of toxins from the use of air conditioners and heaters can further increase the temperature. Therefore, the relation between surface temperature, in either \(T_{\text{skin}}\) or \(T_{\text{air}}\), and residential and commercial energy use is potentially useful for energy management.

Utility companies and electricity generation companies forecast electricity needs at a short-term and a long-term scale. The long-term forecast for a given region can extend from ten years to five decades, for a given region. This forecast is critical for governments to plan the electricity plant and transport for the future. On the contrary, short-term forecast can last from hourly to two-week time scales and can help utility companies to quantify electricity needs for a specific period of time. In addition, short-term forecast can also be used by the commercial energy traders to purchase or sell electricity on the market. Currently, weather impacts on electricity need is well-recognized in the energy industry and a traditional “hot-day degrees and cold-day degrees” approach, based on 2-meter \(T_{\text{air}}\) measurements at an airport, is widely used in energy need forecasting. The \(T_{\text{air}}\)-based electricity forecast has been considered as an adequate tool by utility companies since the fluctuation of electricity use is balanced out over a large area. Nevertheless, for small grids such as urban regions where smart city or green building efforts focus, fine spatial resolution electricity need forecast is desired.

\(T_{\text{skin}}\), the surface temperature at the skin level, was originally proposed by remote sensing people back to 1970s (Susskind et al. 1984). This variable has been used to calculate vegetation properties (Huband and Monteith 1986) and to simulate land-atmosphere interactions in land scheme (Dickinson et al. 1986). In the 1990s, with the coming of NASA Earth Observing System era (King et al. 2003), \(T_{\text{skin}}\) is significantly used in both research and applications (Sellers et al. 1990, Prata et al. 1995, Hahmann et al. 1995). Recent decades, \(T_{\text{skin}}\) has been widely studied in urbanization research (Jin et al. 2005, Jin et al. 2007). A detailed discussing on the retrieval and physical properties of \(T_{\text{skin}}\) can be found at Jin and Dickinson (2010).

Compared with the 2-meter \(T_{\text{air}}\), \(T_{\text{skin}}\) has the following advantages: (a) \(T_{\text{skin}}\) can now be retrieved from satellite remote sensing at very high resolution. For example, National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) can measure \(T_{\text{skin}}\) at 1 km resolution, 4-time/day. \(T_{\text{air}}\), measured by a weather station, is at a much more irregular, coarse resolution. (b) \(T_{\text{skin}}\) better represents UHI than \(T_{\text{air}}\) (Jin 2012). For an urban region, UHI and, in particular, heatwave or “cold-wave” events can cause abnormal needs for electricity. Therefore, \(T_{\text{skin}}\) may be a strong index for this use. (c) Global coverage. Satellites can monitor the land surfaces over the globe. In addition, \(T_{\text{skin}}\) is now has a long-duration historical record. Satellite \(T_{\text{skin}}\) can be retrieved for more than 30 years (AVHRR, Landsat, etc). These high-resolution data can be combined with historical electricity use data to develop regression-based electricity need forecast model. In a changing climate, determining how much a city needs electricity is critical. Given the fact that the 2-meter \(T_{\text{air}}\) and \(T_{\text{skin}}\) have very different signal on UHI, \(T_{\text{skin}}\) may be a new approach to use in forecasting electricity needs.

There are two goals of this paper. The first one is to prove that the urban heterogeneity and UHI make the building outside air temperature evidently differs from the airport \(T_{\text{air}}\), which is traditionally used in energy industry. The 2nd goal is to suggest that a new \(T_{\text{skin}}\) variable, which is from satellite remote sensing measurement, may be useful for energy use assessment, in particular, at a large-scale.
2. Study Area and Datasets

2.1 Study Area

University of Maryland, College Park (UMCP) is the pilot study site to compare surface temperature and campus-wide electricity use. Summer temperature data and electricity use data, at a 15-minute interval, were analyzed to test the building envelop temperature impacts on the electricity use.

At state-scale, three US states are studied: California, New York, and Arizona. California (32.5°–42.0° N, 114.0°–124.5° W) is the most populous state with population of 37,691,912 (US Census Bureau, 2011). New York (40.5°–43.5° N, 73.0°–80.0° W) is the third most populous state in the USA with a population of 19,465,197. Arizona (31.5°–37.0° N, 109.0°–115.0° W) has a population of 6,482,505 with a differing, desert climate. By examining the three states that locate at different climate regimes, the impacts of different natural climate conditions on electricity use could be better understood.

2.2 Data Sets

2.2.1 In Situ Surface Skin Temperature Measurement

Radiometric temperature (or skin temperature) is measured on twelve different surfaces at the Goddard Space Flight Center (GSFC) from October 2013 to November 2015 (Mark Carroll, personal communication, 2016). Onset Hobo U23-002 was the primary instrument used to measure temperature and humidity (http://www.onsetcomp.com/products/data-loggers/u23-002). GSFC is 5 miles northeast from UMCP with surrounding land cover, underlying surface, and sky conditions similar to UMCP. Therefore, in this study, we use the surface skin temperature measured at GSFC to represent UMCP campus. These temperatures were compared to UMCP Kilowatt Hour (kWh) meter readings for three select months (June, July, and August in 2014 and 2015). Corresponding campus total electricity is analyzed to find correlations between energy use and surface temperature at the parking lot, a grass field, two roof surfaces, and the airport of College Park.

2.2.2 MODIS Tskin and Land Cover Measurements

MODIS Tskin observations for 2001-2010 (daytime Terra), 2001-2008 (nighttime Terra), and 2003-2010 (daytime and nighttime Aqua) are analyzed with the residential electricity use in the above mentioned three states. Skin temperatures are measured by MODIS which is one of the five instruments aboard NASA’s Terra satellite, launched in December 1999, and from NASA’s Aqua satellite that was launched in May 2002 (King et al. 2003). Tskin is retrieved using seven thermal infrared bands at 10:30 AM and 10:30 PM daily via Terra and at 1:30 AM and 1:30 PM via Aqua. Each pixel has a 1 km resolution at nadir and is scaled up to a 5-km resolution in this study. The daytime and nighttime Tskin data was gathered from NASA’s Giovanni database via http://gdata1.sci.gsfc.nasa.gov/daac-bin/G3/gui.cgi?instance_id=neespi. Terra monthly daytime Tskin was averaged over the urban and built-up regions of each county and state of California, New York and Arizona.

The land cover for each of the states is distinguished using the MODIS land cover product. MODIS classifies the land cover to 17 differing classifications: (1) Evergreen Needleleaf Forest, (2) Evergreen Broadleaf Forest, (3) Deciduous Needleleaf Forest, (4) Deciduous Broadleaf Forest, (5) Mixed Forest, (6) Closed Shrubland, (7) Open Shrubland, (8) Woody Savannas, (9) Savannas, (10) Grassland, (11) Permanent Wetland, (12) Cropland, (13) Urban and Built-up, (14). Cropland/Natural Vegetation Mosaic, (15) Snow and Ice, (16) Barren or Sparsely Vegetated. 0 is water. In this analysis, only urban and built-up pixels are analyzed for averaged Tskin to be compared with electricity use, since estimates indicate urban regions use more electricity.

2.2.3 Residential Electricity Sales

The monthly residential electricity data was available for the county and the state. The monthly electricity sales for each studied state from 2001 to 2010 was downloaded from the US Energy Information Administration via http://www.eia.gov/beta/enerdat/#/topic/.
3. Results and Discussions

3.1 Building Scale Temperature and Electricity Use

UMCP is a public state university located in College Park, Maryland. Located two miles ways from the campus is a small airport surrounded by a well-vegetated land area. The underlying land cover differences causes the surface temperatures at the airport to be lower than that of the building roof temperatures. The building roof temperatures help to determine the electricity amount needed for campus air conditioning. Airport temperature measurements, as traditionally used by the energy community, has large uncertainty in assessing electricity use. For example, roof temperature shows a clear differentiation from the College Park airport temperature, although it is only two miles away from the campus (Figure 1). Specifically, the daily maximum roof temperature on August 5, 2014 was 93.5 °F but was measured at 88.6 °F for the airport. In general, higher temperatures cause more electricity use. Between August 24 and 28, the temperature increased and the electricity use increased accordingly, from 10255 kWh on August 24 to 19654 kWh on August 27. Then on August 28, 2014, maximum temperature decreased about 6 °F and correspondingly the maximum electricity use dropped about 1300 kWh. Nevertheless, the relation between surface temperature and electricity use is not linear. Between August 8 and 10, which was a Friday, Saturday and Sunday, temperature increased but the electricity use decreased from 27,000 kWh to 12,5000 kWh. This decrease is primarily because during the days of the weekend less electricity was used when the campus was mostly unoccupied. Furthermore, events such as concert, sporting events or ceremonies can cause a slight increase in kWh (not shown). Furthermore, the correlation coefficient between daily maximum airport temperature and electricity use was 0.13 but, for building roof temperature (e.g., envelop temperature) and electricity use was 0.63 (Table 1).

![Figure 1. Daily maximum temperature for building roof (unit: F, right y-axis), College Park airport, and daily maximum electricity use (unit: MWh, left y-axis) of University of Maryland, College Park (UMCP) for campus-wide buildings during August 1, 2014 to August 31, 2014.](image)

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<td>Airport College Park</td>
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Table 1. Correlation coefficient among UMCP campus electricity use and temperatures measured at different surfaces.
How does the urban surface heterogeneity affect electricity use? The temperatures measured on two building rooftops, in a parking lot, in grass, and at an airport were compared with the UMCP campus electricity use (Figure 2a). On one hand, the airport temperature is distinctly lower than the roof temperatures because the underlying surface at the airport has dense vegetation coverage and soil moisture. Specifically, on June 10, 2014, the daily airport temperature was measured about 7 °C lower than the roof temperature (86.0 °F vs. 92.1 °F). Partly due to the surface boundary-layer turbulence, two different buildings had slightly different roof temperatures (~1 °F), but their overall change trends were similar. In addition, the airport temperature is consistently higher than the grass field temperature and occasionally higher than the parking-lot temperature. The measured grass field was not confined to an open area but bounded by a nearby road, two parking lots, and one of the measured buildings (Mark, personal communication, 2016). By choosing a grass field surrounded by these manmade surfaces, measurements of the grass field can be impacted by the other surfaces. In addition, the parking lot is located nearby trees and affected by shade temperature measurements. More importantly, the roof, parking lot and grass field temperature had a consistent altering trend, but airport temperature showed some differences—specifically, on June 7 and 8, 2014, all temperatures showed a decrease except the airport temperature, which increased.

In general, higher the temperature higher the campus energy use (Fig. 2b). But on weekends this might be change. For example, June 1, 8, 15, 22, and 29, 2014 are Sun days and the electricity use were lower than other days of those weeks. The two daily peak uses of electricity were June 11, 2014 (Wednesday) and June 15, 2015 (Friday). Hourly data was further examined for the reasons (Fig. 2c). First of all, both June 11 and June 13 have the peak surface temperatures, with the field temperature around noon as high as 83 °F. As a result, the electricity use closely reflected the temperature increase and reached the peak use almost at the same time (e.g., 15:00 LT). Second, rehearsal event occurred on June 13, 2014 which might have also contributed to the electricity use. In addition, June 15, 2014 also had a high temperature around 83 °F, but, since it was a Sunday, the campus electricity use was much lower than that of June 11 and June 13, 2014. Note that the correlation coefficient between the field temperature and electricity use during June 11-15, 2014 was only 0.58, since abrupt changes in electricity use such as on June 14, 2014 occurred but the reasons remain unknown. On some other days, the correlation coefficients could be as high as 0.90.
3.2 State Scale

California State

Land cover over California from MODIS measurements shows that urbanization area (the red color in Fig. 3a) is only a very limited part of the California state. Nevertheless, most of the population resides in the urban areas. Therefore, one needs to use urban-area-averaged $T_{\text{skin}}$ instead of the whole state-averaged $T_{\text{skin}}$ to calculate energy use-$T_{\text{skin}}$ relation. $T_{\text{skin}}$ was closely related to the residential electricity use with clear seasonality (Fig. 3b). Nevertheless, $T_{\text{skin}}$ had only one peak in the summer as a response of the peak surface insolation, while the residential electricity usage peaks twice for each year during the summers for cooling and winters for heating. The maximum residential electricity sales was reported in 2008 at 10.1231 million megawatt hours (e.g. million MWh). In addition, an increase in electricity consumptions by homes in California occurred between 2001 and 2002 but, the monthly averaged $T_{\text{skin}}$ did not significantly differentiate between these two summers. This suggests that surface temperature is an important, but not the only factor, that determines electricity use. In addition, diurnal range of $T_{\text{skin}}$ and vegetation index are also used to examine the possible relation with the electricity use (not shown), but these factors cannot not fully explain the variations of the later, either.

Although the residential electricity use peaked during the summers (July, August and September, Fig. 3c), the inter-annual variation was significant. For example, Julys were the warmest months with an average daytime $T_{\text{skin}}$ (2001-2010) of 107.5 °F, and the mean residential electricity usage was 8.2032 million MWh with a range from 7.4 million MWh to 9.2 million MWh, which is about a 25% variation. Similarly, the second warmest month was August with a mean daytime $T_{\text{skin}}$ of 104.4 °F, and residential electricity usage of 8.7273 million MWh with slight variation from year to year. Besides the summer months, another peak in the electricity sales occurred during the winter months (December and January) due to the increased use of heaters. Specifically, the average daytime $T_{\text{skin}}$ for January was 45.0 °F and for December was 44.6 °F. Correspondingly, the averaged electricity usage for residential homes during January was 7.7408 million MWh and for December was 7.4195 million MWh. The fact that two days with same skin temperatures may have different electricity use suggests that skin temperature is only one of the important factors that determine the amount of residential energy use. Economy, relative humidity, and government green energy policy also affect electricity use (Feinberg et al. 2003). Finally, a non-linear regression model, developed based on $T_{\text{skin}}$ – residential electricity data and adjusted by the historical data, was proposed to forecast the residential electricity use as function of monthly mean skin temperature (dashed line, Fig. 3c). The RMS was ~0.43 million MWh at monthly scale. This model captures the first order variation of the electricity use but, corrections as function of other factors including economy, relative humidity, population, and policy impact are needed based on future research.
Different land cover types have different correlation coefficients with electricity use (Table 1) because, under the same sky condition, the surrounding surfaces and structures have different surface albedo and directly affect absorption of surface insolation. Nevertheless, the correlation coefficient at hourly scale is similar (e.g., 0.6-0.7) for all surfaces except for the airport temperature, which was lower (e.g., 0.1-0.5). The highest correlation measured was associated with the grass field surface for all summer months in 2014, suggesting an observation over grass fields might be adequate to capture the energy use fluctuation.

Urban heat island effect – higher temperatures in the urban or city region with lower temperatures in the surrounding rural regions – suggests that cities filled with manmade surfaces such as roads, parking lots, commercial and residential buildings have higher surface temperatures than the rural regions. An accurate temperature is important to forecast the electricity use for the city grid scale or for building scale. Furthermore, an airport $T_{air}$ information often times is not adequate to represent electricity use in a city.

**New York State**

The warmest months for New York state (averaged on all land covers, Fig. 4a) were July and August with a mean 10-year, monthly daytime $T_{skin}$ of 73.5 °F and 73.7 °F, respectively. The coolest months for the entire state were January, February, and December with a 10-year, monthly average daytime $T_{skin}$ of 20.8 °F, 24.6 °F, and 27.4 °F, respectively. The monthly mean residential electricity use during July and August were 4.80960 million MWh and 5.03380 million MWh, respectively (Fig. 4a). For the winter, the mean residential electricity consumption for January, February and December were 4.41990, 4.00250, and 4.12850 million MWh, respectively. The residential electricity usage peaked during both summer and winter, similar to the case in California. Nevertheless, the electricity consumption overall is less than that in California, partly, because California is a bigger state with a greater population than the New York State and alternative energy sources such as gas and wood are used at homes during winters in New York state.
The residential electricity use seemed to follow the summer $T_{\text{skin}}$ closely (Fig. 4b). Similarly, to California, the electricity sale has two peaks, one during the summer months and another during the winter months. The years 2002, 2005, and 2010 had higher monthly summer daytime $T_{\text{skin}}$ than other years and their corresponding electricity sales were also higher than other years. In the winter, when daytime $T_{\text{skin}}$ is low, the electricity consumption peaked indicating the increased use of heaters. Nevertheless, the two peaks for New York State are more prominent compared to California. For example, in 2009, the electricity use for homes were almost the same during August and January.

Specifically, in January 2009, 4.761 million MWh of electricity was used but, in August 2009, 4.946 million MWh of electricity was used by homes. In addition, the winter of 2009 was colder than 2008 and thus there was an increased need for heaters. But, summer of 2009 was cooler than that of 2008 and there was less of a need to use air conditioners compared to 2008. Again, the regression model (dashed line, Fig. 4b) was developed to simulate the 1st order of residential energy use variations.

Arizona State

The warmest months for Arizona state (averaged over all land types) were June and July with a mean daytime $T_{\text{skin}}$ of 116.8 °F and 113.2°F, respectively (not shown). If the urban regions of Arizona were only examined, the mean monthly daytime $T_{\text{skin}}$ for June and July would be 120.9 °F and 118.3 °F, which indicate a 4–5.5 °C UHI. The coolest months for the entire state were January and February with an average daytime $T_{\text{skin}}$ of 55.2 °F and 54.4 °F, respectively (Fig. 5). The mean residential electricity consumption during June, July and August were 3.06090, 3.90400, 3.850304 million MWh, respectively (Figure 5). For the winter, the mean residential electricity consumption for January and December were 2.31870 and 2.14110 million MWh, respectively. The electricity usage at homes peaked more during the summer than the winter. More importantly, the temperatures during summers were much higher than those in New York state, but its summer residential electricity use was not as much as that in New York state, due partly to the small population in Arizona state. Again, the non-linear regression model, based on $T_{\text{skin}}$ and historical data, simulates the energy use well (dashed line, Figure 5).

Humidity is also a critical parameter in determining buildings consumption in electricity in Arizona. For example, Phoenix, the largest city of Arizona, had 46% relative humidity on average in August but, only 40% in July, and Tucson, the state’s second largest city, had a relative humidity of 57%
in August and 50% in July. As a result, its residential use of electricity was generally higher in July than in August (Figure 5).

3.3 County Scale Electricity Use in California Bay Area

In order to further understand other factors important to the residential energy use, a county-scale analysis was conducted for the surrounding San Francisco bay area (SF bay, Fig. 6a). Eight counties located in the northern California with very different populations (Fig. 6b), household incomes and home sizes were studied. Santa Clara County had the highest population with 1,781,642 in 2010 and the homes in this county use the most electricity (Fig. 6c). The per person electricity use is about 0.445 MWh. Alameda County, the second most populated county in the east bay area, had a population of 1,510,271 in 2010 and the per person residential use of electricity was 0.487 MWh. These numbers suggest that even in the same climate region, the home size may affect the residential electricity use. In addition, the \( T_{\text{skin}} \) of Santa Clara County was higher than that of Alameda County because Santa Clara, which locates at the center of Silicon Valley, had the most significant UHI (Jin, result not published). Although Salano

![Figure 6a. Counties of San Francisco Bay area. (b) Population for each county since 1880-2010 (http://www.bayareacensus.ca.gov/historical/copop18602000.htm. (c) Annual residential energy use for the counties in San Francisco Bay Area during 2006-2010. Data before 2006 is not public available.](image_url)

and Sonoma counties had similar high temperatures (> 75 °F), they are not as populated as Alameda, and thus used less electricity (~1.0 million MWh vs. 3.1 million MWh).

San Francisco County, which had the most dense population density, had averaged an annual residential use ~0.4 million MWh for a 808,235 population. As a result, it had the highest personal use of electricity up-to 2.02 MWh/person/year, which is much higher than the numbers for Santa Clara and Alameda. Clearly, urban regions have more need for residential electricity use.

For the counties with smaller populations, little variations occurred on total residential use on an annual, county-averaged scale, even though the temperatures vary evidently from year to year. Specifically, for example, Napa County temperature varied from 73 °F to 77 °F between 2001 and 2010, but its annual residential use was nearly constant. Nevertheless, for counties like Contra Costa and Santa Clara, more residential use occurred corresponding to higher annual temperature. If more data is available, determining if the population was the primary reason for the little variation in residential energy use is a question for future research.
4. Conclusion and Future Direction

This study examines hourly, daily, monthly skin temperature and electricity use at building scale, county/city scale, and state scale. Accurate skin temperature is more important for forecasting electricity use for a building or a city grid than a 2-meter air temperature measured at an airport. $T_{\text{skin}}$ is closely related to the residential electricity consumption because this physical parameter immediately responds to the surface insolation and measures the ground or building surface thermal conditions. Studies suggest that $T_{\text{skin}}$ is a better index for the spatial coverage and intensity of UHI than 2-meter $T_{\text{air}}$ (Jin et al. 2005, Jin 2012). In addition, $T_{\text{skin}}$ observation is at fine scale resolution while the 2-meter $T_{\text{air}}$ is generally measured by weather stations at an irregular, coarse resolution. Using $T_{\text{skin}}$ in energy need forecasting is a novel, but potentially more accurate approach than the traditional airport 2-meter $T_{\text{air}}$ approach. More importantly, $T_{\text{skin}}$ – electricity use forecast also has potential to become a globally standard index given the facts that satellites observe $T_{\text{skin}}$ a few times per day over the globe at high spatial resolution.

Different geometry, local climate, and vegetation coverage also affect the energy use. More importantly, in addition to weather information, economy, population and governmental policy impact the energy consumption. For example, although Arizona is a desert state and warmer than California and New York, the total uses of electricity is less than the usage measured in California or New York because of its smaller population. Energy forecasting models need to include all these natural and unnatural parameters.

$T_{\text{skin}}$, in addition to being monitored from satellite remote sensing, is currently simulated from weather forecast models like 2-meter $T_{\text{air}}$. Therefore, both long-term and short-term energy need forecasts can access $T_{\text{skin}}$ information. The atmospheric remote sensing community, weather forecast community, electricity industry, and energy resource managers may work together to develop a next generation electricity forecast approach for long-term and short term forecasts.

Existing, traditional “hot-degree/cold-degree day” methods based on 2-meter $T_{\text{air}}$ measured at airports for energy use forecasting is unable to accurately capture the future weather modification induced by urban system at city-grid or building-scale. Extreme events such as heatwaves and “coldwaves”, with increased frequency and intensity as a result of climate change, are critical to having accurate electricity need forecasts. Therefore, green building and smart city developments over the globe may substantially benefit from a fine resolution, accurate electricity use forecast based on $T_{\text{skin}}$, as proposed in this study.

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