Urban climate change impacts on building heating and cooling energy demand

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ABSTRACT: The challenges of warming urban climate on building energy needs for space conditioning are discussed by assessing the impact of intra-urban microclimatic changes, also called as urban heat island (UHI). This paper presents the results of a simulation study on the energy consumption for heating and cooling of a small-office building within intra-urban microclimatic conditions of the Chicago metropolitan area. The urban development influences: land-use land-cover and anthropogenic heat by buildings, industry, and transportation and the lake effect that modify climatic conditions are reflected in the weather files selected from five locations in the study area. The study simulated a small-office building per ASHRAE Standard 90.1-2013 with typical construction, heat gains and operational patterns with a whole building energy simulation program eQuest 3.65 for selected locations. The results confirm that heating load decreases, and cooling load and overheating hours increase as the office location moves from rural (less developed) to urban (developed) sites however, these changes are influenced by the distance from the downtown and the Lake Michigan. It is shown that prominent intra-urban climatic variations are an important factor affecting energy performance. The paper presents detailed results of the typical small-office placed within intra-urban climatic zones of the metropolitan area, arguing the necessity to consider using weather files based on UHI for the design of current buildings to safeguard their efficiency in the future.

KEYWORDS: Urban Climate, Heat Island Effect, Building Energy

INTRODUCTION

Urban areas modify their climate (Arnfield 2003) due to high rates of urbanization that resulted in drastic demographic, economic and land use changes. These modifications include increasing temperature, changing wind speeds, precipitation patterns, cloud cover, and solar irradiance. The most significant modification is the creation of Urban Heat Islands (UHI) which refers to elevated temperature over urban (developed) areas compared to rural (less developed) areas. UHI is more prominent during nighttime when wind speed is relatively lower than daytime wind speeds. The paved urban surfaces like streets, sidewalks, parking lots and building and its configurations are crucial in the formation of UHI because it reduces evapotranspiration due to loss of vegetation. When studied using satellite thermal infrared images (Lo, Quattrochi, and Luvall 1997) surface heat island is more prominent where the albedo and emissivity properties of paved urban surfaces is often intensified and vertical surfaces is often ignored. The role vertical urban surfaces like building facades plays within dense urban environment is brought forward by Sky View Factor (SVF) (Oke 1988, Erell, Pearlmutter, and Williamson 2011) of the urban canyon. In addition, geography, topography, large bodies of water, land use, population density and physical layout of the urban area influence UHI (Oke 1987). The rapidly expanding urban boundaries constantly modify rural landscape and the nature of constantly evolving urban landscape varies per land-use land cover changes. The increasing anthropogenic heat contribution of the urban environment is significant (Stone, Hess, and Frumkin 2010, Sailor 2011) and it includes waste heat from buildings, industries, and transportation (Sailor 2011). Therefore this paper focuses on and emphasizes the need to recognize intra-urban climatic conditions to inform building heating and cooling energy needs.

UHI modify microclimatic conditions, increase air pollution (Hankey, Marshall, and Brauer 2012) and exacerbate heat waves in urban areas (Stone, Hess, and Frumkin 2010). Heat related mortalities are observed globally (McMichael, Woodruff, and Hales 2006) and in particular, 1995-96 Chicago heat wave and 2003 European heat wave is most reported in the literature. As the frequency of heat waves is increasing, the mortality rates are decreasing where use of air conditioners is prevalent (Bobb et al. 2014, O'Neill 2005, Davis et al. 2003). The increased use of air conditioners to counterbalance warming effect subsequently increase building waste heat contribution from buildings and such practices adds warmth to the urban environment. Although, warm urban condition reduces building heating energy needs, it increases cooling energy needs and internal heat load dominated buildings operated during day time, like office buildings, are significantly affected. Therefore, the major contribution of UHI is the increased summertime peak electric demand (Akbari and Konopacki 2005) that adds burden on the existing power infrastructure and increases GHG emissions.

Further, most UHI studies linking building energy needs presents air temperature as the climatic variable for its energy impact and suggest increased vegetation and increased albedo of pavements and roof for energy savings (Akbari and Konopacki 2005). Studies have also reported air temperature and relative humidity for its impact on heating and cooling energy needs (Kapsomenakis et al. 2013). The prevalence of nighttime

UHI is often associated with lower nighttime wind speed that prevents transportation of urban heat absorbed during the daytime by urban thermal mass allowing it to rise above the city. While urban and building material properties are important, its organization within urban form (Bhiwapurkar 2007) is critical for nighttime urban cooling and night flushing is a commonly suggested energy saving strategy for warming climate (2012). However, variation in day and nighttime UHI, especially in the case of Chicago metropolitan area, is not well established with promising evidences (Coseo and Larsen 2014). Also, UHI studies are often reported during clear sky conditions with low wind speed and both these conditions are constantly changing through the year. To account for combined influences of the urban environment and climatic influences, on building space conditioning energy use especially in view of synoptic weather conditions of the great lakes region by seeking answers to questions such as:

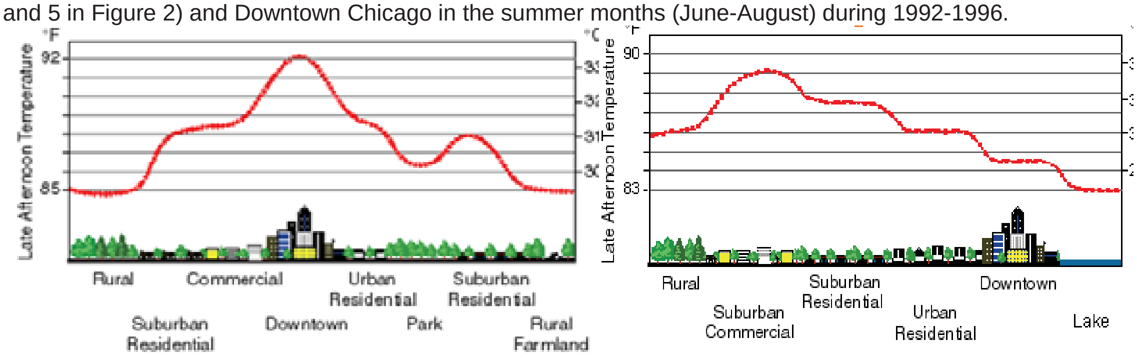
- Do intra-urban or microclimatic variations exist in the study area and how does it vary seasonally?
- How do intra-urban microclimatic changes influence peak building energy use and peak demand?

2.0 METHODS AND MATERIAL

2.1. Context

As reported by Coseo and Larsen (2014), Chicago metropolitan area lies on the flat Lake Michigan plain (41º52’ North and 87º37’ West with minimal elevation changes of 176.5 m (579 ft.) to 205.1 m (673 ft.) above sea level (USGS, 2012). Chicago, Illinois, has a moderate continental climate with an average mean air temperature from May to September of 25.9◦C (1961–1990) (Hayhoe, Sheridan, Kalkstein, & Greene, 2010). In July and August, prevailing west-southwest (240◦) winds average 13.2 km/h (8.2 mph) (1981–2010) transporting in warm humid air from the central and southern plains (Angel 2014).. Tree cover plays an important role in moderating air temperatures in the region. McPherson and colleagues (1997) found that the city of Chicago had an average tree canopy of 11%. Street trees comprised 10% of the total canopy in the city. According to Imhoff and colleagues (2010), Chicago falls within a grassland bioclimatic region. Another important contextual factor is Chicago’s location on the west side of Lake Michigan. While the 2010 population of the Chicago-Joliet-Naperville metropolitan statistical area was 9,461,105, the city of Chicago’s population was 2,695,598 residents (US Census, 2012). In 2010, Chicago had an average population density of 45.7 persons per ha (18.1 persons per acre) within the city limits. Researchers suggest that Chicago’s current UHI patterns are likely to intensify with a warming climate and further urbanization in the region (Hayhoe et al., 2010; Vavrus & Van Dorn, 2010). This will significantly alter Chicago’s micro-climate and increase its vulnerability to ecological and financial risks (Weinstein and Turner 2012).

The typical UHI effect is often studied under calm wind conditions on clear sunny days (Figure 1) in which urban heat rises above the built environment and raises air temperature of the downtown area. In contrast, the Chicago heat island often appears in the westerns suburbs, not in the Downtown Area (Gray and Finster 2004). The lake wind influences transport of urban heat over the west side development (Figure 2 (a)). Gray and Finster (2004) reported an average about 3-5ºF temperature gradient between Lisle (located between 2 and 5 in Figure 2) and Downtown Chicago in the summer months (June-August) during 1992-1996.



(a) (b)

Figure 1: (a) Typical urban heat island profile under calm wind conditions (b) Chicago’s heat island profile (Gray and Finster 2004)

2.2. Climatic data: sources and suitability

The National Climatic Data Center (NCDC) monitored weather stations are selected for investigating climatic variations in the Chicago metropolitan area for quality purposes (Figure 2). These stations are located at varying distances from the Lake Michigan: Waukegan (3.37 miles), Midway (9 miles), O’Hare (13.5 miles), DuPage (31.5 miles) and Aurora (45 miles). The hourly climatic data obtained from these five weather stations in TMY-3 format (Wilcox and Marion 2008) are suitable for this study as it reflects combined influences of land-use/land cover changes, related anthropogenic heat from buildings, transportation, and automobiles, and the lake effect. In this way, the interaction of climatic variables and urban landscape is well accounted for predicting energy needs.

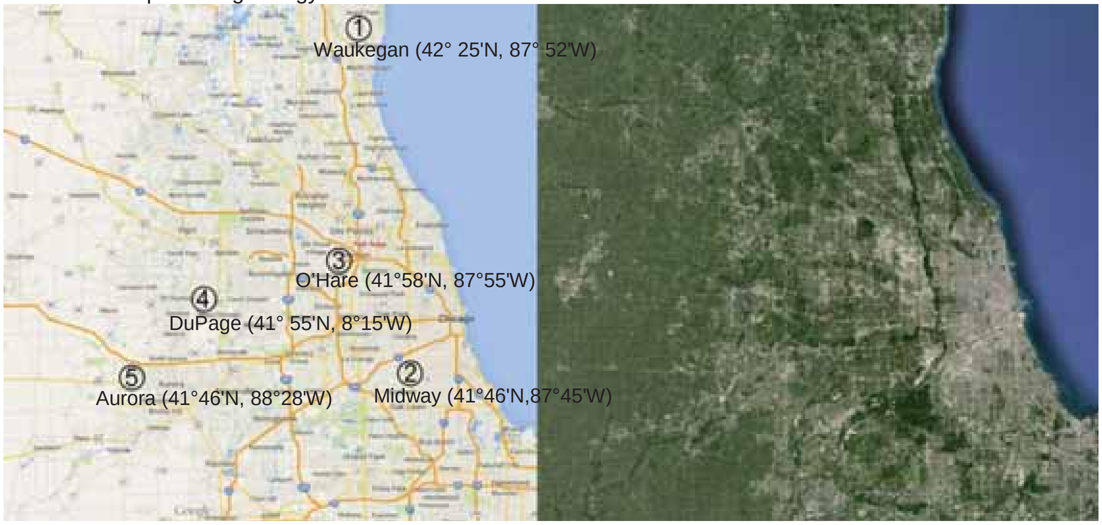


Figure 2: Climatic data collection locations (Google Maps) and LandSAT Image of the Chicago metropolitan area showing urbanized to rural landscape pattern (Google Earth).

2.3. Physical model characteristic

A representative 3-storied, small-sized office building (CBECS 2012) of 1366 m² (14,700 ft²) is modelled per ASHRAE Standard 90.1-2013, Climatic Zone:5A (ASHRAE 2013) and Appendix G requirements to estimate energy needs. The building footprint of 21.30m x 21.3m (70' x 70') is chosen for orientation neutrality (Thornton et al. 2010) in which 40% of the area is allotted for open office, 30% for enclosed/private office, 10% for corridor, 5% for conference room and remaining areas include printing/photocopying room, stairwell, and electric/mechanical rooms. The perimeter and core zoning pattern is adopted for energy modeling purposes and perimeter zone depth is 3.65m (12'). The floor to floor height is 3.96m (13') and clear floor to ceiling space is 2.74m (9'). The floor to floor glazing of 40% (27% for floor to ceiling) is equally distributed on all sides and includes internal blinds that are 20% closed during occupied hours and 80% closed when unoccupied. Building opaque constructions in the small- and medium-sized office prototype include mass walls, flat roof with insulation above the deck and slab-on-grade floors. Windows are defined as manufactured windows in punch style openings. These envelope constructions represent common practice for small-office buildings in the U.S. (CBECS 2012, Richman et al. 2008) and are followed in the study. The building operating hours are from 8am-5pm, Monday-Friday, and are closed on Standard Holidays in the US. Following (Table 1) building characteristics are used for energy estimation purposes.

Table 1: Spec office building characteristics.

Envelope		**Lighting (w/ft²)**	
Roof	R-30ci (albedo 0.4, light)	Office (open/enclosed)	0.98 /1.11
Walls	R13+R10ci	Conference Room	1.23
Slab on grade	R-15 for 24in	Restroom	0.98
Door	U-0.5	Corridor	0.66
Fenestration	U-0.42,	Mechanical	0.42
	SHGC-0.4	Copying Room	0.72
	VT-1	Plug loads	0.75 (Mercier 2011)(p3)

The baseline HVAC system for this building type and size, and climatic zone (5A) adopts ASHRAE 90.1-2013 Appendix G suggestion on use of (System3: PSZ-AC) constant volume packaged rooftop air conditioner. The space is conditioned by a packaged single zone DX system with furnace. The efficiency of packaged unit, EER, is 10 and furnace minimum efficiency is 80%. Also, the natural gas non-residential domestic hot water system is modeled at 80% efficiency. The HVAC system maintains a 23.8ºC (75ºF) cooling set point and 21.11ºC (70ºF) heating set point during occupied hours. During off hours, thermostat set point is 27.77ºC (82ºF) for cooling and 17.77ºC (64ºF) for heating. The economizer is set to maximum DB temperature 70F.

2.4. Comparison method

The distance from the Lake Michigan and distance from the Downtown are significant factors for intra-urban microclimatic variation. Among selected locations, Waukegan is less urbanized, less populated location and it is it is closer to the lake. It is far north of the Downtown and it is not influenced by the UHI. The west side developments where summertime UHI influences are significant hosts other study locations. The variations in UHI and related building heating and cooling energy needs on the west side locations are compared with Waukegan location.

Climatic changes: The temperature influences of UHI among selected locations are compared seasonally and particularly during the extremely hot week identified per NCDC. The summer months are particularly crucial due to increase in cooling related peak electric demand and energy. The summer months considered in this study are July-September whereas winter months are January-March. The autumn and spring months are represented by October-December and April-Jun respectively. The extremely hot week is from July 15-21 and the extreme winter week is from February 12-18. The average temperature of seasonal months is used to compare seasonal UHI. The average hourly temperature data is used to compare day and nighttime UHI. The day and nighttime hours are decided based on available global horizontal solar radiation which is the sum of direct normal irradiance, diffuse horizontal irradiance, and ground-reflected radiation.

Annual energy use: A whole energy simulation program, eQUEST 3.65 (DOE, 2013) has been previously validated for its algorithm and published elsewhere, and is considered suitable for this study (see Bhiwapurkar and Moschandreas, 2010) to estimate energy performance of the small-office building which is kept constant through the study. This allowed for focused investigation on shifting heating and cooling energy due to changing climate by keeping lighting, plug loads, and other energy needs constant through the study. The weather files collected from the five stations in the Chicago metropolitan area are used to estimate intra-urban variations in Energy Use Intensity (EUI), peak electric demand, annual electric and heating energy use. The variations in intra-urban HDD and CDD are also included in the study.

3.0 RESULTS AND ANALYSIS

3.1. Intra-urban climatic changes

There is a significant variation in average seasonal temperatures among all locations in Chicago metropolitan area. The average seasonal temperature includes hourly day and nighttime temperature for three months. The highest average temperature of 23.52ºC is observed during summer months at Midway and the lowest temperature of 20.6ºC is observed at Waukegan (Table 2). The temperature trends are opposite during winter months; DuPage (1.01ºC) and Midway (-0.85ºC) are warmer compared to Waukegan (-2.18ºC). During spring months, DuPage (15.95ºC) is reporting highest temperature and Waukegan (13.42ºC) being the lowest in the group. Although, the average temperatures are lower at all location in autumn, Midway reported highest temperature at 7.13ºC and Aurora is showing lowest among the group at -1.41ºC. In general, average seasonal temperatures at Waukegan are lowest, thus it is a reasonable assumption for baseline case when comparing intra-urban UHI.

The highest seasonal intra-urban UHI variation among four locations is observed during autumn months (October-December) and the lowest temperature variations are observed during spring months ranging from 1.42ºC at Aurora to 2.53ºC at DuPage. When average temperatures are compared with Waukegan, the variation ranges from 3.76ºC at Midway to -1.41ºC at Aurora. The negative temperature difference is representing a cool island effect. This variation is consistent with the distance from the Lake Michigan as well as the Downtown area. Thus, average wind direction and speed was analyzed at these locations. The average wind direction at Midway, O'Hare, DuPage and Aurora is from Southwest to Northwest direction. The combined influence of wind direction and speed seem to minimize temperature gradient across the east-west axis although industrial land use and high percentage of paved areas exists on west side developments (Konopacki and Akbari 2002, Gray and Finster 2004). Based on this observation, it is expected that the Downtown area remains warmer during autumn months although Downtown specific measurements will provide insights on such a claim.

Table 2: Seasonal UHI variation within Chicago metropolitan area (^{0}C).

	Waukegan	Midway	O'Hare	DuPage	Aurora
T (avg. summer)	20.60	23.52	21.34	20.54	21.44
ΔT (summer)		2.92	0.75	-0.05	0.85
T (avg. winter)	-2.18	-0.85	-1.11	1.01	-1.37
ΔT (winter)		1.33	1.07	3.19	0.81
T (avg. spring)	13.42	15.48	15.46	15.95	14.84
ΔT (spring)		2.06	2.04	2.53	1.42
T (avg. autumn)	3.37	7.13	4.00	3.89	1.96
ΔT (autumn)		3.76	0.63	0.52	-1.41

The summertime UHI intensity of 2.92ºC is highest at Midway and the west side locations, DuPage and Aurora, are showing marginal difference of -0.05ºC and 0.85ºC when compared with Waukegan location (Table 2). When compared with Midway locations, the temperatures at O'Hare, DuPage, and Aurora are cooler by 2.18ºC, 2.98ºC, and 2.08ºC. The lowest average summer temperature at DuPage is the most surprising result as this location is on the west side and it is closest to the center of heat island reported by Gray and Finster (2004). This summertime temperature trends, like autumn observations, are not following previously published trends of warmer climate on west side development. One of the significant influences is the prevailing west-southwest wind that averages 13.2 km/h transporting in warm and humid air from the central and southern plains (Angel 2014) does not support the UHI phenomenon presented in Figure 1(b). In addition, while the major water body can provide summertime cooling the location of the lake downwind from the prominent southwest wind may lessen its effect. The lake's cooling influence also wanes in late summer when water temperature can reach as high as 26.7ºC

The UHI effect is reported during day as well as night time. Table 3 summarizes day and night time averaged temperatures. The maximum seasonal day and night temperature difference (1.95ºC) is observed at Aurora during summer, followed by spring (1.14ºC), autumn (1.48ºC), and winter (0.61ºC) months. Similar pattern is followed by DuPage, O'Hare, and Midway showing lowest changes. Waukegan shows minimal change during winter and autumn month (1.91-2.1ºC) while spring and summer months show temperature differences in the range of 3.44ºC-3.76ºC respectively. Table 2 and Table 3 provided averaged temperature differences of the season. In order to investigate non-averaged temperature differences, this study delves into extremely hot week.

Table 3: Average Day and Night time UHI variation.

	Waukegan	Midway	O'Hare	DuPage	Aurora
T (summer day-night)	3.76	3.02	4.20	4.54	5.71
ΔT (summer day-night)		-0.74	0.44	0.78	1.95
T (winter day-night)	2.10	1.64	2.16	2.45	2.71
ΔT (winter day-night)		-0.47	0.06	0.35	0.61
T (spring day-night)	3.44	2.70	4.41	4.30	4.58
ΔT (summer day-night)		-0.74	0.44	0.78	1.95
T (autumn day-night)	1.91	2.06	2.47	3.38	3.39
ΔT (autumn day-night)		0.15	0.56	1.47	1.48

The extreme summer week varies per location so an overlapping period of two weeks from July 13-26 is considered for this analysis. During this time, the maximum daytime temperature (40.0ºC) is recorded at Midway on July 24 (with standard deviation of 12.81ºC). This record temperature is reflected in the overlapping peak demand for the building on the same day for Midway location. Similarly, high daytime temperature is increasing peak electric demand, although dates vary among selected location. The highest day and night temperature difference is observed at Aurora (19.00ºC) followed by Waukegan (15.20ºC), Midway (14.00ºC), O'Hare (13.30ºC) and DuPage (13.00ºC). The weekly average day and night temperature difference is highest at Aurora (13.00ºC) followed by O'Hare (10.64ºC), DuPage (10.31ºC), Midway (9.21ºC) and Waukegan (9.06ºC). The higher night time temperature that minimizes day and night time differences is an indication of night time UHI. When compared with Waukegan, Midway is showing high nighttime UHI and Aurora is showing minimum nighttime UHI. (Kolokotroni et al. 2012) suggests warm nighttime temperature can improve nighttime ventilation opportunities in office building for warming climate. The warm nighttime urban temperature may potentially increase use of air conditioners during evening hours, especially in residential buildings. However, spring and autumn month might benefit most from natural ventilation as an energy saving strategy. Since currently studied small-office building is operating during daytime (8am-5pm), this discussion focuses on daytime hours and following section explores the UHI influences on predicted energy needs.

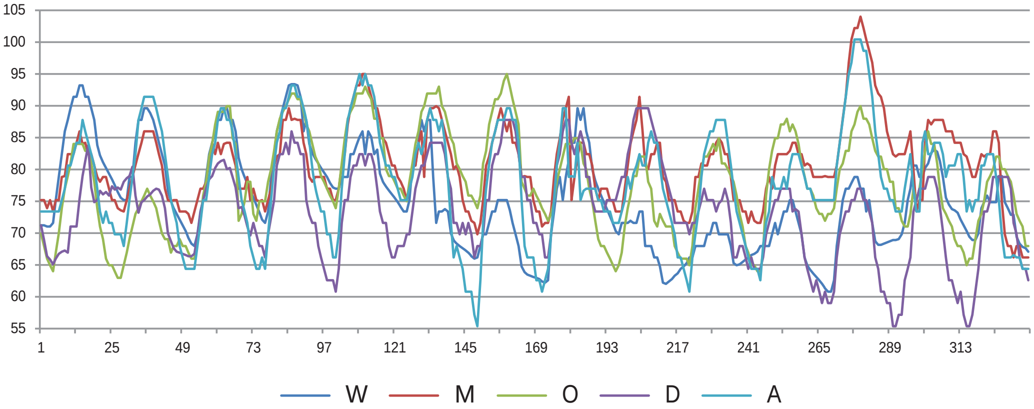


Figure 3: Extreme summer week, July 13-26 (change temperature scale from ^{0}F to ^{0}C).

The variation in intra-urban climatic conditions is changing annual heating and cooling degree days for each location as shown in Table 4. Midway location represents the most modified urban climate and it is observed in highest CDD (691) and lowest HDD (3106) among other locations. In comparison to Waukegan, Midway has 70% higher CDD and 17% lower HDD. While CDD and HDD are representative of climatic zone and does not account for specific building condition that may have unique indoor climatic conditions, the building cooling and heating hours vary significantly. The small-office building investigated in this study, shows 21% increase in building cooling hours and 22% decrease in building heating hours for Midway location. These changes are mainly due to external and internal gains. It is important to note that improved energy efficiency criteria of ASHARE 90.1-2013 allows for less building cooling hours (21%) however, it needs further study.

Table 4: Annual heating and cooling degree days.

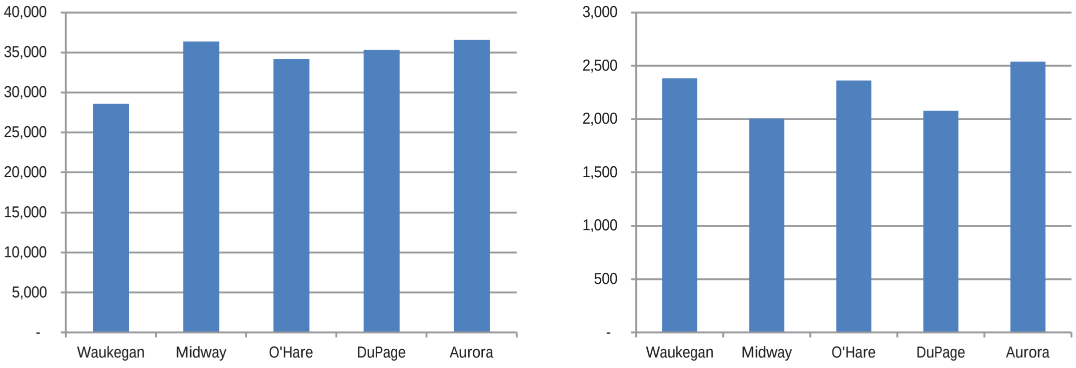
	Waukegan	Midway	O'Hare	DuPage	Aurora
CDD (18°C baseline)	407	691	506	523	444
Increase in CDD*		284 (70%)	99 (24%)	116 (29%)	37 (9%)
Building Cooling Hours	877	1065	1098	1097	1072
Increase in Building Cooling Hours		188(21%)	221(25%)	220(25%)	195(22%)
HDD (18°C baseline)	3747	3106	3430	3300	3629
Decrease in HDD*		-641(-17%)	-317(-8%)	-447(-12%)	-118(-3%)
Building Heating Hours	1329	1042	1188	1137	1133
Decrease in Building Heating Hours		-287(-22%)	-141(-11%)	-192(-14%)	-196(-15%)

* Changes in CDD and HDD in relation to Waukegan location

3.2. Building heating and cooling energy use

The annual building energy needs (gas, electric, and peak demand) of a 3-storied office building for selected locations in Chicago metropolitan area are discussed. For quality checks, the EUI at O'Hare location was compared with CBECS (2013) data for small buildings and then with EUI published by Pacific Northwest National Laboratory (PNNL) study on a small-office building (Thornton et al. 2010) (Table 5.5) that utilized similar weather file. The EUI estimated at O'Hare location in this study (26.75 KBtu/ft²) is lower than published PNNL study (27.40 KBtu/ft²) that applied advanced energy saving strategies. This change is in fair agreement for small-office buildings because PNNL study adopted ASHRAE 90.1-2004 and applied Advanced Energy Design Guide for Small Office Buildings available that time.

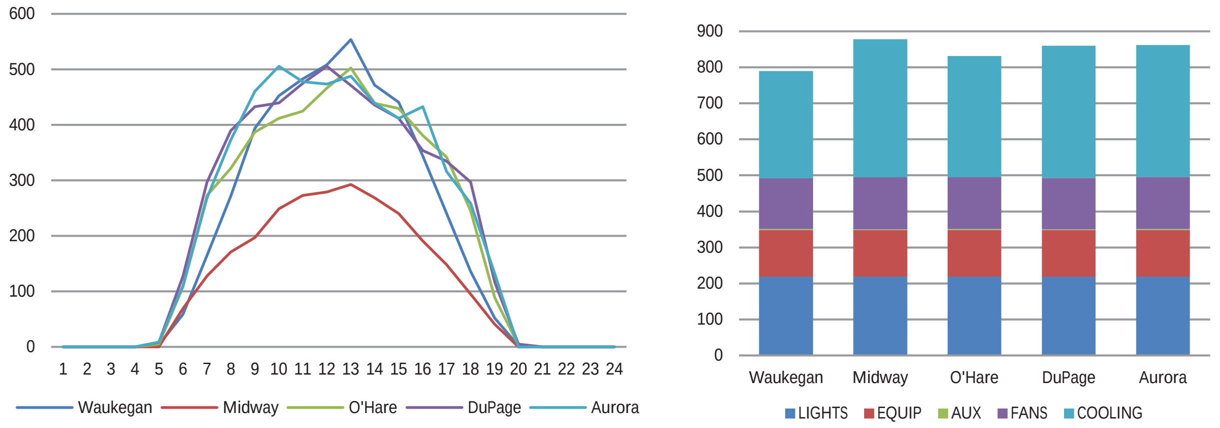
The highest EUI (6.863 kWh/ft²-yr) is observed for Midway location whereas the lowest EUI (6.559 kWh/ft²-yr) is reported at Waukegan location. The simulation results for EUI at OHare (6.781 kWh/ft²-yr) and Aurora (6.796 kWh/ft²-yr) locations are very similar whereas EUI (6.825 kWh/ft²-yr) at DuPage location it is slightly higher which is similar to Midway location. The annual electric energy needs shown in Figure 4(a) follows the similar trend. The energy consumption categories are lights, miscellaneous equipment (plug loads), space cooling, pumps and auxiliary, and ventilation fans in the building. The building energy consumption at Midway location is highest at 100,879kWh compared to the Waukegan at 96,424kWh. O'Hare and Aurora locations are showing similar results at 99,682kWh and 99,899kWh respectively.



(a) (b)

Figure 4: (a) Annual cooling energy (kWh) (b) Annual heating energy (Therms).

The cooling energy (kWh) needs are 34%-37% of the total electric needs of the building. When annual cooling energy needs among these locations are compared with Waukegan (Figure 4(a)), the energy needs are higher and cooling energy needs is emerged as the most fluctuating energy category. In this category, the small-office building at Aurora (28%) is consuming highest energy, and it is followed by Midway (27%), DuPage (24%), and O'Hare (19%). These variations are significant and affecting overall EUI. Also, it is surprising to note that Aurora location is consuming higher cooling energy than Midway location. Main reason for such fluctuations is location is warm daytime starting conditions due to nighttime UHI as well as daytime UHI that is influenced by wind speed and directions in the metropolitan area. Further, cloud cover plays an important role in the amount of global solar radiation received at these locations. Figure 5(a) shows average hourly global horizontal solar radiation received at selected locations through the year. Aurora receives highest solar radiation (386 w/m²) whereas Midway (200 w/m²) receives almost half the radiation because of high cloud cover. This is affecting external heat gain at Midway location compared to Aurora while internal heat gain remains constant for all locations.



(a) (b)

Figure 5: (a) Average hourly global solar radiation (w/m²) (b) Annual peak demand (kW) distribution by major categories**.**

The cooling related peak electric demand is significant. Annually, it constitutes 41-44% of the total electric demand except for Waukegan (38%). This contribution increases to 52%-56% during summer months and 46%-51% and 39%-44% during spring and autumn months respectively. Midway location required 56% of the peak energy for cooling during summer, which is not very different than Aurora (55%), DuPage (54%) and even O'Hare (52%). One of the major influences of climate change is increased extremes hot and cold weather events. This is observed during spring and autumn months as early heat waves are reported in April and the late heat waves are observed in October (reference). Early warming trends in spring are showing significant cooling related peak demand where Aurora and O'Hare locations need 51% peak demand for cooling and Midway and DuPage are at 49% and 46% respectively. During autumn months, Midway location shows highest cooling energy contribution towards peak demand.

High heating energy needs at Waukegan location (2382 Therms) is not surprising because of its proximity to the Lake Michigan. The lake tends to increase cloudiness in the area and suppress summer precipitation. Winter precipitation is enhanced by lake-effect snow that occurs when winds blow from the north or northeast. These winds allow air to pass over the relatively warm lake, boosting storm system energy and water content, and leading to increased snowfall. Similarly, far west side location of Aurora is showing high (2539 Therms) heating energy needs as north or northeast winds does not seem to be influenced by urban heat: combination of land-use land-cover, and anthropogenic heat sources, that are decreasing heating energy needs at Midway and DuPage locations.

The lake effect is significantly influencing building energy needs; especially at Waukegan which is closest and Aurora is the farthest from the Lake Michigan. Also, it is observed that the variations in energy needs are not consistent among studied locations. There is no direct relationship of cooling energy needs and UHI in the study area because UHI can change wind speed and wind direction and lake effect transport air mass with high moisture content. These in fact influences received solar energy by the urban surfaces and its interaction with boundary layer climate. While the lake can provide some summertime cooling, the prominent southwest wind may lessen its effect. The Lake's cooling influence also wanes in late summer when water temperatures can reach as high as 26.7◦C (80◦F).

These intra-urban climatic changes modified CDD and HDD. In comparison to Waukegan, Midv DuPage, and Aurora showed increase in CDD by 70%, 24%, 29%, and 9% respectively wl decreased by 22%, 11%, 14%, and 15% at Midway, O'Hare, DuPage and Aurora respectively.

The changes in CDD and HDD modified building energy use. The annual cooling energy needs 27%, 19%, 24%, and 28% at Midway, O'Hare, DuPage, and Aurora respectively in relation tc The cooling related peak energy demand increased by 20.62%, 1.69%, 5.12%, and 14.24% O'Hare, DuPage, and Aurora. In contrast, heating energy needs decreased by 16%, 1%, 13% Midway, O'Hare, DuPage, and Aurora locations respectively. The cooling energy needs is most affected by the microclimatic variation and it is reported to reach up to 52-56% of the total buildir

This study provides evidences on existing intra-urban climatic changes and its influences energy needs. This study for a great lake city is applicable for other lake cities and it is useful foi climate resilient strategies that will safeguard energy efficiency of future buildings.

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