Presenting author
Aiko Nakano

Urban Weather Generator User Interface Development: New Workflow for Integrating Urban Heat Island Effect in Urban Design Process

Aiko Nakano[1], Bruno Bueno[2], Leslie Norford[1], Christoph F Reinhart[1]
1 Massachusetts Institute of Technology, Cambridge, USA
2 Fraunhofer Institute for Solar Energy Systems ISE, Germany

Dated: 04 June 2015

Abstract

It is well known that local urban heat island (UHI) effects impact the urban environment from a public health standpoint and with regards to heating and cooling energy used by buildings. Unfortunately, neither urban planners and designers nor energy consultants currently have quantitative tools or methods at their disposal to incorporate this effect into the design of a neighborhood. This work is an application of the Urban Weather Generator (UWG) (Bueno et al., 2012a, 2014) as a design tool to provide climate-specific advice for cityscape geometry and land use. It is combined with a parametric simulation module that works either stand-alone or through the urban modeling interface (umi) (Reinhart et al., 2013) in Rhinoceros 3D. The user interface focuses on optimizing the key parameters for UHI according to the sensitivity analysis: site coverage ratio, façade-to-site ratio, building surface albedo and emissivity, as well as sensible anthropogenic heat in the urban canyon. We demonstrate a new workflow using the developed tool through a case study of the MIT East Campus development in Cambridge, MA, USA, which includes the addition of 130,000 m^2 of laboratory space and residences to an existing urban condition. IPCC climate change predictions (Nakicenovic & Swart, 2000) are coupled with UHI to capture local and global heating on the site to ensure thermally comfortable development at each planning phase.

1. Introduction

In 2007, more than 50% of the human population was living in cities that are trending towards increasing population densities. Overall urban densities are projected to increase in all major areas except Europe until 2050, with the most pronounced increases in Asia and Africa (United Nations, 2004). As cities develop, tall buildings fill the open spaces with dense structures (urban canyon) and artificial building materials replace natural terrains. These modifications lead to warmer nighttime temperatures in cities than in rural areas, a phenomenon known as urban heat island effect (UHI). UHI tends to be most intense at city centers and has a diurnal pattern, reaching minima in the later afternoon and maxima at night (Oke, 1987). This behavior is observed in numerous field studies around the world for a variety of climate regions (Crawley, 2008). The UHI is logarithmically proportional to population size (Oke, 1987) and is accelerated with the current trend in urban population growth.

While the UHI necessarily influences outdoor thermal comfort conditions, public health, and heating and cooling loads for buildings (Gorsevski, Taha, Quattrochi, & Luval, 1998), urban planners, designers and their consultants currently lack tools or methods to deliberately incorporate this effect into the design of new or renovated neighborhoods. Besserud and Hussey (2011) detected a need for simulation tools to assess the effect of varying urban massings on outdoor thermal comfort and building energy consumption. CitySim (Robinson, 2011) is an urban modeling platform that includes integrated custom modules for modeling microclimatic effects, transient heat flow, plants and equipment as well as occupant presence and behavior. Its atmospheric flow modeling is based on mass, momentum, and energy conservation equations.

We propose a new tool and workflow of the urban design process with UHI considerations and its implications for the thermal comfort and energy. Since the UHI intensity is a function of how buildings are clustered together in a city, we propose an intervention in the urban design process when the urban canyon forms take shape. The relatively fast algorithm of Urban Weather Generator (UWG) developed by Bueno (2012a, 2014) allows users to iteratively improve their massing designs. UWG models UHI from measurements at an operational weather station based on neighborhood-scale energy balances. The morphed temperature output can be used to study the effect of localized UHI on outdoor thermal comfort and building energy use profiles. The user interface (UI) helps users to focus on key parameters that impact the UHI and compare their designs based on thermal comfort and energy metrics. The tool is developed as a stand-alone tool and a plug-in for a 3D modelling interface Rhinoceros ("Rhino") (2014) that is widely used by design practitioners and students around the world.

With this tool urban planners can advocate zoning regulations for building height and land use as well as policies for traffic intensity and cool and green roofs with energy and thermal implications. Urban designers can articulate their designs with microclimatic conditions and parametrically test built densities and vegetation for masterplanning. Finally, when used in conjunction with energy simulation tools, urban energy consumption predictions are improved compared to our current practice of using weather files from rural weather stations that do not reflect the microclimatic conditions of the urban sites.

2. Simulation Platforms: Urban Weather Generator (UWG) and Urban Modeling Interface (umi)

Bueno (2012a) developed UWG using a building energy model that has been integrated in the Town Energy Balance scheme (Bueno et al., 2012b) and energy balances applied to control volumes in the urban canopy and boundary layers. UWG calculates the hourly values of urban air temperature and humidity based on rural weather data measured outside a city. It requires an EnergyPlus weather (epw) file (2013) and an Extensible Markup Language (xml) file describing the urban and rural site characteristics. The recent evaluation in Singapore (Bueno et al., 2014) demonstrated a range of land uses, morphological parameters and building usages that the model is able to simulate. UWG's performance is comparable to a more computationally expensive mesoscale atmospheric model and it shows satisfactory performance for all weather conditions and for different reference sites. The simplifications and assumptions of the model prevent it from capturing very site-specific microclimate effects. Yet it is still robust enough to produce plausible values across urban morphology and vegetation parameters based on validations in three different sites.

Urban Modeling Interface (umi) (version 02.0039; Reinhart, et al, 2013) was developed to streamline the workflow from formal design conceptualization through energy simulation within a single design platform. It is a plug-in tool for Rhino for simulating urban-scale operational energy, walkability, and daylighting. umi's custom toolbar guides necessary user inputs, requiring minimum training to start using the tool. The energy component uses EnergyPlus (2013) and approximates massing into four small shoeboxes facing each direction to reduce the simulation time (Dogan & Reinhart, 2013). UWG is developed as a plug-in for umi to take advantage of its existing energy component and to complement other aspects of environmental performance simulations.

3. Key UHI Parameter Identification through Sensitivity Analysis

As UWG requires over 50 parameters including those related to climatology, sensitivity analysis is performed to identify the most important parameters and reduce the number of user inputs such that the urban weather and underlying physical processes can be used by designers and energy consultants. The goal of the sensitivity analysis is two-fold: (1) test significance of parameters that are of high interest to urban designers and planners, such as massing and land use as well as (2) ensure that the inputs that are difficult to obtain (i.e. meteorological parameters) are not significant to the UHI nor site-specific.

An earlier study for Toulouse and Basel (mild climates) (Bueno et al., 2012a) showed that site coverage ratio (= total building footprint/ site area), façade-to-site ratio (= total façade area/ site area), and vegetation are the most sensitive parameters for UHI. Additional studies for Punggol, Singapore (tropical, residential district) and Boston Financial District, MA, USA (cold, commercial and densest district in Boston) are conducted to determine the most effective design strategies for each climate. If a parameter is determined to be significant across all climates, then we can conclude that such parameter is a key contributor to the UHI. Conversely, if it has a minor impact across all climates, then we can assign a default value. The Boston parametric study is documented here, and the readers are referred to Nakano (2015) for Singapore study setup.

3.1 Setup and Metrics

Each parameter is changed one at a time and its simulation result is evaluated against the base case for its impact on temperature and energy use. The base case is the urban epw file generated using actual values for the Boston Financial District. Urban morphology data is extracted from geographic information system (ESRI, 2014) data using Grasshopper (Davidson, 2015) (definition available at http://urbanmicroclimate.scripts.mit.edu). The anthropogenic heat input is estimated as the vehicular contribution of anthropogenic heat flux (Sailor, 2011) for compact highrise neighborhoods based on Stewart and Oke's Urban Classification (2012). The meteorological parameters are based on existing data from Toulouse and Basel (Bueno et al., 2012a). Building construction materials and schedules are obtained from the U.S. Department of Energy (US DOE)'s Commercial Reference Buildings (n.d.) for small office in Boston. We use "USA_MA_Boston-Logan.Intl.AP.725090_TMY3.epw" (US DOE, 2013) as the reference weather file. Rural vegetation and obstacle height are estimated from satellite images. Following weather morphing using UWG, energy implications are measured using EnergyPlus (2013).

Four metrics are compared against the urban base case to measure the UHI sensitivity: (a) temperature change (significant if more than 0.5% of the 8760 hours in a year deviate more than 0.5K from the original temperature profile), (b) percent change in annual heating and cooling energy use (significant if the total difference is greater than 2.0% compared to the base case), (c) percent change in winter (November - January) heating energy consumption, and (d) percent change in summer (June - August) cooling energy consumption. A parameter is determined significant if it fails one or more metric for either low or high end of the sensitivity range.

3.2 Results

Site coverage ratio, façade-to-site ratio, anthropogenic heat, and roof materials are important for UHI in both Boston (Figure 1) and Singapore (Table 1), similar to the earlier studies in Toulouse and Basel. The site coverage ratio affects canyon width and it is the most important parameter for Boston and Punggol, especially at night. The façade-to-site ratio describes the canyon height in the UWG model and thus solar radiation received by building façade. It is not significant for Punggol, perhaps because the variations were too small for the low and high ranges. The sensible anthropogenic heat defines the amount of heat released to urban canyon mostly from traffic, and it affects the thermal comfort in the late afternoon and at night. The effects of using green and cool roofs are preliminarily tested via parametric studies for albedo and emissivity (values noted in Figure 1). In particular, green roofs affect the urban sensible heat flux into the urban boundary layer at night. The authors also found that the "reference height at which vertical profile of potential temperature is assumed uniform" seems to affect the UHI for Boston. For cities with high wind velocities, advection can play a relevant role in the energy balance of the urban boundary layer. This represents a limitation for UWG and is left accessible in the UI via Advanced Setting.

The consistency of results reduced required user inputs to the model by 46% without decreasing the simulation accuracy. The UI thus asks users to provide inputs for these key parameters and vegetation (urban tree coverage) that are important for the sensitivity analyses in European cities. Other user inputs include morphological parameters such as average urban building and rural obstacle heights (site-specific and easily obtainable) as well as building constructions and schedules (constants in the sensitivity analysis).

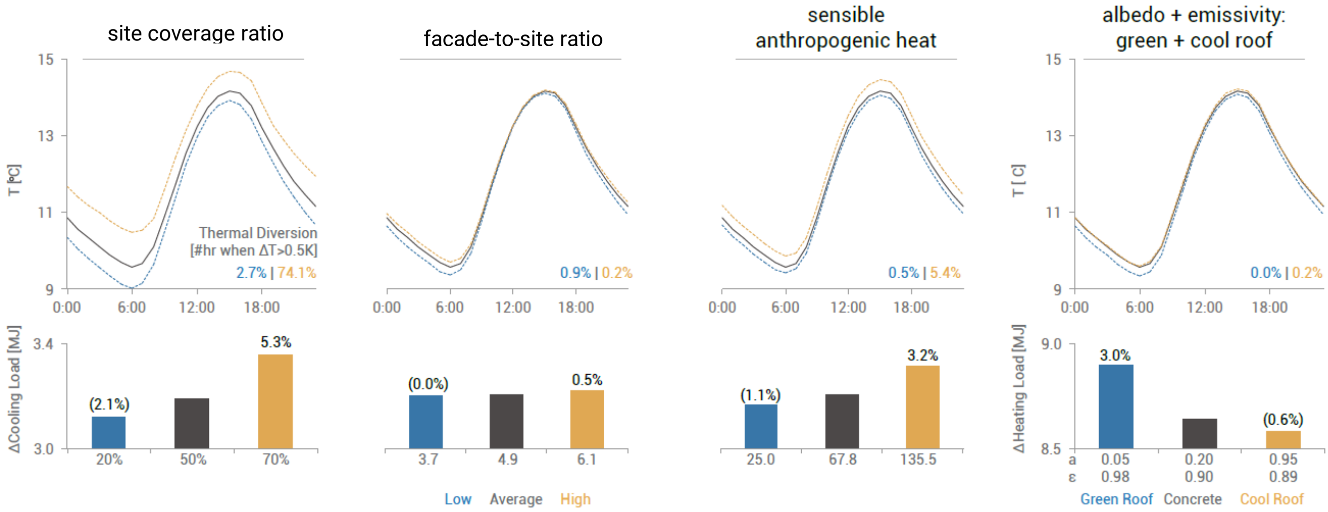


Figure 1 Boston sensitive parameters. Thermal diversion is defined as the average annual air temperature

Table 1 Sensitivity analysis results for Boston (Logan Airport and Bedford Hascom reference sites) and Punggol (Changi Airport reference site). The metrics that are determined to be significant are highlighted in bold red.

	Boston-Logan		Boston-Bedford		Punggol	
SITE COVERAGE RATIO (Avg Value)	0.51		0.51		0.38	
	Low	High	Low	High	Low	High
Value	0.20	0.70	0.20	0.70	0.20	0.70
%Change from Average	(60.8%)	37.3%	(60.8%)	37.3%	(47.2%)	84.7%
ΔT below 0.5K	**97.3%**	**25.9%**	**90.9%**	**16.2%**	99.8%	**21.7%**
Annual Heating/Cooling % Change	**4.9%**	**(7.0%)**	**5.6%**	**(8.0%)**	**(2.7%)**	**4.3%**
Winter Heating % Change	**6.2%**	**(10.1%)**	**7.8%**	**(11.5%)**	**(2.7%)**	**4.4%**
Summer Cooling % Change	**(2.1%)**	**5.3%**	**(3.1%)**	**5.0%**	**(2.7%)**	**4.3%**
FAÇADE-TO-SITE RATIO	4.87		4.87		1.55	
	Low	High	Low	High	Low	High
Value	3.65	6.09	3.65	6.09	1.16	1.94
%Change from Average	(25.0%)	25.0%	(25.0%)	25.0%	(25.0%)	25.0%
ΔT below 0.5K	**99.1%**	99.8%	**97.2%**	**97.9%**	100.0%	100.0%
Annual Heating/Cooling % Change	2.0%	(1.0%)	1.7%	(1.1%)	(0.0%)	(0.1%)
Winter Heating % Change	2.0%	(1.4%)	1.9%	(1.2%)	(0.1%)	(0.1%)
Summer Cooling % Change	(0.0%)	0.5%	(0.1%)	(0.2%)	0.0%	(0.1%)
SENSIBLE ANTHROPOGENIC HEAT	67.75		67.75		4.00	
	Low	High	Low	High	Low	High
Value	--	135.50	--	135.50	2.00	6.00
%Change from Average	(100.0%)	100.0%	(100.0%)	100.0%	(50.0%)	50.0%
ΔT below 0.5K	99.5%	**94.6%**	**91.4%**	**82.0%**	**50.0%**	**99.3%**
Annual Heating/Cooling % Change	1.6%	(1.4%)	1.5%	(1.4%)	**(2.6%)**	**2.3%**
Winter Heating % Change	**2.2%**	**(2.7%)**	**2.8%**	**(2.7%)**	**(2.8%)**	**2.5%**
Summer Cooling % Change	**(2.2%)**	**3.2%**	**(3.2%)**	**3.1%**	**(2.5%)**	**2.2%**

4. UWG Architecture towards a Usable Design Tool

The wrapper for UWG (referred to as UWG from hereon) assists users to create the xml input file required by the UWG, run parametric simulations, and evaluate results. Users can repeat these steps based on simulation results as demonstrated in the case study below. The UI is simplified via sensitivity analysis and has default values assigned to parameters with small effects on UHI to shorten simulation setup time for even novice users. Parameters with small contributions to the UHI are moved to the Advanced Setting. Users who are familiar with urban heat flow can access them via the expander or directly from the xml files to fine-tune their assumptions.

The Rhino- integrated version is invoked by typing "UmiRunUWG" in Rhino's command line while the user is in an umi project. It takes advantage of Rhino and umi's functions to automatically extract site coverage ratio, façade-to-site ratio, average building height (weighted by building footprint), characteristic length (√(site area)), as well as average window-to-wall ratio and U-value (weighted by facade area) to further reduce user inputs and the extra step previously required to manually calculate or use Grasshopper definition provided above.

5. Demonstration of the New Urban Design Workflow using UWG

The vision of the East Campus urban design study (MIT 2030 East Campus Urban Design Study, 2014) is to create a gateway from the Kendall Square to the MIT campus to enhance connection and foster innovation between MIT and commercial partners. We propose an alternative to MIT's development plan by incorporating outdoor thermal comfort as one of the drivers for the urban design process. Table 2 summarizes the two main schemes with parametric variations of the morphological parameters and insulation thicknesses. Our Connection scheme aims to envelope the open space better with shorter buildings in order to create a more welcoming arrival experience to the campus with a sense of openness and connectivity to Kendall Square. This opening is also oriented towards the summer breeze direction for natural ventilation (not modeled as UWG does not currently consider it). The strategies focus on average building height, site coverage ratio, and façade-to-site ratio based on the sensitivity analysis and each simulation result guides the direction for the new alternative. The final alternative also explores the effect of using green roofs. The Logan Airport weather file is used for the reference site.

Table 2 Summary of building characteristics for each alternative as well as current and planned MIT design

	Avg bldg. height [m]	Avg site coverage ratio	Avg façade-to-site ratio
Current MIT campus	30.52	0.36	1.19
MIT's plan	34.26	0.48	2.52
Alt 1: MIT scheme - high rise	41.16	0.40	2.33
Alt 2: MIT scheme - low rise	29.41	0.53	2.43
Alt 3: MIT scheme - better insulation	30.52	0.36	1.19
Alt 4: Connection scheme	35.65	0.43	2.31
Alt 5: Connection scheme - low rise	34.61	0.47	2.31
Alt 6: Connection scheme - increased insulation and vegetation	34.61	0.47	2.31

5.1 Thermal Comfort Results

The diurnal UHI intensities are compared against the current campus in Figure 2. The minimum and maximum UHI intensities are -0.1K and 0.4K for the summer and 0.2K and 0.7K for the winter. The negative values indicate that there is urban cooling between the hours of 9am – 1pm in July for all cases. This is expected because much of the parking lot (concrete) is replaced by vegetation. Alternative 2 has the most cooling effect possibly because urban canyon height is short and thus heat can easily escape from the urban canyon. Based on the result from this simulation run, the future schemes explore shorter urban canyon heights. This is exactly done for Alternatives 5 and 6, which are derivatives of Alternative 4.

Alternative 6 (turquoise) achieves urban cooling via shorter canyon heights as well as through cool roof and increased vegetation and shading on the streets. We also observe that urban cooling is greater for cases with higher levels of insulation (Alternatives 3 and 6) because the building construction is improved on average when new buildings with higher levels of insulation replace old buildings. Furthermore, Alt 6 has the least amount of urban heating in the summer from 3pm – 9pm and the third smallest increase in the winter. We note that the UI can visualize monthly results, but we show here the compiled July and December results for the purpose of the study. Boston has the highest dry bulb temperatures in July, so the effect of urban heating/cooling is more relevant in the summer months than in the winter. In Figure 3 (left and middle), we observe a small shift in annual thermal comfort based on Universal Thermal Climate Index (UTCI) (Bröde, et al., 2010). For these reasons we select Alt 6 as our best case for thermal comfort.

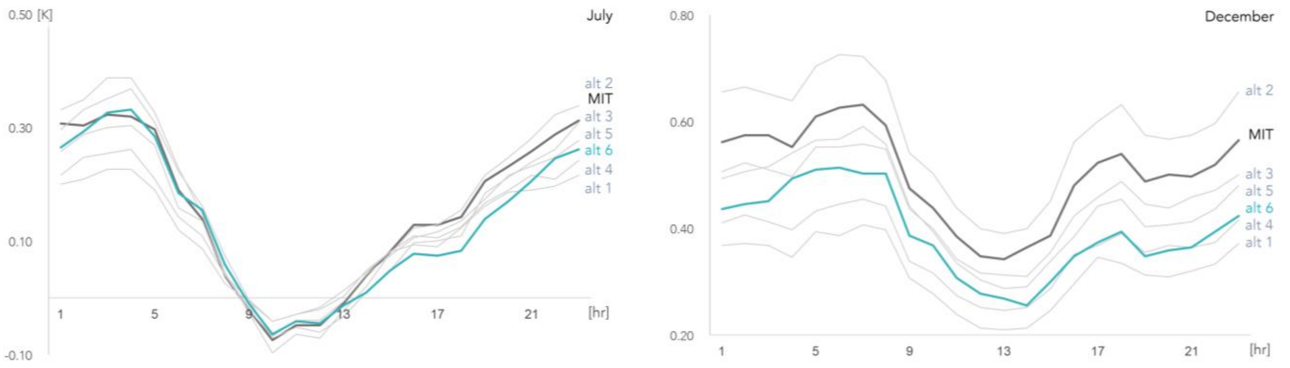
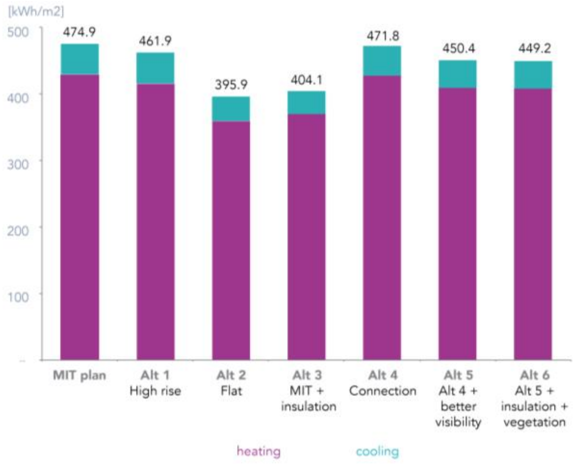


Figure 2 Comparison of UHI intensity against the current campus. MIT case in black and selected case 6 in cyan

Figure 3 Annual UTCI histograms for the selected case 6. There is no thermal stress between +9 < T < 26 C˚ (highlighted in cyan).Climate change and UHI are combined (right, discussed below)

5.2 Energy Performance Results

The energy demand values from umi are shown Figure 4 (left). They are the normalized energy demand for heating and cooling loads for the new buildings representing a mix of 51.6% lab, 29.8% commercial, and 18.6% residential buildings. The estimations for each program are in line with energy consumption of the template buildings for 2008 – 2012 provided by the MIT Department of Facilities (Figure 4, right).



Program	Template building	Cooling Energy [kWh/m²]	Heating Energy [kWh/m2]
Labs	Koch Institute (76)	462.8	497.6
Office, retail, and classroom	Sloan School of Management (E62)	52.0	58.6
Residential	Massy Dormitory (W1)	-- [1]	105.6

Note:
1. No air conditioning

Figure 4 Heating and cooling energy simulation results (left) and actual usage by template buildings (right)

The comparisons of the MIT design with each of its variations (alternatives 1 - 3) reveal the following effects of changing the urban design parameters. Alt 1 (high rise) has lower cooling energy consumption than the MIT case, possibly due to the increase in open green space. Alt 2 (low rise) is the extreme case for minimizing the average building height. It has the lowest energy consumption for heating because buildings do not shade each other. Alt 3 (increased insulation) improves the energy performance as expected. These observations show that shorter buildings, open space (to mitigate shading), and façade insulations are effective strategies for improving the energy performance. Alternatives 4 – 6 test the same strategies and see the reduction in energy consumption as insulation levels are increased and average building heights are reduced. We note here that the insulation levels tested are for demonstrative purposes and should be refined further in the individual building design phase. Furthermore, energy consumption in turn affects the UHI, so we recommend to continue using UWG in that stage to get a more accurate estimation of the UHI.

Based on the simulation results, we recommend Alternative 6 for improved thermal comfort particularly because urban heating is minimized during prolonged summer afternoons when cooling is most desired.

5.3 Application: UHI with Climate Change

Urban heating is the local and direct heating effect from urbanization. Here we discuss UHI in combination with the global heating effect – climate change – to holistically capture urban thermal comfort and energy consumption over time. Specifically we will evaluate the recommended Alternative 6 at each phase to ensure a thermally comfortable campus throughout the urban development. We assume Phase 1 is in 2020 and phase 2 in 2050. The development of graduate housing space is prioritized in the first phase to meet student housing demand. The demolition of existing buildings and the conversion of parking lot space to green space happens during this stage as well. In phase 2, labs and commercial programs are built. This evaluation also represents an application of how UWG can be used in conjunction with other tools towards a more holistic urban design process.

We use the CCWorldWeatherGen tool (2008; Jentsch, James, Bourikas, & Bahaj, 2013) that incorporates Intergovernmental Panel on Climate Change (IPCC) medium to high emissions scenario (A2) (Nakicenovic & Swart, 2000). The monthly average dry bulb temperatures in East Campus in 2020 and 2050 are shown in Figure 5 (left). Compared to the current MIT campus in 2015, the annual average temperature increases are 0.9K by 2020 and 2.2K by 2050. The increases are most prominent for the summer and winter months.

This morphed file is used in the UWG simulation to capture the local UHI and global warming effects. Figure 5 (right) breaks out the contributions of UHI and climate change on urban average monthly dry bulb temperature profiles from 2015 base (Boston Logan Airport reference site) to the current East Campus (UHI only) then to 2020 and 2050. The average annual temperature is projected to increase by 2.2K from 11.3˚C in 2015 to 13.5˚C in 2050 in the East Campus. The predicted maximum and minimum monthly average temperatures on the East Campus site in 2050 are 26.1˚C and 0.5˚C. We observe that the average contribution of UHI is about a tenth of that from the climate change. The urban cooling in 2020 is most likely from the increase in open space (i.e. the urban canyon is wider and less heat is trapped) as some existing buildings are removed. In other words, the climate change is mitigated via a local change in the site morphology.

In addition, there is an upward shift in the UTCI histogram (Figure 3, right). The hourly count of the thermally comfortable hours (i.e. no heat stress) decreased by 2% by 2050. The thermally stressful hours (above “no thermal stress”) increase from 5% to 12% in 2050 compared to 2015 (Figure 3, left). There are 6 hours in July 2050 when the UTCI reaches above 38˚C (very strong heat stress) while the highest level is “strong heat stress” at 35˚C on current campus and in 2050, when only UHI is considered (Figure 3, left and middle).

This case study demonstrated the methodology to improve thermal comfort and energy performance of an urban development through a change in the urban morphology. Other aspects of environmental performance such as daylighting, mobility, and embodied energy should be considered for a complete evaluation of the performative urban design.

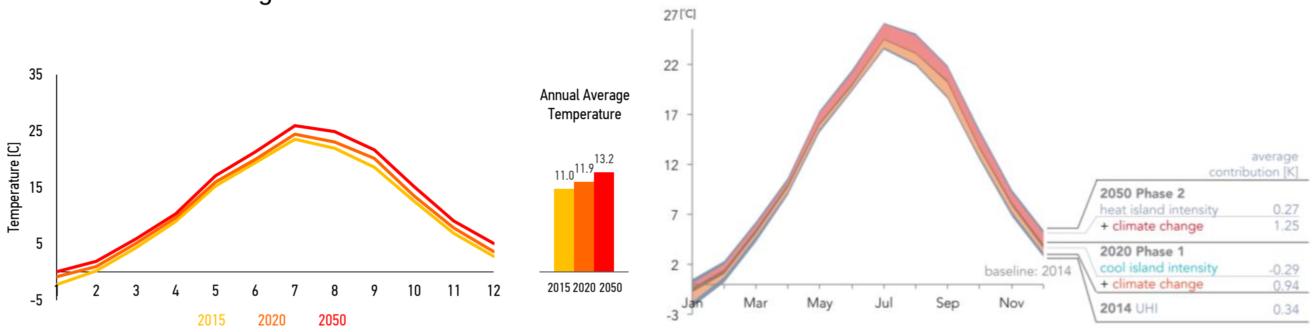


Figure 5 Monthly average temperature for East Campus using IPCC-A2 scenario (Left) and changes in urban dry bulb temperatures from 2015 (Logan Airport) through 2050 (Right)

Downloading the Software

The initial version of UWG is available for download free-of-charge at http://urbanmicroclimate.scripts.mit.edu and will also be available in the next release of umi at http://urbanmodellinginterface.ning.com.

Acknowledgment

This work is funded by the National Research Foundation (NRF) through the Singapore-MIT Alliance for Research and Technology Center for Environmental Sensing and Modeling. Cody Rose was instrumental in implementing the umi version of the tool and Lingfu Zhang and Bokil Lopez-Pineda made possible many functionalities of the UI.

References

Besserud, K., & Hussey, T. (2011). Urban design, urban simulation, and the need for computational tools. *IBM Journal of Research and Development, 55*(1.2).

Bröde, P., Jendritzky, G., Fiala, D., & Havenith, G. (2010). The Universal Thermal Climate Index UTCI in Operational Use. *Adapting to Change: New Thinking on Comfort.* Cumberland Lodge, Windsor, UK.

Bueno, B., Norford, L., Hidalgo, J., & Pigeon, G. (2012a). The urban weather generator. *Journal of Building Performance Simulation, 6*(4), 269–81.

Bueno, B., Pigeon, G., Norford, L. K., Zibouche, K., & Marchadi, C. (2012b). Development and evaluation of a building energy model integrated in the TEB scheme. *Geoscientific Model Development, 5* (2), 433–448.

Bueno, B., Roth, M., Norford, L., & Li, R. (2014). Computationally efficient prediction of canopy level urban air temperature at the neighbourhood scale. *Urban Climate, 9*.

CCWorldWeatherGen [Computer Software]. (2008). Retrieved from http://www.energy.soton.ac.uk

Crawley, D. B. (2008). Estimating the impacts of climate change and urbanization on building performance. *Journal of Building Performance Simulation, 1*(2), 91–115.

Davidson, S. (2015). Grasshopper [Computer software]. Retrieved from http://www.grasshopper3d.com

Dogan, T., & Reinhart, C. (2013). Automated conversion of architectural massing models into thermal ‘shoebox’ models. *International Building Performance Simulation Association.* Chambéry, France.

EnergyPlus [Computer Software]. (2013). Retrieved from http://apps1.eere.energy.gov

ESRI. (2014). ArcGIS/ArcMAP [Computer software]. Retrieved from http://www.esri.com

Gorsevski, V., Taha, H., Quattrochi, D., & Luval, J. (1998). Air pollution prevention through urban heat island mitigation: An update on the Urban Heat Island Pilot Project. *ACEEE Summer Study.* Asilomar, CA.

Jentsch, M. F., James, P. B., Bourikas, L., & Bahaj, A. S. (2013). Transforming existing weather data for worldwide locations to enable energy and building performance simulation under future climates. *Renewable Energy, 55*, 514-524.

MIT 2030 East Campus Urban Design Study. (2014). Retrieved Feb 21, 2014, from http://web.mit.edu/mit2030/projects/eastcampusgateway/index.html

Nakano, A. (2015). *Urban Weather Generator User Interface Development: Towards a Usable Tool for Integrating Urban Heat Island Effect within Urban Design Process.* Retrieved from DSpace: https://dspace.mit.edu

Nakicenovic, N., & Swart, R. (2000). *IPCC Emissions Scenarios.* Retrieved Apr 1, 2015, from http://www.ipcc.ch

Oke, T. (1987). *Boundary Layer Climates. .* London: Methuen and Company.

Reinhart, C., Dogan, T., Jakubiec, A., Rekha, T., & Sang, A. (2013). umi - An Urban Simulation Environment for Building Energy Use, Daylighting, and Walkability. *International Building Performance Simulation Association.* Chambéry, France.

Rhinoceros [Computer software]. (2014). Retrieved May 1, 2015, from http://www.rhino3d.com

Robinson, D. (2011). Computer Modelling for Sustainable Urban Design: Physical Principles, Methods and Applications.

Sailor, D. J. (2011). A review of methods for estimating anthropogenic heat and moisture emissions in the urban environment. *International Journal of Climatology, 31*(2), 189 - 199.

Stewart, I. D., & Oke , T. (2012). Local Climate Zones for Urban Temperature Studies. *Bulletin of American Meteorological Society, 92*.

U.S. Department of Energy. (2013). *Weather Data*. Retrieved from EnergyPlus Energy Simulation Software [Data file]: http://apps1.eere.energy.gov/

U.S. Department of Energy. (n.d.). *Commercial Reference Buildings.* Retrieved from http://www1.eere.energy.gov

umi [Computer software]. (2014). Retrieved from http://urbanmodellinginterface.ning.com

United Nations . (2004). *World Population to 2300.* Retrieved from Department of Economic and Social Affairs: http://www.un.org