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From the IAUC President

Colleagues, welcome to the 47th edition of *Urban Climate News*, which has been edited to the inimitable standards of David Pearlmutter. Much of the material that makes up this issue is drawn from the recipients of the student awards at the ICUC8 event in Dublin, last August. At that conference, which was hosted jointly by the IAUC and the AMS' Board of the Urban Environment, 13 awards were presented. The contributions presented here are from the AMS recipients, just as the 46th edition carried the IAUC recipients. The diversity and depth of work completed by these students is an indication of the strength of our field and its vibrancy. The collection includes both observations and modelling approaches and focuses both on scientific understanding and on applications.

One of the chief motivations for studying the climates of cities is the desire to apply this knowledge to the planning and design of urban areas. However, with few exceptions, this has rarely been the case. One of the reasons for this is that climate issues alone are not predominant or even significant in most urban decisions. A more realizable aspiration might be to have these issues incorporated within a broader concern for the urban environment. In this respect, it is encouraging to the establishment of The Marron Institute on Cities and the Urban Environment at New York University. According to the Institute's Dean (a professor of Law) *rapid urbanization, and particularly the challenges and opportunities it poses for the natural environment, must prompt a rethinking of higher education's role in the research and teaching of cities.* One hopes that climate at all scales (not just global) is integrated into any curriculum that develops and that the thinking behind the Marron Institute will inspire similar initiatives elsewhere.

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Inside the Spring issue...

Stay tuned this summer,
as *Urban Climate News* introduces
a new generation of multi-media
features…

Masdar City: Urban Energy and Climate Change Solution?

March 2013 — The United Arab Emirates was built on traditional fossil fuels – an OPEC member since 1967, home to the world's seventh largest oil and natural gas reserves and the first Middle Eastern country to export LNG. Recently, however, it inaugurated the largest thermal solar power plant in the world and is about to begin producing nuclear power, a significant accomplishment given the region's geopolitical complexity. Against that backdrop, the UAE has embarked on an aggressive experiment into urban sustainability designed to rely upon and pioneer cutting edge renewable energy technology with a project called Masdar City.

But is Masdar just an expensive gamble bankrolled by oil wealth, or a visionary approach to sustainable urban development that could help turn down the climate change dial? The answer most likely falls somewhere in between. Lessons learned along with technology solutions developed as part of this unique project could be applied in other parts of the developing and developed world to assist governments seeking to reach greenhouse gas reduction targets.

Masdar City is named for the government-owned renewable energy company – *Masdar*, meaning "the source" in Arabic – which is a subsidiary of the massive government investment vehicle Mubadala Development Company. Upon completion, the city will be a technology cluster complete with research laboratories, residential housing and commercial space for 40,000 permanent residents and 50,000 daily commuters. It will be completely powered by renewable energy – 20% of which will be generated on site – and have a limited carbon footprint.

The developers are using state of the art building materials, passive and intelligent design techniques along with ancient Islamic architectural features to achieve an unprecedented level of energy efficiency. High and low density materials are used to minimize heat gain and maximize cooling breezes. Passive building technology accounts for 60% to 80% of Masdar City's energy savings. In summer, when 130°F is a common occurrence, surface temperatures in Masdar City are significantly cooler than adjacent Abu Dhabi where asphalt and traditional concrete absorb and hold the sun's heat.

Airflow is maximized inside and out of the library building by designing it with a baseball cap-like roof that shades the sun-facing façade while catching and swirling desert breezes in a shady area on the other side. Centrally-located circular stairs inside also help keep air circulating, thus limiting the energy needed for air conditioning.

A public transport system of electric buses, electric cars, and other clean-energy vehicles will provide trans-

Source: AOL Energy

port within the city, while Abu Dhabi's light rail and Metro lines will pass through the center of Masdar City, providing transport within the city and serving as a link to the wider metropolitan area. The city also has initiated an electric car pilot to test a point-to-point transportation solution for the city that uses Mitsubishi Motor's i-MiEV, five-door hatchbacks.

Masdar has a 10 megawatt PV solar field – installed in 2009 and still the largest in the Middle East – that currently supplies more energy than required, allowing the excess to be fed into Abu Dhabi's public power grid. Blowing sand and dust is a problem for solar in desert locations because it collects on the panels and reduces their efficiency, so scientists at Masdar Institute are conducting research into light/matter interaction and working on coatings that repel sand or bacteria for use on solar panels and other applications.

But none of this comes cheap. The project has benefitted from historically high oil prices in recent years – the average annual OPEC basket price has remained above $100 per barrel since 2011 – which has helped finance Masdar City's development. The total cost is estimated at $18-$19 billion – making it an expensive experiment.

If Masdar can pioneer, prove up and deploy new technology that decreases in cost with economies of scale and can be applied to other parts of the world, the experiment will likely be deemed a success regardless its initial of cost. The project's funding, which largely comes from the UAE government, appears somewhat dependent on the price of oil. A price collapse similar to that of late 2008 and 2009 when the OPEC basket fell as low as $34/bbl could challenge the project's capital structure.

Nevertheless, Masdar City is in a part of the world with skyrocketing population growth that needs energy-efficient housing, cooling, water desalination and renewable energy solutions – and in pursuing such solutions it can help advance renewable energy technology, which is projected to make up an increasing share of the global energy mix. *Source*: AOL Energy

Phoenix's too hot future

Look no further than the aptly named Valley of the Sun to see the brutal new climate to come

March 2013 — If cities were stocks, you'd want to short Phoenix.

Of course, it's an easy city to pick on. The nation's 13th-largest metropolitan area crams 4.3 million people into a low bowl in a hot desert, where horrific heat waves and windstorms visit it regularly. And it depends on an improbable infrastructure to suck water from the distant (and dwindling) Colorado River.

If the Gulf Coast's Hurricane Katrina and the Eastern Seaboard's Superstorm Sandy previewed how coastal cities can expect to fare as seas rise and storms strengthen, Phoenix — which also stands squarely in the cross hairs of climate change — pulls back the curtain on the future of inland empires. If you want a taste of the brutal new climate to come, look no further than the aptly named Valley of the Sun.

In Phoenix, the convergence of heat, drought and violent winds is creating an ever-more-worrisome situation. Let's take heat first. If, in summer, the grid there were to fail on a large scale and for a significant period of time, the fallout would make the consequences of Sandy look mild. Phoenix is an air-conditioned city. If the power goes out, people fry.

In the summer of 2003, a heat wave swept Europe and killed 70,000 people. The temperature in London touched 100 degrees Fahrenheit for the first time since records had been kept, and in portions of France, the mercury climbed as high as 104. Those temperatures, however, are child's play in Phoenix, where readings commonly exceed 100 degrees for more than 100 days a year. In 2011, the city set a record for days over 110. There were 33 of them.

It goes without saying that Phoenix's desert setting is hot by nature, but humans have made it hotter. The city is a masonry world, with asphalt and concrete everywhere. The hard, heavy materials absorb daytime heat more efficiently than the naked land, and then give it back more slowly after the sun goes down, preventing the cool of the desert night from providing much relief.

Sixty years ago, nighttime lows never crept above 90. Today such temperatures are a commonplace, and the vigil has begun for the first night that doesn't dip below 100. And heat is a tricky adversary. It stresses everything, including electrical equipment. Transformers, when they get too hot, can fail, and thermoelectric generating becomes less efficient.

And the great hydroelectric dams of the Colorado River, including Glen Canyon, which serves greater Phoenix, won't be able to supply the "peaking power" they do now if the reservoirs behind them are fatally shrunken by drought, as multiple studies forecast they will be. Not to worry, say the two major utilities serving the Phoenix metroplex, Arizona Public Service and the Salt River Project: Much of this can be mitigated with upgraded equipment, smart-grid technologies and redundant systems. And they have managed to keep outages brief. So far.

Phoenix sits in a bowl in a hot desert; heat waves and windstorms visit its 4.3 million residents regularly. ***Source:*** LATimes.com

But before Katrina hit, the Army Corps of Engineers was similarly reassuring to the people of New Orleans. And until Superstorm Sandy landed, almost no one worried about storm surges filling the subway tunnels of New York. Every system, like every city, has its vulnerabilities. Climate change, in almost every instance, intensifies them.

One looming vulnerability for Phoenix is that the beefed-up, juiced-up, greenhouse-gassed overheated weather of the future is likely to send the city violent dust storms of a sort we can't yet imagine, packed with ever greater amounts of energy. Already Phoenix is seeing more intense dust storms that bring visibility to zero and life to a standstill.

There is also, of course, the problem of water. In dystopian portraits of Phoenix's unsustainable future, water — or rather the lack of it — is usually painted as the agent of collapse. Indeed, the metropolitan area, a jumble of jurisdictions that includes Scottsdale, Glendale, Tempe, Mesa, Sun City, Chandler and 15 other municipalities, has tapped groundwater supplies at unsustainable rates.

All along, everyone knew that couldn't last, so in the early 1990s, a new bonanza called the Central Arizona Project (CAP) was brought on line — a river-sized, open-air canal supported by an elaborate array of pumps, siphons and tunnels to bring Colorado River water to Phoenix and Tucson.

Today, the project is the engine of Arizona's growth. Unfortunately, to win authorization and funding to build it, state officials had to make a bargain with the devil, which in this case turned out to be California. The concession California forced on Arizona was simple: It had to agree that its CAP water rights would take second place to California's claims.

A raw deal for Arizona? You bet, but not exactly the end of the line. Arizona has other "more senior" rights to the Colorado, and when the CAP water begins to run dry, you may be sure that its masters will pay whatever is necessary to lease those older rights and keep the 330-mile canal flowing.

Longer term, if habits don't change, the Colorado River poses issues that no water claims can resolve. Beset by climate change, overuse and drought, the river and its reservoirs, according to various researchers, may decline to the point that water fails to pass Hoover Dam. In that case, the CAP system would dry up, but so would the Colorado Aqueduct, which serves greater Los Angeles and San Diego, as well as the All-American Canal, on which the factory farms of California's Imperial and Coachella valleys depend.

These are giant problems that cities and the region as a whole must rally to face, a prospect that brings up another issue: Communities that survive stern challenges are those that learn how to pull together. Phoenix's winner-take-all politics, exemplified by Sheriff Joe Arpaio's storm-trooper tactics, give little cause for optimism. A few decades hence, after the climate screws have tightened with excruciating force, don't be surprised if the drivers steering U-Hauls out of town are spurred along as much by discord as by drought.

Source: LATimes.com (William deBuys is the author of "A Great Aridness: Climate Change and the Future of the American Southwest.")

In response: "Phoenix is doomed – doomed to be an easy target for doomsayers"

It comes as no surprise to those of us who live here in the Valley of the Sun that it's hot and that it is likely to get hotter. In Phoenix, more than any other American city I know, we debate our future constantly. Maybe that's because we fully realize that Phoenix is built in a place with geographical challenges. In fact, every system that supports this city was built in recognition of those challenges. Balmier places have taken for granted that their hospitable climate will continue into the future, so a place like Atlanta is greatly challenged when rainfall decreases by 15 or 20 percent. Phoenix, on the other hand, depends virtually not at all on rainfall occurring within its geographic proximity.

Let's look at deBuys' criticisms of Phoenix and its future:

First, he notes that heat waves in Europe can kill tens of thousands of people. Those heat waves usually represent Fahrenheit temperatures in the high 90s or maybe even 100. Phoenix last year had 14 days greater than 110^{0}F. How many people were killed by this unimaginable heat? Maricopa County, which includes Phoenix and neighboring cities, recorded 21 heat-caused deaths (and an additional 22 heat-related deaths) during the weeks above 110. Tragic, yes. Thousands, no. Phoenix is built to deal with very high temperatures. Yes, temperatures may go even higher in the future, but we acknowledge and even expect that.

Second indictment: The "heat island" effect is making Phoenix hotter because it does not cool off at night like it once did. DeBuys is correct. Over the last decade Arizona State University has been researching the heat island and developing ways to mitigate its effects through landscape, building materials, and energy efficiency. We have not fully solved the problem but all the evidence leads us to conclude that the heat-island effect is a plateau that levels off in the range of today's current temperatures, and is a problem we can manage.

Third count: It takes a lot of electricity to support Phoenix. Indeed, air conditioning consumes significant electricity but the state of Arizona (with nearly 70 percent of the population being in metro Phoenix) ranks 45th out of the 50 states in per capita energy consumption. The stark reality is that it takes less energy to cool than it does to heat. U.S. migration to the Sunbelt has lowered per capita energy consumption. Another fact: In warm places we do not burn diesel oil in the basement to modify temperature. The Center for Climate Strategies notes that Arizona emits about 30 percent less carbon per person than is the average in the United States.

The next and the most common indictment of Phoenix is that there's no water so people shouldn't live in such a desert city. DeBuys criticizes Phoenix for its reliance on Colorado River water and water from the mountains of central Arizona. Similar criticisms can be leveled at every city in the arid Southwest – especially Los Angeles. Most Western water managers will tell you that Phoenix has a water supply to support its future growth more robust than that of Los Angeles, San Diego, Las Vegas or Denver. Half the water that comes to Phoenix is still being used for agriculture. Agriculture is being retired here and that water is slowly being converted to other uses.

DeBuys is right about another point, however: In order to build the Central Arizona Project, Arizona had to agree to allow California to have a more senior water right. This historical fact comes as no surprise to the people of Phoenix. Because of that lower seniority, nearly 4 million acre feet of water (about 4 years' worth of Phoenix urban use) have been "banked" underground to protect against future drought. Is that enough? Probably not, but it's more "water banking" than has been completed by any other city in the world.

Next, deBuys goes after the huge "haboobs" that Phoenix has seen in the last few years. These massive dust storms are indeed spectacular, unpleasant meteorological events that attract much national news awe. But they are much less of a threat to human existence than hurricanes or tornadoes that plague other parts of the country. And the prime reason we get such huge clouds of dust is because of all the farming south of Phoenix that has tilled up the natural desert. As farming diminishes, so will the haboobs. However dirty the storms are, they are not close to the problems presented by earthquakes or rising sea level as a consequence of climate change.

DeBuys' final point may be his most trenchant. He notes that Arizona seems often to be politically dysfunctional. Local elected officials rail against government, public-land ownership, "the feds," and immigration. Actually, the cities of metro Phoenix all have relatively stable, professionally managed nonpartisan government. When he characterizes Phoenix as having "winner take all politics," he overstates the reality, but I'll give him a point taken. But such is the politics of all of the United States in the present day. Solving problems is not high on politicians' agendas. Scoring points is. Political dysfunction is a legitimate threat to the future not just to Phoenix but to U.S. cities in general. It takes a belief in government and recognition for its capacity to solve problems to sustain cities. A city is, after all, a gigantic public/private partnership.

Yet, I remain hopeful even on this last count. While Phoenix politics are sometimes zany, our city has been built by people who understand government was not the problem but the solution. We need only to turn on the water faucet to be reminded of that fact.

— Grady Gammage Jr. is a senior research fellow at Morrison Institute for Public Policy at Arizona State University. Source: AZCentral

Is it time to move past urban studies and toward urbanization science?

March 2013 — William Solecki compares the current study of cities to natural history in the 19th century. Back then most natural scientists were content to explore and document the extent of biological and behavioral differences in the world. Only recently has science moved from cataloguing life to understanding the genetic code that forms its very basis.

It's time for urban studies to evolve the same way, says Solecki, a geographer at Hunter College who's also director of the C.U.N.Y. Institute for Sustainable Cities. Scholars from any number of disciplines – economics and history to ecology and psychology – have explored and documented various aspects of city life through their own unique lenses. What's needed now, Solecki contends, is a new science of urbanization that looks beyond the surface of cities to the fundamental laws that form their very basis too.

"What we need is a comprehensive, integrated, system-level analysis of the city-building process," says Solecki.

Solecki recently made the case for a new science of urbanization in an issue of *Environment* magazine [PDF], alongside environmental scholar Karen Seto of Yale and geography colleague Peter Marcotullio of Hunter. The current fragmentary nature of urban studies, they write, has led to a disconnected "smorgasbord of information" about cities. In response, they suggest moving away from the study of cities as "places" and toward the study of urbanization as a "process."

"Urban studies illustrates the diversity of cities, the conditions under which cities are built," says Solecki. "But that really, in large part, hasn't focused on the process through which there's this ongoing development or change of cities. … I think one of the things we can start to ask is how do we look at cities as not only objects, but also to look at them in a slightly more sophisticated way."

In *Environment*, the researchers outline three basic research goals for their proposed science of urbanization:

1. To define the basic components of urbanization across time, space, and place.
2. To identify the universal laws of city-building, presenting urbanization as a natural system.
3. To link this new system of urbanization with other fundamental processes that occur in the world.

The result, Solecki believes, will be a stronger understanding of the "DNA" of cities – and, by extension, an improved ability to address urban problems in a systemic manner. Right now, for instance, urban transport scholars respond to the problem of sprawl and congestion with ideas like bike lanes or bus-rapid transit lines. Those programs can be great for cities, but in a way they fix a symptom of a problem that still lingers. An improved science of urbanization would isolate the underlying processes that caused this unsustainable development in the first place.

Image by Michael Rosskothen. ***Source:*** **TheAtlanticCities.**

"…urban transport scholars respond to the problem of sprawl and congestion with ideas like bike lanes or rapid transit lines… An improved science of urbanization would isolate the underlying processes that caused this unsustainable development in the first place."

"This is maybe the tension or the difference between urban studies and let's say urbanization science," says Solecki. "What we're really looking at are the forces, the laws, the principles, the axiomatic statements that we can say about how these cities are constructed, built, and rebuilt. So the object of study isn't so much the final thing" – meaning the city itself – "it's the process of building that thing."

With a background in environmental studies, Solecki sees a pressing need for a science of urbanization so cities can make smarter decisions about sustainability moving forward. An improved understanding of urbanization could guide recovery from natural disasters like Hurricane Sandy that are sure to increase as climate change worsens. There aren't strong enough standards for these types of efforts at regional or national levels, he says, let alone a global one.

"Now's our window – now's our time to build these cities as best we can," he says. "So we must study this fantastic city-building process that's underway with all the rigor of a science."

Eric Jaffe is a contributing writer to TheAtlanticCities.

Urbanites combat climate change with rooftop farms

January 2013 — President Obama brought the issue of climate change out of exile during his State of the Union address by issuing a demand for Congress: if they don't act swiftly, he will. But as Congress continues to lightly mull a plan of action, urban visionaries John Stoddard and Courtney Hennessey of Higher Ground Farm are cultivating their own solution to environmental problems.

"In our vision we've got this amazing green roof that produces food and then also has these great environmental benefits, one of which is mitigating climate change," said Stoddard.

Higher Ground Farm in Boston is in production to be the second-largest rooftop farm in the world, following New York City's Brooklyn Grange flagship farm. "There are acres of rooftops in cities," explained Stoddard when he described the process of utilizing unused space to create productive resources. Recover Green Roofs is the Massachusetts-based company set to build the Higher Ground Farm roof, which will be their largest green project to date.

Hennessey compares the process of urban farming to any other commercial-scale food production company or farm. "There are always challenges, but instead of groundhogs and gophers, our problems will be seagulls and wind," she explained.

The development of city farms comes at a critical legislative time for the United States. Last year, the 112th Congress failed to pass a new farm bill that would in part help fund more healthy crop subsidies and assist farmers with growing major commodity crops. Instead, the existing bill was extended and is now scheduled to expire at the end of September 2013.

Regardless of whatever policy changes are made at the end of this year's crop season, Hennessey expects to have plenty of farmed products by then. "We'll hope to grow about 100,000 pounds of produce in our 2013 season," she projected.

The city of Boston and surrounding areas should also expect reduced pollution in addition to an abundance of fresh produce. "When we get heavy rain – which happens frequently – the combined sewage overflow goes into the bay," said Hennessey. "The green roof system will slow the flow of water off the roof, and also retain some of the water that the plants will use."

Positive effects on the environment would not be the only result of large-scale urban farming. As the plants on the farm would naturally absorb the sunlight, they would be combating the heat island effect that so commonly afflicts large cities. Consequently, electricity and cooling costs would be reduced for companies that invest in a green roof for their buildings.

In the Jan. 6 edition of *Melissa Harris-Perry*, Just Food

Source: **MSNBC.com**

executive director Jacquie Berger spoke about the lack of access to healthy food options in lower-income and urban areas. "If you have access to fresh healthy food there's so much more you can do in terms of nourishing yourself and your family," Berger explained.

Hennessey and Stoddard both entered their partnership with firsthand knowledge on how food access affects what is consumed. "Growing food closer to city centers where people live is an important step to creating a better food system," Hennessey said. She mentioned the relationship Higher Ground Farm has with Boston Collaborative for Food and Fitness, an organization that subsidizes food and brings produce to neighborhoods that have a noticeable lack fresh and affordable options.

Altruism will remain a priority with Higher Ground Farm, but engaging local restaurants will also be a major part of the green farm project. Stoddard and Hennessey both have experience working in restaurants as well as a background in farming and agriculture. The two rely on the direct correlation between locally grown produce and a booming economy as part of their business plan. "There's definitely a difference and distinction in the taste, flavor, and texture," Hennessey said as she discussed selling food from Higher Ground Farm. "Restaurant owners prefer food picked that day and served that night instead of food that's been in a warehouse for possibly up to a week." Better food will bring more customers, stimulating the local economy.

As far as the rooftop-farming trend catching on in the rest of the country, Hennessey hopes that the process is at least considered. "I hope that we move away from what is really a broken system of food production in our country [with] monocropping and genetically modified food. I don't think cities will be able to sustain their entire population with urban farms, but it's an important thing to look at."

Source: MSNBC/Melissa Harris-Perry

A multi-layer radiation model for urban neighbourhoods with trees

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1. Introduction

Urban development alters local climate. This has implications for the prediction of weather and air pollution dispersion, and for neighbourhood design/modification for pedestrian thermal comfort and building energy conservation. Fortunately, urban effects on local climate can be predicted by well-evaluated numerical models that incorporate the relevant urban elements and physical processes.

Numerical models of urban meteorology and climate have primarily been limited to the buildings and streets that together form the archetypal 'urban canyon' (Nunez and Oke, 1977; Masson, 2000; Kusaka *et al*. 2001; Martilli *et al*. 2002; etc). Yet, vegetation is common in many cities worldwide, and its inclusion in models is critical for the simulation of neighbourhood energy balance, street-level climate, and air pollution dispersion. Furthermore, vegetation is an important candidate for urban climate modification in many neighbourhoods. The challenge, then, is to account for the effects of urban vegetation in numerical models of urban climate and dispersion. In essence, the direct interactions between vegetation and the 'built' fabric (i.e., buildings, streets) in cities must be better understood and modelled. These interactions are more significant, and more complex, for trees than for shorter vegetation.

Trees not only provide evaporative cooling, but also offer shade and shelter to pedestrians and buildings and impact air pollution concentrations. They interact with buildings primarily in terms of flow dynamics (e.g., sheltering) and radiation exchange, the latter of which is the focus of this article. Buildings shade trees and other buildings, and trees shade buildings and other trees. Diffuse radiation is exchanged between buildings, between trees, and between buildings and trees, enhancing 'radiation trapping'. The representation of these varied and complex interactions with a simple and consistent model is a challenge.

To date, most modelling of vegetated neighbourhoods has 'tiled' urban and soil-vegetation surface models such that they may interact only indirectly via an atmospheric model. With this approach, important vegetation-building interactions are not included. Recent work has integrated vegetation into urban canopy models and accounted for vegetation-building interaction (Lee and Park, 2008; Lemonsu *et al*. 2012); however, these contributions are limited to trees in single-layer models and/or ground-level vegetation.

Multi-layer canopy models (e.g., Martilli *et al*. 2002) are well-equipped to represent vertical distributions of tree foliage and built elements and their effects on canopy-layer climates, but no model is capable of both at present. The present contribution develops a model for exchange of shortwave and longwave radiation in urban canopies that explicitly includes building-tree interaction and retains significant flexibility in terms of the layout of building and tree foliage elements. The new model discussed herein represents a significant improvement over 'tile' approaches to the inclusion of vegetation.

2. Urban canopy radiation model with integrated trees

The model builds on the two-dimensional multilayer 'canyon' geometry with probabilistic height distribution of Martilli *et al*. (2002; Figure 1). It largely reformulates the model physics and computational methods in order to incorporate several processes, most significantly the effects of tree foliage on radiation exchange in the urban canopy. The model also addresses the weaknesses in the Martilli *et al*. (2002) formulation identified by Schubert *et al*. (2012); it incorporates sky-derived diffuse solar radiation, permits full radiative interaction of lower roofs with canyon (and foliage) elements, and fully accounts for the radiative effects of fractional building coverage at each height (i.e., it conserves energy).

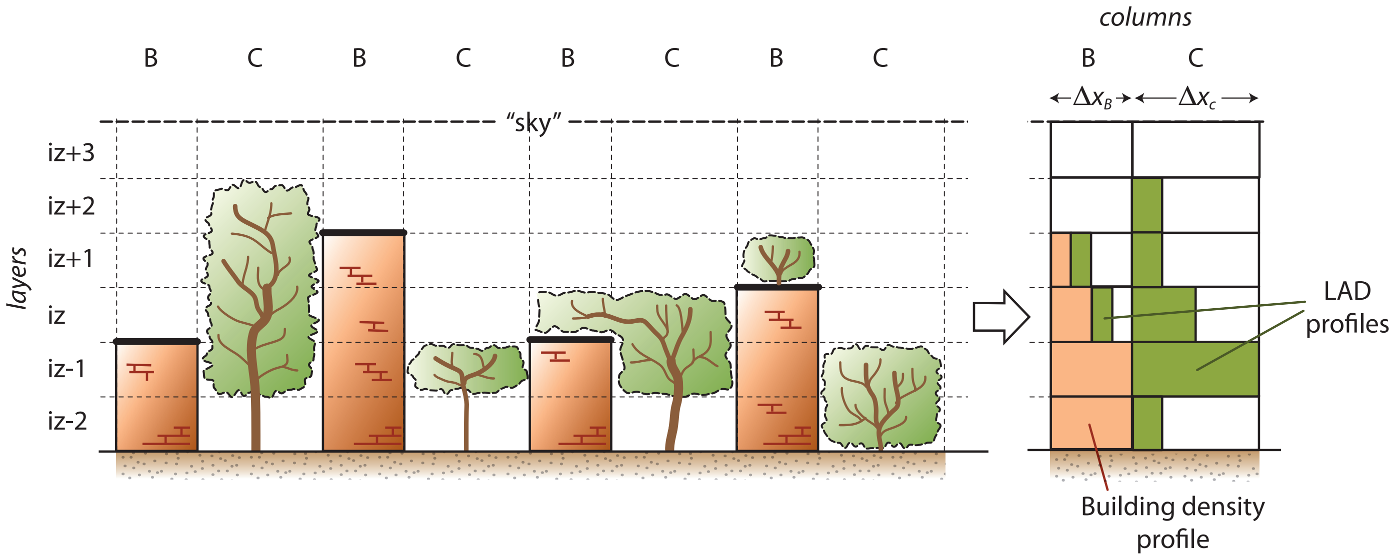

Figure 1. A two-dimensional view of the conceptualization of the urban surface that underlies the model geometry: equal width and equally-spaced buildings with a height frequency distribution, randomly ordered in the horizontal. Foliage layers of different densities are present above and between buildings and at random horizontal locations. An example urban height distribution, building order, and foliage distribution is shown. B = building column; C = canyon column.

A range of computational methods are exploited in order to permit urban configurations of variable complexity while optimizing both accuracy and computation time. Ray tracing tracks direct shortwave radiation as it descends through the domain, impinging on different elements of the urban system. A Monte Carlo ray tracing implementation computes view factors between building and tree foliage elements for *diffuse* shortwave and longwave reflection and emission (i.e., this calculation is performed only once at the beginning of a model run). A system of linear equations is then solved at each timestep to simulate an 'infinite' number of reflections between these elements.

While the radiation model operates in two dimensions, it accounts for the three-dimensional path length of each ray as it travels through layers containing foliage. Foliage layers are characterized by their leaf area density (LAD, in $m^2\ m^{-3}$) and clumping index (Ω), and may be present in the building column above rooftops and in the canyon column at any height (Figure 1). The Bouguer-Lambert-Beer law is used to model radiation interception by layers of foliage, assuming a spherical leaf angle distribution. All elements are assumed to be Lambertian and hence emit and reflect radiation diffusely.

The model is designed for both shortwave (≈0.4-3.0 μm) and longwave (≈3.0-100 μm) radiation wavelength bands. The subsequent discussion assumes that shortwave and longwave are 'broadband', that is, they encompass the ranges as defined above; however, provided wavelength-specific reflection/scattering coefficients the model can be applied to scenarios with narrower bands (e.g., photosynthetically-active radiation vs. near-infrared radiation).

3. Model testing and application

System response tests are performed to demonstrate modelled distributions of radiation exchange for different arrangements of building and foliage elements. Further model testing is discussed in Krayenhoff *et al*. (2013).

Shortwave radiation: Zenith angle, tree foliage location and density

Incident direct and diffuse shortwave irradiance and subsequent reflections are modelled to determine the vertical distribution of absorbed shortwave radiation in each case. Figure 2 and Table 1 outline the geometrical parameters for all scenarios. The following also apply to all scenarios: diffuse is 15% of incoming shortwave; roof, ground and wall albedos are 0.15, 0.15 and 0.25, respectively; tree foliage reflection and transmission coefficients are both 0.25.

The impact of solar zenith angle on the vertical distribution of shortwave absorption in the canopy is first demonstrated for a canyon with two building heights (Scenarios 1 and 2, Fig. 3). Cumulative percent of total incoming solar radiation absorbed is plotted in 1 m increments; hence, the slope is an indication of absorption at each level. Most obvious is the large absorption at 0 m, 6 m and 12 m for both cases, corresponding to the ground and the two roofs, respectively. As the sun moves lower in the sky (i.e., to $\phi = 45°$/Scenario 2), the wall absorption increases as indicated by the greater slope in the cumulative absorption curves below 12 m. As a result, the street-level absorption drops and the overall neighbourhood albedo increases moderately, according to expectation.

In Scenario 3, solar zenith angle remains at 45° and a layer of tree foliage with leaf area density 0.375 m^2 m^{-3} and considerable clumping ($\Omega = 0.5$) is added between 7 m and 11 m in the canyon, corresponding to a neighbourhood-average leaf area index (LAI) of 1.0 (Fig. 3). This layer absorbs significant solar radiation at the expense of the roads and the lower walls and roofs. Furthermore, the overall albedo increases by ≈0.01. Subsequently, this same layer of foliage is moved up to 13-17 m (Scenario 4). The elevated tree foliage now absorbs about 20% of the total incoming solar radiation and reduces the absorption by all roofs, walls, and the street. Interestingly, the neighbourhood albedo changes inconsequentially.

If the foliage layer is retained above the canyon but its density increased to 1.125 m^2 m^{-3}, the neighbourhood-average LAI becomes 3.0 (Scenario 5). More than 40% of the total incoming shortwave radiation, and almost half the total absorbed radiation, is now absorbed by the foliage (Fig. 3). Notably, the overall albedo does not change significantly. Extending this same total amount of foliage over both columns preserves the LAI but reduces the leaf area density to 0.750 m^2 m^{-3} (Scenario 6). The foliage layer

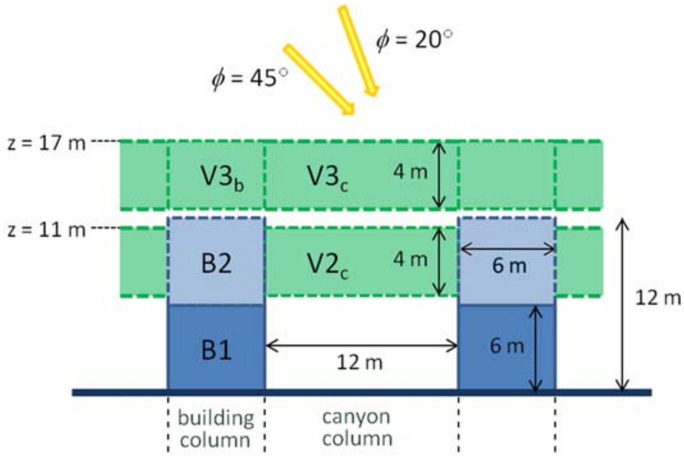

Figure 2. Model geometries and solar zenith angles for shortwave radiation system response tests. "B" = building, "V" = vegetation foliage, numbers refer to vertical layer, and subscripts refer to building (e.g. "$V3_b$") or canyon (e.g. "$V3_c$") columns. Vertical resolution is 1 m and solar azimuth is perpendicular to the canyon orientation for all simulations.

now absorbs slightly more solar radiation. Perhaps most intriguing, however, is the 0.013 increase in overall neighbourhood albedo that results from this change in the horizontal distribution of the foliage.

The model results in Figure 3 indicate that tree foliage shifts shortwave absorption away from built surfaces, and does so to a larger extent for greater foliage density and horizontal distribution. For the particular scenarios modelled here, added horizontal coverage of foliage significantly increases the overall albedo, whereas foliage height and density matter less. Furthermore, the mean height of radiation absorption increases consistently through the scenarios, from 4.0 m in Scenario 1 to 10.6 m in Scenario 6. Such effects are unlikely to be accurately represented without a flexible, consistent urban radiation scheme with integrated tree foliage. The tile approach would not account for any of these effects.

Table 1. Solar and tree foliage characteristics for the six shortwave scenarios.

Scenario	Solar zenith angle (ϕ)	Leaf Area Index (LAI)*	Foliage layer height	Foliage layer column
1	20	0.0	–	–
2	45	0.0	–	–
3	45	1.0	V2 (7-11 m)	c (canyon)
4	45	1.0	V3 (13-17 m)	c (canyon)
5	45	3.0	V3 (13-17 m)	c (canyon)
6	45	3.0	V3 (13-17 m)	c, b (canyon, building)

*Neighbourhood-average LAI.

Longwave exchange: net ground and canyon fluxes

This section explores the impacts of sky view reductions due to buildings and trees on the rate of energy loss from canyon surfaces. Specifically, net longwave flux density (L^*) is computed for the canyon floor alone, and for the complete canyon system, for a range of scenarios. All surface, foliage and air temperatures are 28°C and downwelling longwave is 320 W m^{-2}, representing an early evening cooling scenario during midlatitude summer. Surface and foliage emissivities are 0.95. Canyon width is 12 m and vertical resolution is 1 m for all simulations. Simulation results represent a "snapshot" in time with imposed surface temperatures.

Greater canyon height-to-width ratio (H/W) decreases sky view factor of the canyon floor (streets), reducing net longwave magnitude and leading to warmer nocturnal street surface temperatures (Oke, 1981; Oke *et al.* 1991), and this relation is reproduced here by both the TUF2D model (Krayenhoff and Voogt, 2007) and the new model (Figure 4). This phenomenon has been postulated as a leading cause of the nocturnal canopy-layer urban heat island. However, this relation does not apply to urban neighbourhoods (or canyons) as a whole. While the canyon floor and walls each individually have reduced L^* losses, together they exhibit L^* (per unit horizontal area) of similar or greater magnitude to a flat surface ('canyon' in Fig. 4). Given that building walls and streets tend to remain warmer than flat 'rural' surfaces (as opposed to being equal in temperature, as modelled here), it is apparent that canyon L^* magnitude will typically exceed that of more rural areas. Hence, only a sufficient coverage of low emissivity and/or low thermal admittance materials (e.g., roofs), not the urban geometry, is capable of reducing the magnitude of urban L^* below rural L^*.

The introduction of a tree foliage layer with leaf area density 0.19 m^2 m^{-3} between 3 m and 7 m above the street reduces canyon floor longwave losses by ≈34% for all H/W ('LAI = 0.5' in Fig. 4). Hence, the presence of trees reduces the cooling rate of the canyon floor, as expected, an effect that is more pronounced in an absolute sense for lower H/W. For the particular conditions considered here, the addition of a moderate neighbourhood-average foliage density of LAI = 0.5 has an impact equivalent to an increase in H/W of 0.50-0.75. Finally, the total L^* of the whole canyon, including tree foliage, varies little with H/W (as for the non-vegetated cases; not shown).

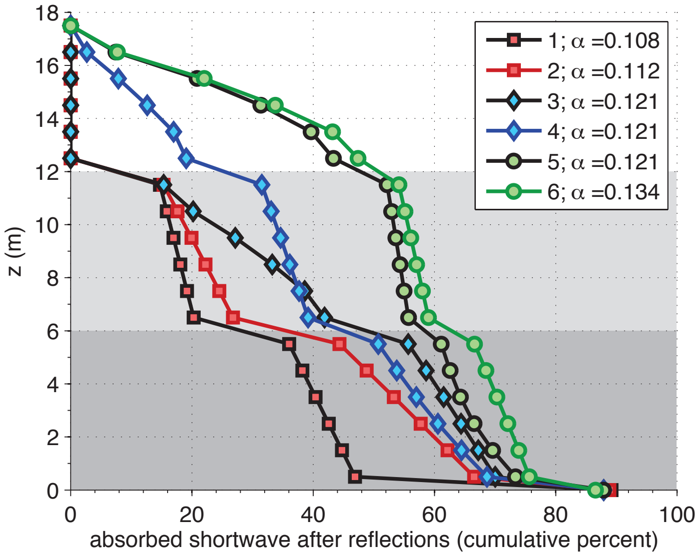

Figure 3. Cumulative percent (from top) of total incoming shortwave radiation absorbed after reflections as a function of solar zenith angle (ϕ), tree foliage location, and foliage density (Table 1, Fig. 2). The neighbourhood geometry includes 50% B1 buildings (6 m height) and 50% B2 buildings (12 m height) and tree foliage. Scenario number (see Table 1) and corresponding neighbourhood albedo (α) appear in the legend.

The new model suggests that both urban geometry and tree foliage can substantially decrease the magnitude of net longwave exchange of individual facets such as the canyon floor. However, the net longwave exchange of canyons or urban neighbourhoods as a whole does not vary significantly with H/W or added foliage for the isothermal conditions modelled here.

4. Summary

A multi-layer urban radiation model with trees is developed that explicitly computes building-tree interaction and represents a substantial improvement over the 'tile' approach to urban vegetation simulation. The model is flexible—any tree heights and thicknesses, foliage densities and clumping, and building heights and height frequency distributions are permitted. The use of ray tracing renders the model quasi-independent of the complexity of the geometry, while the initial calculation of inter-element view factors permits a computationally speedier matrix solution to diffuse exchange for the remainder of a mesoscale or urban canopy model simulation.

Simulations with the new model demonstrate appropriate system responses to varying geometries, foliage characteristics, and solar zenith angle. Both the vertical distribution of shortwave radiation absorption and its partitioning between buildings, vegetation and ground are demonstrated. Denser foliage layers absorb more shortwave at the expense of building and ground surfaces, and the horizontal distribution of foliage can significantly modify overall neighbourhood albedo.

System response scenarios in the longwave spectrum focus on the net exchange. Simulated canyon floor (street) and whole canyon net longwave flux density (L^*) as a function of canyon H/W are in agreement with the independent radiation model TUF2D. The magnitude of ground-level L^* is shown to decrease with deeper canyons and with the addition of canyon foliage. For the isothermal conditions modelled here the L^* of the whole canyon system does not vary significantly with canyon H/W.

The new 'treed' urban radiation model is intended for use at the local scale. Furthermore, it is designed to simulate any combination of shortwave and longwave radiation bands, and to be portable to any urban surface model based on the urban canyon. Further details will be available in a forthcoming publication (Krayenhoff *et al*. 2013).

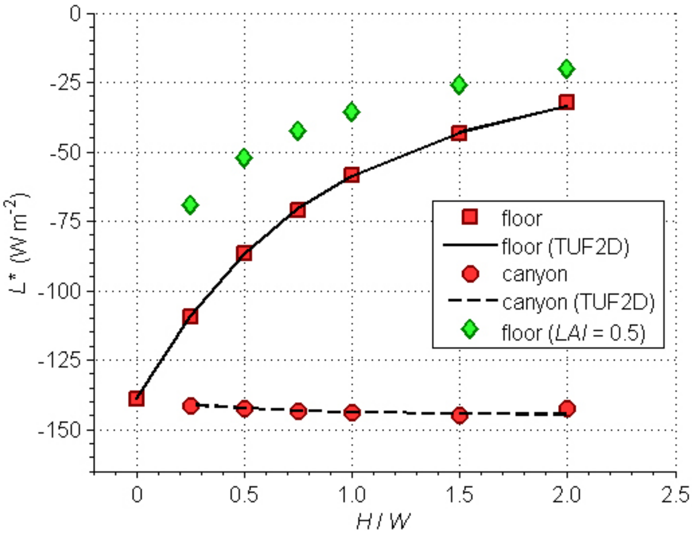

Figure 4. Net longwave flux (*L) per m2 horizontal (plan) area of the canyon as a whole, and of the canyon floor only, as a function of canyon height to width ratio (H/W). Results are from the current model and from the TUF2D model (where indicated).**

Acknowledgements

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Impact of urban microclimate in street canyons on building cooling demand predictions

Introduction

A significant part of the world's energy consumption is used for heating and cooling of buildings. With increasing urbanization, minimizing the energy demand of buildings in urban areas is of great importance. Energy demand predictions for buildings in an urban context have to account for heat fluxes at several scales, considering interactions with the surrounding buildings at local scale as well as urban heat island (UHI) effects at micro- and mesoscale. Building energy simulation (BES) models are commonly used to predict space cooling demands of buildings. Most BES models were developed for stand-alone buildings. To predict the space cooling demands of buildings in urban areas the following additional urban aspects have to be considered: (i) the exchange of solar and longwave radiation between neighbouring buildings, (ii) the urban heat island effect and (iii) the reduced convective heat transfer at the building façades due to wind sheltering. All these effects have an important impact on the energy demand of buildings, as they affect the conductive heat transmission through the envelope, the energy exchange by means of ventilation, and the potential to employ passive cooling by night-time ventilation. To consider these effects, the neighbouring buildings also need to be modelled for the determination of the radiative heat balances at the building surfaces. Further, most convective heat transfer coefficients from the literature should not be used for buildings in urban areas, because they are based on measurements of stand-alone buildings. To model the urban heat island effect, either measured temperatures at the building site need to be used or an urban heat island model needs to be applied to determine the temperature difference between the meteorological station and the buildings site.

In this article an approach to account for the urban microclimate in street canyons, when predicting the space cooling demand of buildings, is described. A more detailed analysis is given in Allegrini *et al*. 2012a.

Building model

The energy demand of a modern three storey office building is analysed in a rural and urban context, where urban street canyons are chosen as a generic element of a city. In the former case, the office building is considered as a stand-alone building in an open field, while in the latter case it is placed in between two identical buildings (Figure 1). Street canyons with different aspect ratios (H/W = 0.5, 1 and 2, with H the height of the building and W the street canyon width) are analysed.

The studied building has a length of 110.5 m (to minimize lateral boundary effects in the radiation model) and a total height and width of 13.5 m. It is well insulated with U-values of 0.25 W/m^2 K for the walls and 0.15 W/m^2 K for the roof. Windows with double glazing (g-value 0.589, U-value 1.4 W/m^2 K) are used and the glazing fraction is 50%. Internal gains caused by persons, devices and lights are considered. The buildings have an orientation showing a north and a south façade. A mechanical ventilation system is used (also at night-time to cool the building, if needed). The BESs are conducted with climatic data for the Swiss city of Basel.

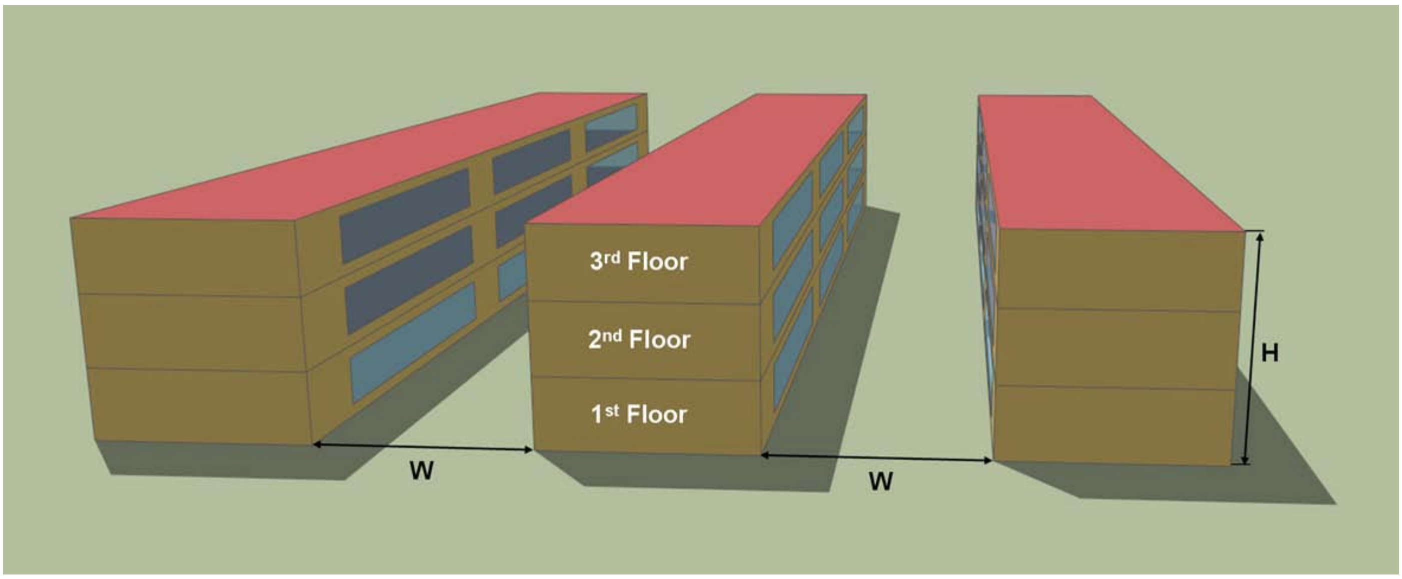

Figure 1. Studied building (in the middle) surrounded by street canyons with aspect ratios of 1.

Numerical modelling

The space cooling demands are determined using TRNSYS 17, which is a transient 3D single building, multi-zone BES software. One year simulations with time steps of one hour are conducted. Part of TRNSYS 17 is a 3D radiation model for interior rooms. Here the street canyon spaces are modelled as "atria" with open ceilings. The radiation model accounts for shadowing and multiple reflections for solar and longwave radiation.

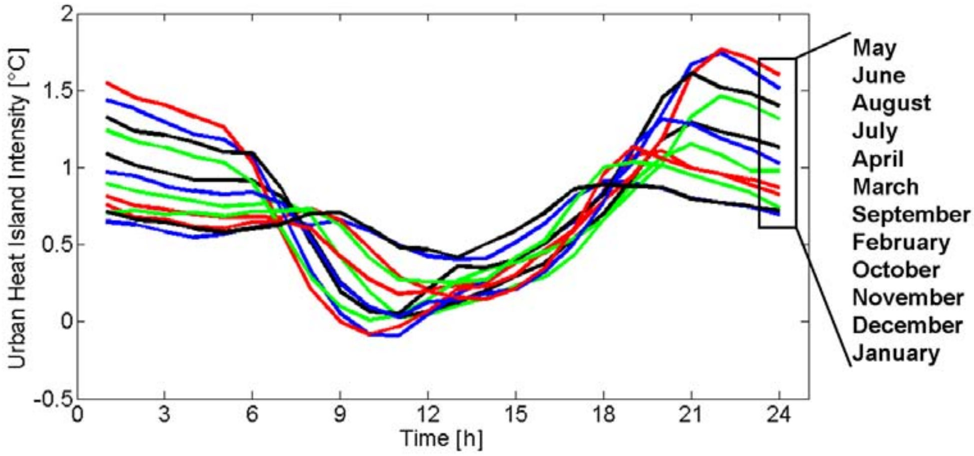

Figure 2. Averaged diurnal UHI intensity schedules for each month of a year.

An UHI intensity approximation is developed based on measured data (Rotach *et al*. 2005) for the city of Basel. A diurnal schedule for the temperature difference between the rural (here Basel-Binningen) and the urban (Basel Spalenring) air temperature is generated for each month (Figure 2). This temperature difference is then added to the air temperature for each time step of the BES for the buildings in urban areas.

To model the convective heat transfer at the building façades, convective heat transfer coefficients (CHTCs) as a function of the wind speed are used (Allegrini *et al*. 2012b). These CHTC correlations were established using CFD (computational fluid dynamics). Different CHTC correlations for different building and street canyon geometries are used to consider the reduced convective heat transfer due to neighbouring buildings. In a second step coupled BES-CFD simulations are conducted. For each BES time step the CFD software is called one time by the BES software (Figure 3). The surface temperatures used for the CFD simulations are the temperatures obtained in the BES. The resulting CHTCs are then used for the next BES time step.

For the CFD simulations to establish the CHTC correlations and for the coupled BES-CFD simulations, steady 2D RANS simulations using ANSYS-Fluent are conducted with a realisable k-ε turbulence model. For the near-wall modelling, adaptive wall functions (Allegrini *et al*. 2012c) are used. These wall functions were derived for buoyant flows inside street canyons and are more accurate in terms of wall heat flux than standard wall functions. For the CFD simulations the street canyons are modelled as a cavity (Figure 4). At the inlet of the computational domain atmospheric boundary layers for the wind speed, the turbulent kinetic energy and the rate of dissipation of turbulent kinetic energy are imposed.

Results

The influence of the urban microclimate on the annual energy demand for space cooling is analysed in three levels of complexity. For the first level the space cooling demand is determined only considering the radiation exchange between buildings using CHTC correlations for a stand-alone building for all geometries and not considering the UHI effect ("Base Case"). For the second level, the corresponding sets of CHTC correlations for each street canyon geometry are used in addition ("CHTC"). For the third level, the above described UHI intensity approximations are additionally used for the street canyon cases ("UHI"). The space cooling demand for the stand-alone building is much lower than for the

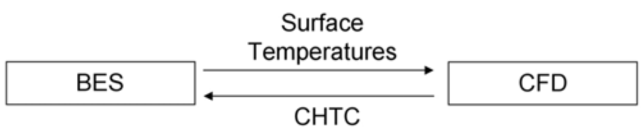

Figure 3. Schematic representation of the coupled BES-CFD simulations.

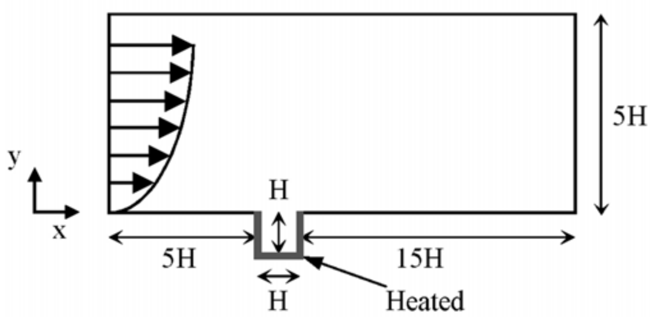

Figure 4. Computational domain.

buildings situated in street canyons (Figure 5). The largest difference is due to the radiation effect. Also the UHI effect increases the demands significantly. The different CHTC correlations only become important in narrow street canyons. Wider street canyons need more energy for cooling, because more solar radiation is entrapped inside the street canyon.

The radiation exchange between neighbouring buildings in urban areas leads to higher surface temperatures and therefore to higher space cooling demands (Figure 6). In street canyons more solar radiation is absorbed, because of multiple reflections between the buildings. Additionally the thermal radiation to the cold sky is partially blocked by neighbouring buildings, causing much higher surface temperatures compared to stand-alone buildings. Here, with the coupled BES-CFD simulations the predicted space cooling demands for a simulated week with rather high air temperatures and wind speeds is 8% lower than with the BESs using CTHC correlations. As discussed above, the radiative heat transfer is more important than the convective heat transfer for buildings in urban areas. For the street canyons studied here, the differences between the two types of simulations are rather low, because the CHTC correlations were already derived for this specific geometry.

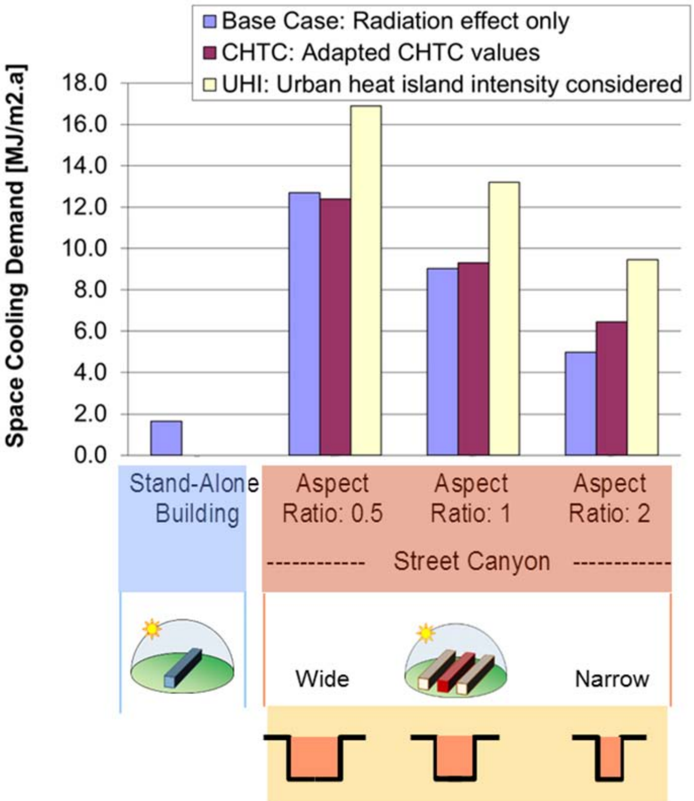

Figure 5. Annual space cooling demand for different modelling cases.

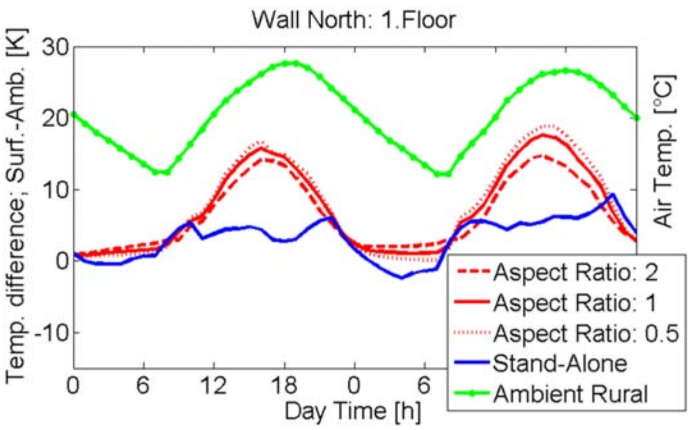

Figure 6. Differences in wall surface temperatures to ambient temperature and ambient temperatures.

Conclusion

In this study the impact of the microclimate in urban street canyons on the space cooling demand of buildings was investigated. It was found that the demand in urban areas is significantly higher compared to the demand in rural areas. Therefore it can be concluded that it is important to account for the local urban microclimate, when predicting the energy demands for buildings in urban areas.

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Green roofs for cities: modelling within TEB

1. Introduction

The need to prepare cities for climate change adaptation requests the urban modeller community to implement within their models sustainable adaptation strategies to be tested against specific city morphologies and scenarios. Greening city roofs is part of these strategies. In this context, a GREENROOF module for the Town Energy Balance [TEB] model developed by Masson (2000) is developed to model the interactions between buildings and green roof systems at the scale of the city. This module is implemented in a version of TEB (TEB-Veg) that already describes the fine-scale interactions between artificial and ground natural surfaces (Lemonsu *et al*. 2012).

2. Implementing green roofs within TEB-Veg

Generic green roof design and dominant physical processes involved

Based on the technical and scientific literature, a generic design has been retained to capture the dominant physical processes involved with green roofs. It consists of four compartments or layers: from top to bottom, a layer of vegetation, a layer of substrate (growing media for plants), a layer of drainage or retention (i.e. a layer with a water regulation function) and a compartment for the structural roof. Consequently, the green roof can be considered as the superposition of a "natural" and an artificial compartment. Experimental studies on green roofs have highlighted within these "natural" layers heat and water transfers which are similar to those which establish themselves within ground-level natural surfaces, except for specific limit conditions (lateral and bottom). Indeed, unlike open ground natural surfaces, for green roof natural surfaces the heat gains or losses from the thermal contact with the bearing roof should be considered. In terms of hydrological transfers, a green roof surface behaves like any other natural surface except that the hydrological properties of green roof soil-forming-materials are very different from those of natural soils and that the water drained out of the green roof base is collected by the rainwater network. These differences do not change the nature of the transfers involved but are to be considered rather as limit conditions.

The GREENROOF module

Since the heat and water transfers established at the surface and within the "natural" layers of a green roof are the same which establish in the case of natural surfaces, they can therefore be simulated by a standard soil and vegetation model, provided that we can calibrate it to account for the peculiar characteristics of green roof soil-forming materials. With this in mind and the constraint of minimum and modular source code development, the soil and vegetation model developed by Noilhan and Planton (1989) and called ISBA (Interaction between Soil Biosphere and Atmosphere) was estimated to be well adapted and detailed enough to model water and energy fluxes within the "natural" layers of green roofs. Considering the different roles and behaviours of the two soil-forming material compartments of the green roof (substrate and "hydrological control" layer) and bearing in mind that the estimation of the soil moisture status of these layers should be good to ensure a good estimate of heat transfers, the diffusive version of ISBA called ISBA-DF (Boone *et al*. 2000) was chosen. This option allows simulation of the water and heat fluxes between

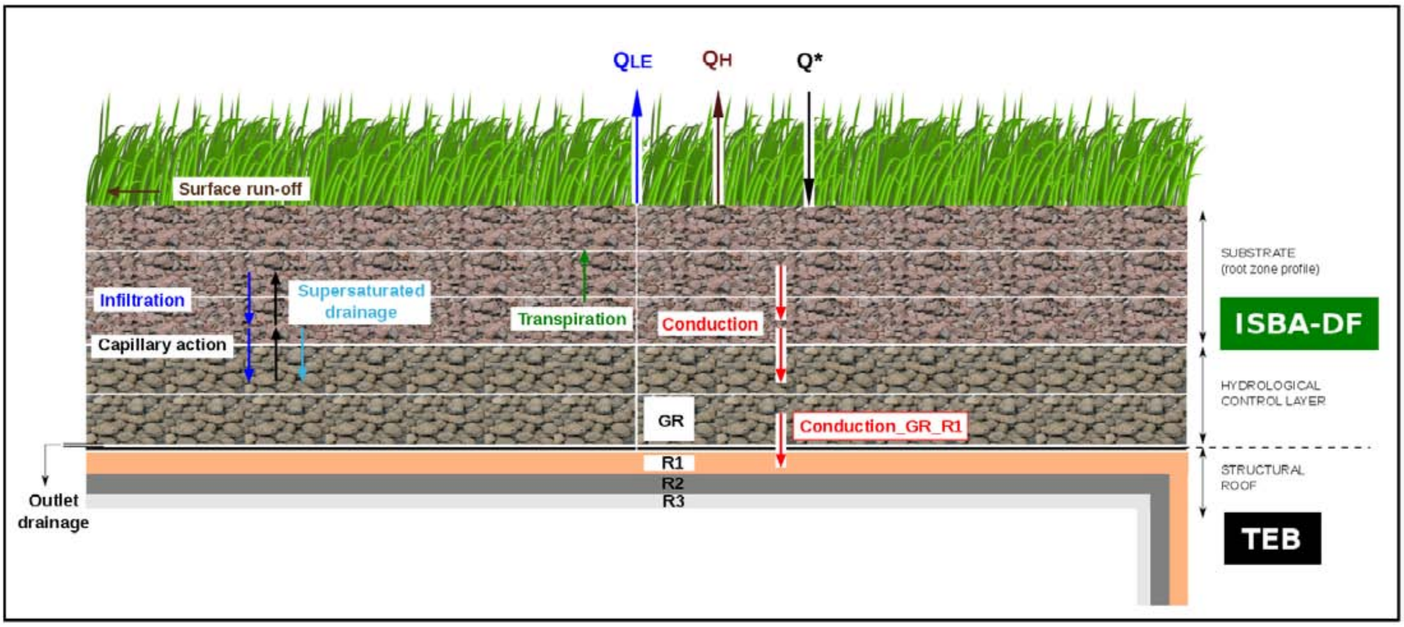

Figure1. Green roof design for TEB-GREENROOF and associated physical processes.

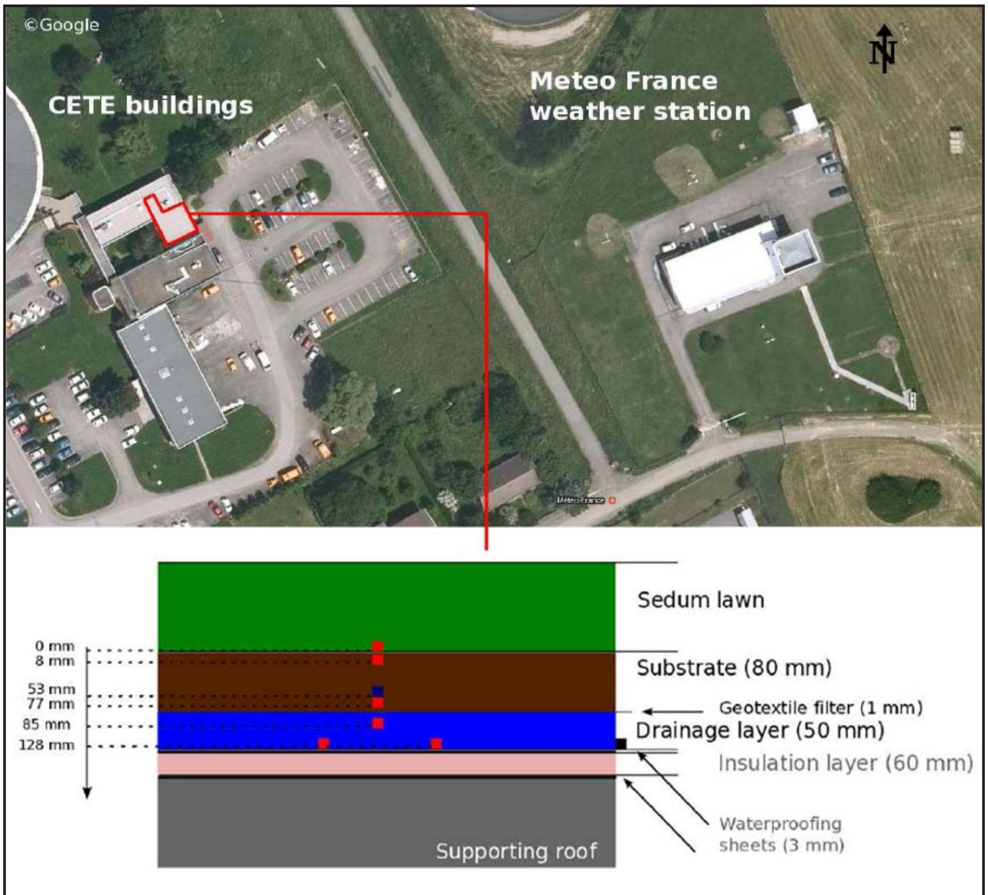

Figure 2. Location and design of the case study green roof modelled, showing the positions of temperature sensors (red), water content sensors (blue) and the water outlet (black).

the atmosphere, the plants and the soil-forming-materials via detailed fluxes. ISBA-DF is based on a set of pedotransfer functions and prognostic equations which are described in Boone *et al.* (2000) and Decharme *et al.* (2011). The coupling between heat and water transfers is realised through effective soil thermal characteristics which evolve in time with the soil moisture status. Finally, modelling the green roof physical design presented hereby implies a configuration with two models (Fig. 1): ISBA-DF to simulate the exchange of heat and water in the natural layers of the roof and TEB (Masson 2000) to simulate heat exchange within the artificial layers of the roof where no water transfer occurs (such as waterproofing membranes, insulating sheets or structural materials).

This model configuration requires implementing a thermal coupling between the hydrological control layer (ISBA-DF) and the structural roof (TEB). This coupling is expressed through the heat conduction flux that establishes between the deepest sub-layer of the natural green roof and the top sub-layer of the artificial roof with which the natural roof is in contact. To ensure the continuity in temperature, the temperature of the deepest layer of the green roof is recalled to that of the top artificial layer of the structural building at each time step.

The input parameters for this coupled model configuration (GREENROOF) are detailed in Table 1 of de Munck *et al.* (2012).

3. Calibration of GREENROOF for a standard case study green roof

Since the pedotransfer functions built in ISBA for computing the thermal and hydrological characteristics from soil textures are not really adapted to the soil-forming materials constituting the substrate or the drainage layers of a green roof, it is better to directly input GREENROOF with specific thermal and hydrological characteristics. Given the coarse soil-forming material texture of green roofs, the difficulty lies in the calibration of the hydrological characteristics, which is essential to optimize the simulation of water fluxes through the natural layers of green roofs. Consequently, a calibration exercise is undertaken to best fit hydrological characteristics to the case study green roof in situ-conditions.

Case study experimental data

This calibration exercise is based on the experimental green roof plot established at the Centre d'Etudes Techniques de l'Equipement de l'Est [CETE] in the North East of France. The green roof plot studied (75 m^2) is composed of three natural layers of significant thickness (Fig. 2): a vegetation layer, a manufactured growing media (substrate) and a drainage layer underneath. Below, two waterproofing membranes to either sides of an insulating sheet have been added to the initial bearing roof. The vegetation consists of a freshly established sedum lawn consisting of a mixture of seven sedum species. The substrate, manufactured by Falienor, is widely used in extensive green roof implementations. The drainage layer consists of expanded clay granules (2-10 mm grain size). The evolution of the thermal and hydrological status within the green roof is recorded as shown in Fig. 2, as well as the excess water that is occasionally drained out of the green roof base. The time series available runs from 4 July to 29 November 2011.

Numerical setup & calibration methodology

The calibration exercise consists of comparing the case study observations to the GREENROOF estimates obtained for a set of simulations differing in their calibration, with the aim of identifying an optimal calibration for the case study green roof. Simulations are carried out on one grid point and the atmospheric forcings prescribed hourly to the green roof are provided by a series of locally observed meteorological data. Fig. 3 presents the methodology for GREENROOF calibration.

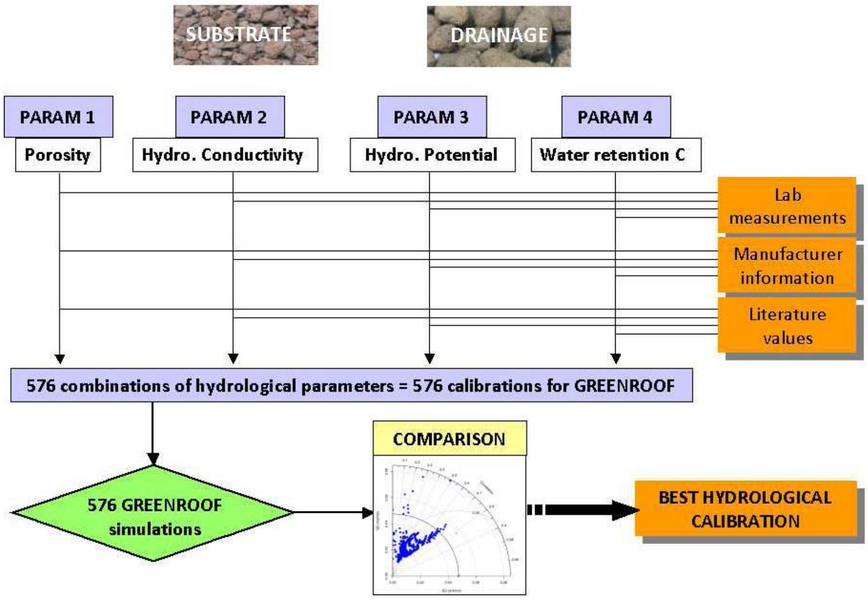

Figure 3. Methodology for GREENROOF hydrological calibration.

The first step consists of compiling for each of the four hydrological characteristics needed as model inputs (PARAM 1 to 4 in Fig. 3), the values available in the technical and scientific literature, and via lab measurements. Then, all possible combinations of substrate-drainage layer hydrological characteristics are established (576 calibrated versions of GREENROOF). Each of them is then run and the outputs are compared against local observations to identify the best hydrological calibration to model the case study plot. The comparison of the 576 simulations focuses on the estimation of the water content recorded in the substrate and the green roof outlet drainage. This comparison, based on the respective statistical scores of the simulations, allows identification of the set of hydrological characteristics for which the agreement between GREENROOF estimates and observations is the best (detailed in de Munck *et al*. 2012).

Evolution of green roof hydrological and thermal status after model calibration

The evolution of the water content and temperature of the substrate layer over the time series available is presented in Fig. 4. GREENROOF reproduces quite well the dynamics and magnitude of the water content in the substrate layer (with a correlation coefficient of 0.7 and bias of - 3.3%), although maxima are frequently over-estimated by the model. Be it at the bottom of the substrate (Fig. 4) or the drainage layer (not shown), the temperatures estimated by GREENROOF demonstrate a good correlation with those observed (over 0.9) but with an amplitude of variation greater than in observations.

4. Conclusions

A parameterization for simulating extensive green roofs across the city has been developed within TEB. Results for a case study green roof show that this parameterization performs well in reproducing the dynamics of water contents and that the differences observed between modelled and observed water contents do not impact too much the simulation of temperatures, which is satisfactory. This indicates good model performance for the simulation of the impact of green roofs on indoor thermal comfort and energy consumption.

Acknowledgements

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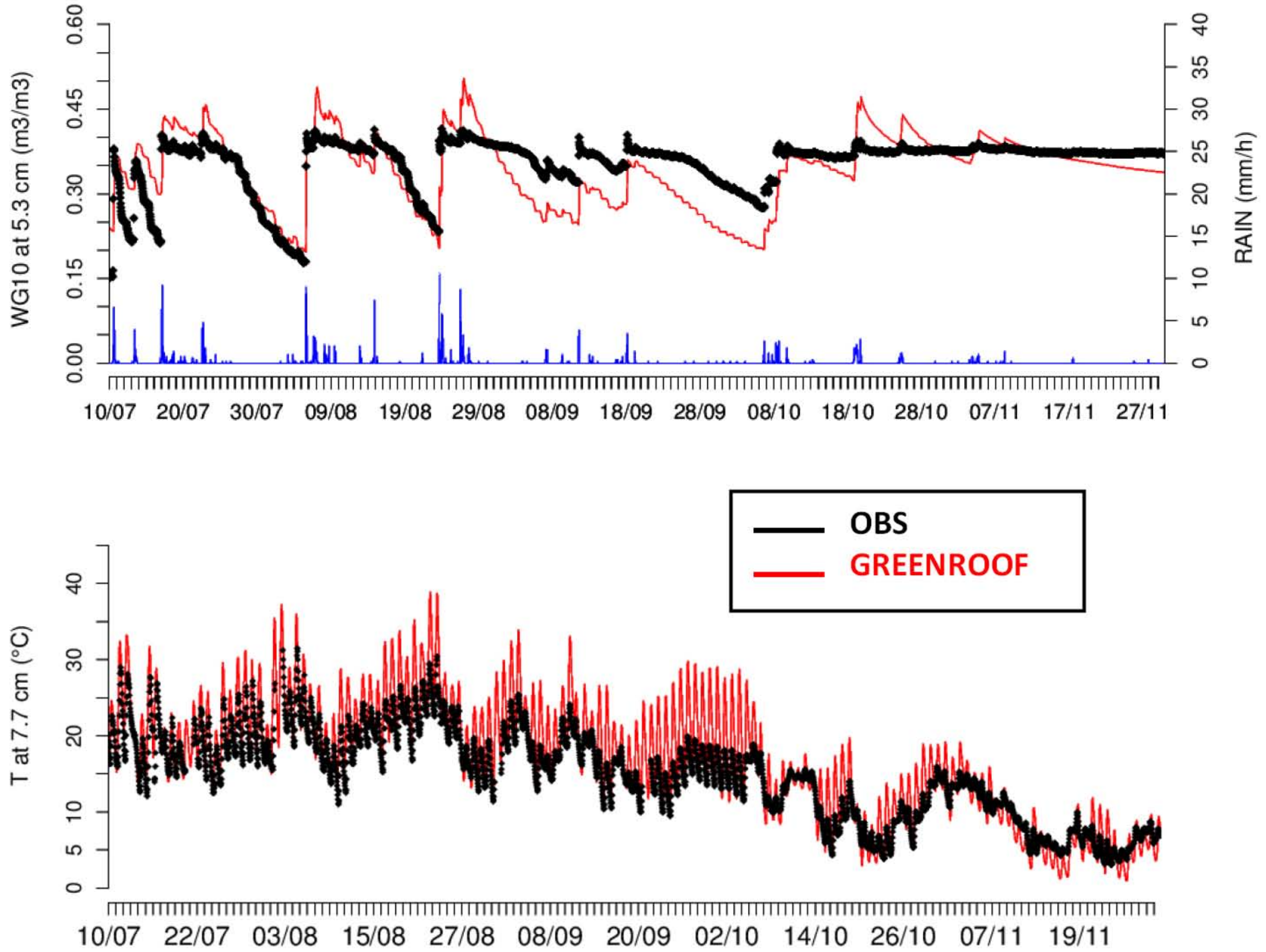

Figure 4. Evolution between July and November 2011 of substrate water content (top) and temperature (bottom) as observed and simulated by GREENROOF.

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Climatic planning according to Vitruvius and its application in the Holy Land

1. Introduction

Throughout the history of civilization, humans have built structures based on various factors: political, economic, and socio-cultural needs, available technology, and climate (Rapoport, 1969; Ozay, 2005; Rudofsky, 1984; Zhai & Previtali, 2010). As such, design varied widely accordingly. Of these factors that alter over the course of time, climate alone is fixed in accordance with a given location (Ozay, 2005). Though climate may not be in itself determining of form, adapting to it has historically been fundamental to the building method. The process of building can be divided into two basic categories: vernacular architecture and planned architecture (Oliver, 1997). Vernacular architecture refers to the buildings of the people, created by their owners or community. Structures are built using available materials and technology while reflecting the specific needs and values of the people (Oliver, 1997). Vernacular architecture characteristically exhibits keen harmony between humans and their environment and a skillful adaptation of building to natural surroundings through transferring of knowledge from generation to generation by trial and error (Rapoport, 1969; Rudofsky, 1984; Fathy, 1986; Zhai & Previtali, 2010). In contrast, planned architecture characterizes the buildings and town plans in which decisions about form, size, and orientation are made prior to inhabitation. Guidelines, standards, and laws often dictate the manner in which they are designed and constructed (Jordan & Perlin, 1980).

Beginning in the first century B.C., unprecedented, large-scale architectural and engineering projects were carried out in Rome. By the time of the early empire, Roman political authority had achieved some semblance of allegiance and continuity among the disparate provinces through its centralized rule. Rome's grandiose building traditions and innovations spread to its colonies far and wide, giving us an early example of single origin design and planning being adapted to various climates and environments. The Ten Books on Architecture by the Roman architect and engineer Marcus Vitruvius Pollio (born c. 80–70 BC, died after c. 15 BC), offer the earliest written source we are able to trace back to find design guidelines that explicitly advocate climatic planning (Oliver, 1997; Potchter, 1991). The Ten Books on Architecture became a design code for Roman and Byzantine architecture.

Though this environmental sensitivity was practiced during classical antiquity, it was not sustained. With the disintegration of centralized rule and then the rise of industrial society, humans began to control nature rather than collaborate, or even escape it with complex mechanical systems (Rapoport, 1969; Fathy, 1986). Using inexpensive artificial light, heating, and air conditioning, buildings were able to become entirely independent of the external environment (Rapoport, 1969). The knowledge of appropriate planning with climate has been lost due to technological revolution and with it, sophisticated architectural solutions based on generations of wisdom have fallen into obscurity (Fathy, 1986). As we strive to cope with the environmental havoc inflicted by industrial society, functional and artistic methods of building from the past beg to be rediscovered. The specific knowledge that local builders and pre-industrial designers possessed with regards to the adaptation of structures to their region is worth preserving as we attempt to create more resilient cities and settlements (Zhai & Previtali, 2010).

2. Objectives

The aim of this paper is to shed light on the concept, methods, and applications of the Roman planning and monumental architecture as they adapted to climatic and environmental conditions. Since the Romans adeptly carried out many monumental infrastructure projects across the vast empire, with climatic and environmental aspects as part of the planning and building process, the Roman remains provide excellent examples for study. The objectives of this research are to (a) present Vitruvius' approach toward climatic and environmental planning in the context within which he worked, (b) present Vitruvian methods, tools, and principles, and (c) examine the application of Vitruvian philosophy in the design of bath complexes in the area of the Holy Land using examples and analyses.

3. Scope and Methodology

The study area

The study area is the Holy Land during the Roman and Byzantine periods (present-day Israel, Palestinian territories, Jordan, and southern Syria) and is an ideal locale to study ancient design and planning practices according to climatic characteristics. The geographical location of the study area is between three continents (Africa, Asia and Europe) and between different climatic zones. The temperate climatic zone in the north and subtropical arid climatic zone in the south, together with a varied topography, create different climatic regions in a relatively small area (Potchter, 1991). Today, the Holy Land retains a wealth of Roman remains in its small land area, offering plentiful opportunity to learn from the manner in which the ancients adapted design to a variety of climatic conditions.

The research was conducted at three levels: region, settlement, and public building. Figure 1 presents a diagram of the details of impacts of climatological elements in planning, broken down into these three levels. By combining Vitruvian design guidelines with the archaeological record, it is possible to determine how each city was sited, laid out, and each public building designed according to its environment.

At the regional level, a map was created that superimposes location of the cities over climatic zones. At the settlement level, cities were grouped according to location and their attributes compared: site selection, city walls, street layout, street orientation, and presence of colonnaded streets. In this way, patterns were revealed and implementation of climatic design principles becomes evident. At the building level, case studies were reviewed to find common principles in design of monumental architecture. Basilicas, theaters, and baths were investigated for the following: thermal comfort demands, the way architectural solutions achieved this demand, and implementation of the design solutions writ large. In this article, only the results of the building-level investigations are explained in detail.

Background: motivation for solar design

The Italian peninsula was facing the grave consequences of large-scale deforestation during the first century B.C. (Butti & Perlin, 1980). Timber and charcoal had to be imported from greater and greater distances to fuel industry and ship-building enterprises, and to heat homes and public buildings. Harkening back to their Greek antecedents, the Romans were able to make use of passive solar design and even make improvements (Butti & Perlin, 1980).

An authority on architecture and proponent of climatic design, Vitruvius compiled centuries of acquired knowledge in fields as diverse as medicine and philosophy. He was well-acquainted with the Greek philosophers and drew from and advanced the works of Socrates, Aristotle, Plato, and other influential Greeks (Lord, 1984). The first to aggregate this wisdom into a comprehensive book of design standards, Vitruvius and his contributions went on to influence architects and urbanists across the Roman empire and beyond, from his time until the present, including Palladio during the Renaissance (Boubekri, 2008) and Le Corbusier in the modern age (Lord, 1984).

4. Results

Climatic aspects of public buildings

Vitruvius wrote in detail on environmental control for the public places of his day. Thermal comfort was a primary factor in design. Like the Greeks, Romans valued solar heat because they believed it to be healthier than heat from combustion. Most crucial, however, was the fact that through good design, the sun's radiation could sup-

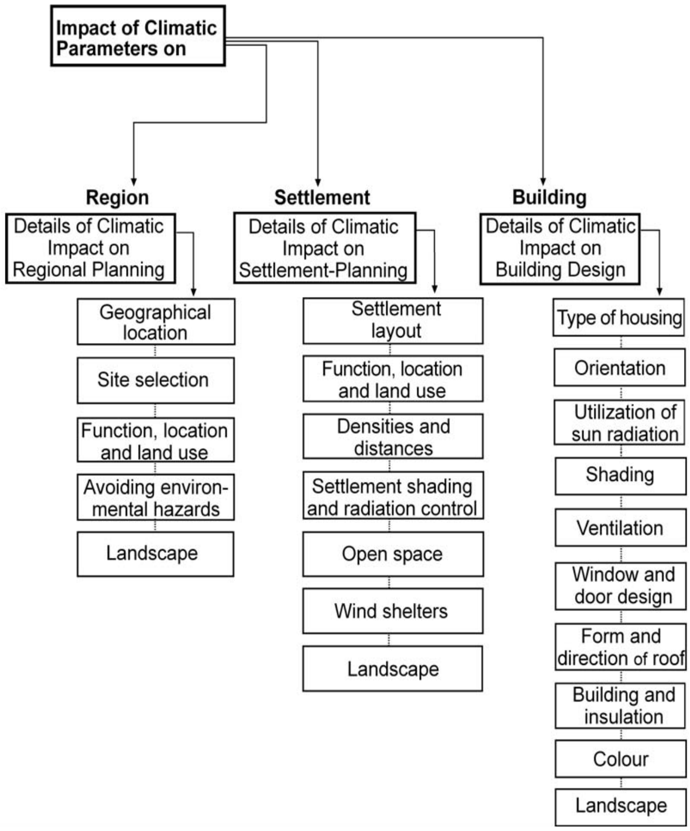

Figure 1. Impact of climatic parameters on level of planning.

plement or even replace the prodigious amount of fuel necessary for thermal comfort (Butti and Perlin, 1980).

The theater

Theaters were an important part of daily life for Romans in the first century CE and their location within the city reflected this. "When the forum has been settled, a site as healthy as possible is to be chosen for the exhibition of plays..." (Vitruvius, 1962). The Roman theater was a freestanding, enclosed structure and as such, was liable to trap stagnant air when filled to capacity. Vitruvius advised "Care also is to be taken, lest it be open to attacks from the south. For when the sun fills the circuit of the theater, the air being enclosed within the curved space and not having the opportunity of circulating, revolves and becomes heated…" (Vitruvius, 1962). The northern orientation provided comfort of the audience as the structure itself provided shade for the cavea (audience section). By facing away from the sun, cooler air could circulate among the spectators and the sun was shaded from their eyes as they viewed the performance.

Figure 2 examines the orientation and size of the theater. The primary direction was determined by pointing a line from the center of the arc of the cavea to the cardinal direction it faces.

An analysis of the size of the theater serves to infer its importance for the city and to investigate for patterns as-

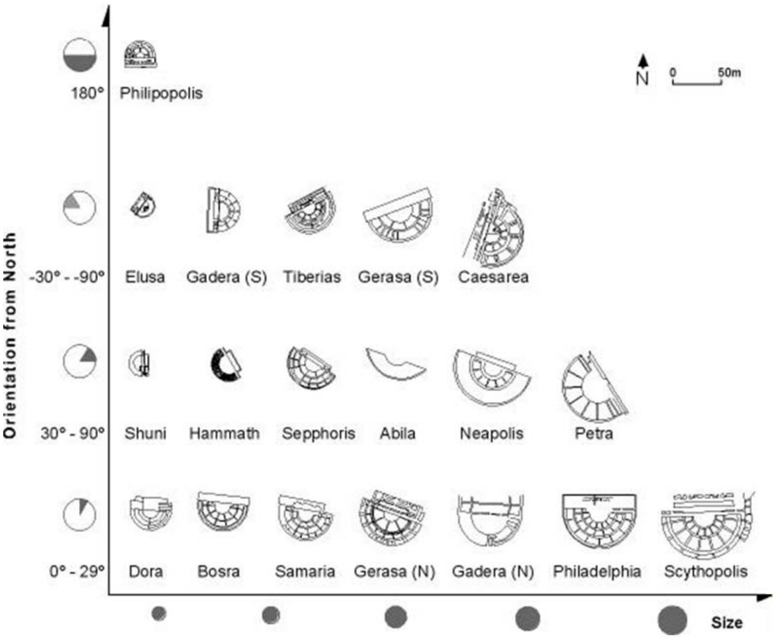

Figure 2. Orientation of the theater.

sociated with this attribute. Of all of the nineteen theaters examined, eighteen fall within ninety degrees of due north. Looking at some of the anomalies, the theaters that diverge from the pattern seem to have environmental factors to explain this. The theater at Petra faces northeast; it is carved into the side of a mountain and is therefore shaded naturally by the tall rock formation behind the cavea (Fig. 3). The theater at Caesarea faces almost due west, but is open to the sea and receives ventilation from the breeze and cooling effect off the water. The theater at Philipopolis is exactly opposite of the recommendations, but there is a mountain to the south of the town, providing natural shade.

The baths

At the time of the early Roman Empire, baths were vanguards of design, spatial discovery, and technological advancement, and contributed greatly to architectural theory (Ring, 1996; Yegül, 1992; Lord, 1984). Unlike temple buildings, bath complexes did not require adherence to defined architectural principles; as such, they were a forum for experimentation by the architect with systems, materials, light, space, and volume (Yegül, 1992). Fundamental to their design, the buildings were oriented to take advantage of natural heating and cooling and the rooms arranged spatially according to thermal requirements (Rook, 1978; Yegül, 1992; Butti & Perlin, 1980). Vitruvius described the intent clearly, "Firstly, a site must be chosen as warm as possible; that is, turned away from the north and east. Now the hot and tepid baths are to be lighted from the winter west; but if the nature of the site prevents, at any rate from the south. For the time of bathing is fixed between midday and evening" (Vitruvius, 1962).

In order to examine the climatic planning of the bath buildings in the Holy Land, two methods were used. The first one consisted of mapping all the floor plans of the bath complexes (Fig. 4), and the second was an investigation for common characteristics that would indicate deliberate planning for climate. In this section, the orientation of the caldarium (the hot room) and the frigidarium (the cold room) were analyzed. For each room, the orientation was drawn according to the cardinal directions by pointing the face of the room, or if there were two walls, the corner between the two faces, to indicate its primary direction. Fig. 5 shows the direction of the caldarium rooms in various bath buildings in the Holy Land.

The vast majority of the caldariums are oriented to the south--all except that of Mampsis, which we cannot explain. There are four distinct anomalies: the caldariums at Masada, Hierico, Scythopolis, and Philoteria are oriented to the southeast. Examination of these four baths reveals they are all on the western side of the Jordan Valley. An understanding of this environment explains the climatic logic of the southeast orientation. The high mountain from the west shades the area during the afternoon such that orientation to the southeast would have a solar advantage in contrast to the southwest, which is exposed to the sun only until midday. Another explanation for this design is the wind regime. From midday, there are very strong prevailing winds from the west in the Jordan Valley. Orientation of the caldarium to the southwest would mean the adjacent furnace for the hypocaust would be exposed to the west. The wind then would excessively feed the fire, causing damage to the bath or even spreading fire through the town. Orientation to the east moderated this effect. It is evident that the designers were cognizant of these specific, local climatic conditions and used a model that contrasts starkly with the rest of the region for the sake of both solar efficiency and fire safety.

Figure 3. Petra Theater with afternoon shade.

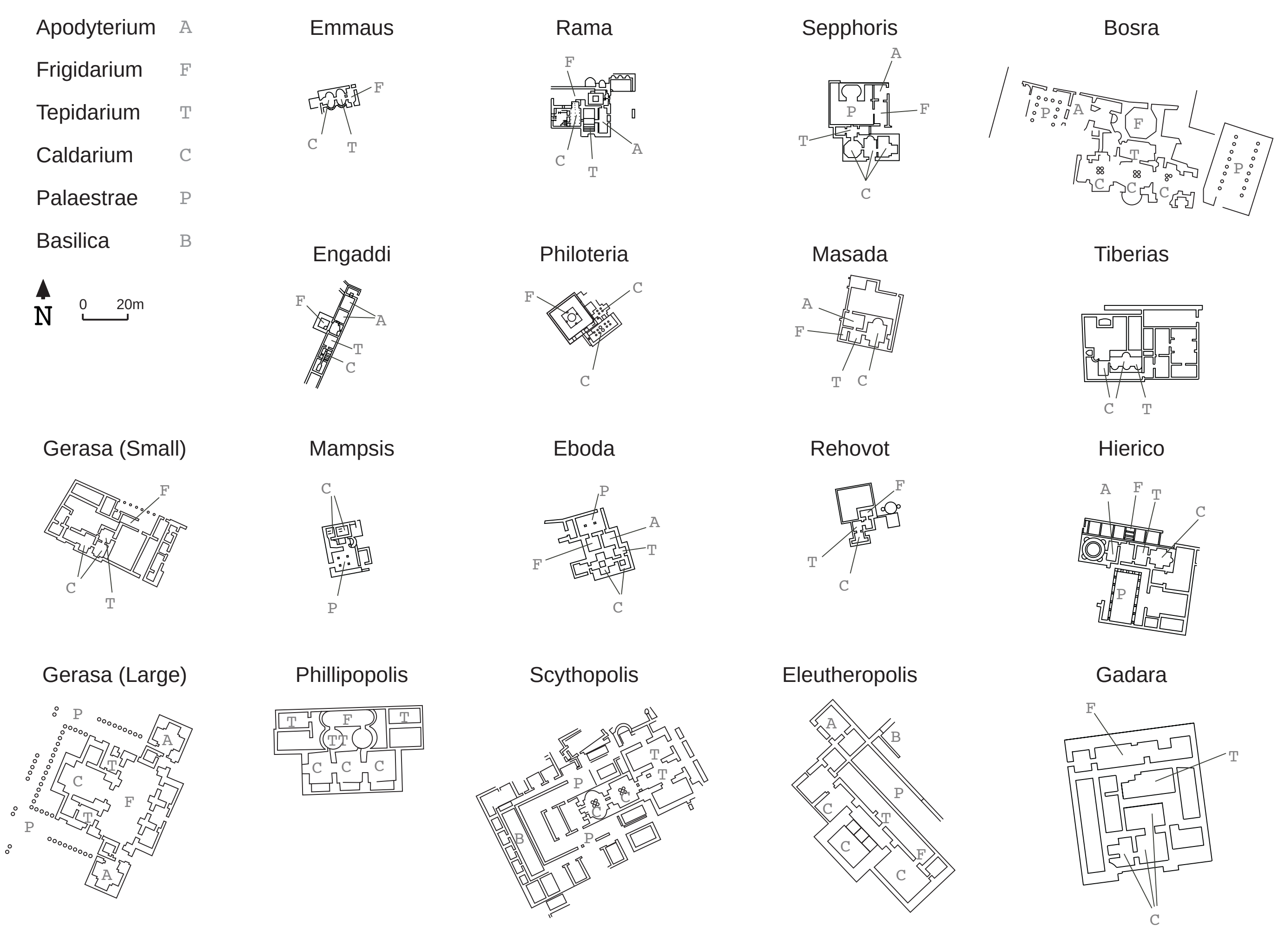

Figure 4. Bath floor plans with room orientation.

Fig. 6 shows the direction of the frigidarium room in various bath buildings in the Holy Land. The majority are oriented to the north as Vitruvius suggested, so that this room could be the coldest in the bath complex. This design also reserved the southwestern orientation for the caldarium and allowed the tepidarium the middle position of neither direct sunlight nor excessive shade.

As glazed windows were also a Roman invention, evidence shows that bath complexes had glazing on their large, south- and southwest-facing windows, greatly increasing the building's ability to retain heat. By the age of Augustus, bathing was no longer a simple ritual for washing, but a popular social activity for the masses and bath complex design reflects this. Some of the baths included sand floors that absorbed solar heat throughout the day and released it as the ambient temperature cooled after dusk (Butti & Perlin, 1980).

5. Discussion

Without the use of high-tech climate-control systems, designers in ancient Roman civilization utilized generations of acquired wisdom to create comfortable thermal conditions (Zhai and Previtali, 2010) by thoughtful manipulation of the urban form. The ancients began using passive solar design because it was efficient and equitable to do so. Solar design was mainstreamed when depletion of the traditional fuel sources required a viable alternative.

Public buildings were sited and oriented according to Vitruvian principles of placement within the city but at times, opposed the guidelines of orientation and positioning for thermal comfort. What looks initially like poor response to the recommendations, in reality is responding in a thoughtful and meticulous manner to a specific site condition.

6. Conclusions

An understanding of the attitude and methods ancient builders used to design for climate is as important today as it was two thousand year ago. We have revealed through this research that planned architecture has significant historical precedents in climatic design and shows skillfully nuanced adaptation according to each site. As competition over limited resources has only increased, contemporary architects, urban designers, planners, and policy-makers would do well to consider climatic conditions as a fundamental factor in good design.

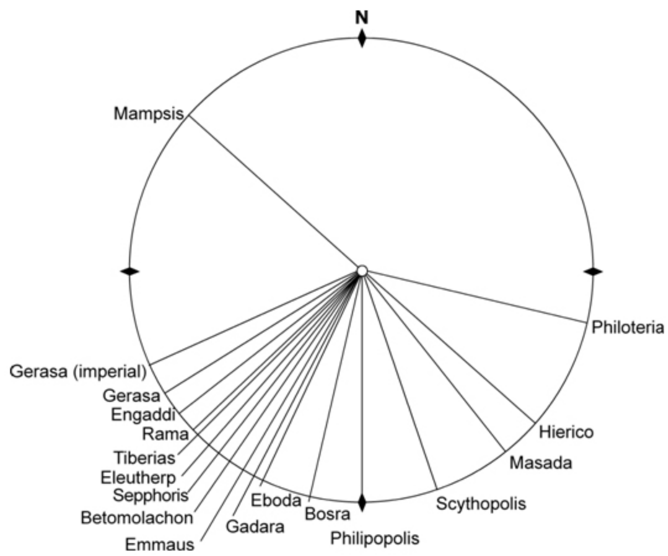

Figure 5. Orientation of caldarium room.

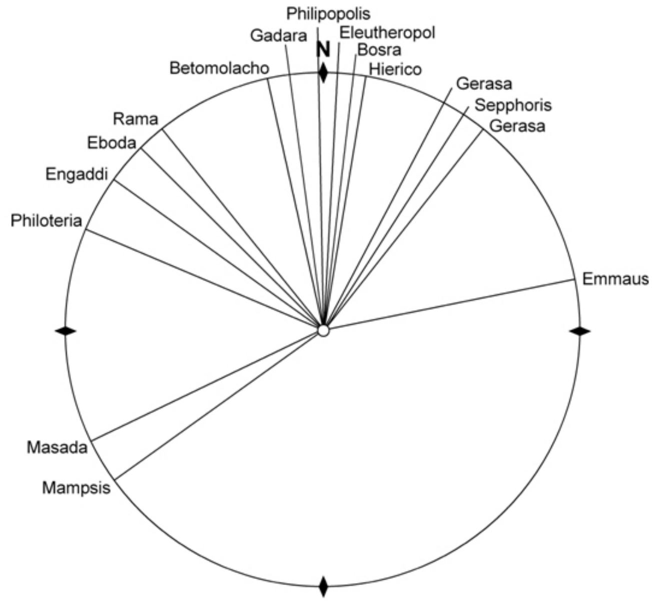

Figure 6. Orientation of frigidarium room.

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A Study of Climate Change in Hong Kong by Extending Past Temperature Record from 1971 to 2010

The present study aims to extend the past temperature record of designated meteorological stations in Hong Kong using regression techniques in order to supplement the understanding of past climatic conditions at the district level where observational records are generally lacking. The temperature trend was found to be associated with land conversion into concrete surface in surrounding areas and reduction in vegetation cover. Findings of the present study contribute to the understanding of the effect of climate change on areas with various land use and provide baseline conditions for temperature projection of future climate change scenarios. Such information will be useful to the incorporation of microclimatic conditions into the urban planning and design framework, especially for potential development in country areas and redevelopment of inner urban areas in the future.

1. Introduction

The effects of climate change on air temperature are often described at a global scale as described by the near-surface air temperature on an annual basis. The increasing global mean surface temperature has resulted in a wide range of impacts such as rising sea level, extreme weather events, and altered patterns of the urban heat island effect (Trenberth *et al*. 2007; Tayanc *et al*. 2009). As people are intrinsically affected by local climate, it is important to describe climatic variations on regional to local scales. Local climate is highly influenced by urban fabrics, air ventilation, and local temperature profiles. Therefore it should be a focus of research, in order to provide information to government authorities and associated parties to assist in urban planning and design for adaptation measures in the future.

The present study aims to extend the past temperature record of designated meteorological stations in Hong Kong using regression techniques, in order to supplement the understanding of past climatic conditions at the district level where observational records are generally lacking. Linear regression was conducted to estimate the air temperature of the periods without observational records. Findings of the present study contribute to the understanding of the effect of climate change on areas with various land use and provide baseline conditions for temperature projection of future climate change scenarios. Such information will be useful for the incorporation of microclimatic conditions into the urban planning and design framework, especially for potential development in rural areas and redevelopment of inner urban areas in the future.

2. Data and Methodology

Data

Hourly temperature data were obtained from the Hong Kong Observatory meteorological stations. The Hong Kong Observatory Headquarters (HKOHq) has the longest data period since it was established more than a century ago. Therefore, it was employed as the reference station in the present study. Urban stations include Shatin (SHA) and Wong Chuk Hang (HKS) while Lau Fau Shan (LFS) and Ta Kwu Ling (TKL) are regarded as rural stations. The forty-year period from January 1971 to February 2011 was extracted from the HKOHq station for the purpose of extending past temperature records of the four selected stations.

Linear regression

Hourly temperature data were divided into two categories, namely daytime and night-time. Monthly means were then calculated for each of the two categories for subsequent regression analysis. The multi-year time-series of monthly mean temperature of the four stations was used as the dependent variable (y) and the reference station, HKOHq, was selected as the independent variable (x). Regression models were then created using Equation (1) to calculate values for estimated y:

$$y = a_0 + a_1x_1 \qquad (1)$$

where a_1 represents a multiplicative coefficient for independent variable x_1 and a_0 represents the constant term. This process was carried out for four different seasons (Spring, MAM; Summer, JJA; Autumn, SON; Winter, DJF) respectively.

Tables

Regression models developed by Equation (1) were validated by 5-fold cross-validation. Model performance was assessed by their corresponding root mean square error (RMSE) values. The model with the lowest RMSE values was then employed for extending past temperature series. The advantage of this method is that all the data in the dataset are eventually used for both training and testing. A 5-fold cross-validation was therefore adopted for a reasonable balance between computational time of regression analysis and the bias of the regression models.

3. Results

Model performance

The regression models for the four different seasons were trained by 5-fold cross-validation and the results are given in Table 1 and 2 for daytime and night-time models respectively. The models with the lowest RMSE values were chosen to perform the extension of past temperature records for the four seasons and the annual data. It was found that the regression coefficients are considerably lower for summer months and the daytime models performed better than night-time models.

Multi-year trend

The trend of temperature series for urban, rural and reference stations are shown in Tables 3 and 4, with four periods (1971-2010, 1981-2010, 1991-2010, and 2001-2010) separately analyzed. A warming trend is observed for the long- and mid-term periods while a decreasing trend of temperature is generally observed in the last 10 years.

Summer – The long-term daytime temperature series exhibited a slightly increasing trend with the highest increasing rate observed at HKS station (Table 3 and Fig 1). However, a decreasing trend was observed at LFS station. In the last 20 years, the highest increasing trends were observed at SHA and HKS stations while a decreasing trend was observed at TKL station. The warming trend observed at HKS station was reduced to 0.0107°C per year while that of SHA station was further increased to 0.0523°C per year in the last 10 years. Moreover, the temperature series of TKL station showed an increase of 0.0261°C per year.

The increasing rates of night-time temperature in the last 40 and 30 years were similar to those of the daytime temperatures. For the last 20 years, the increasing rate of temperature was lower than the increasing rates of daytime temperatures while the cooling rate of TKL station was higher at a rate of 0.0258°C/year. Night-time cooling was observed at most of the stations for the last 10 years, except that a warming rate of 0.0302°C per year was observed at SHA station.

Table 1: RMSE values of the daytime models

Month	SHA	HKS	LFS	TKL
Jan	0.138	0.191	0.310	0.055
Feb	0.253	0.082	0.194	0.209
Mar	0.132	0.126	0.181	0.167
Apr	0.209	0.081	0.255	0.220
May	0.110	0.103	0.327	0.121
Jun	0.183	0.116	0.146	0.256
Jul	0.314	0.223	0.211	0.224
Aug	0.251	0.175	0.235	0.146
Sep	0.162	0.432	0.378	0.049
Oct	0.149	0.195	0.183	0.099
Nov	0.115	0.196	0.338	0.167
Dec	0.226	0.216	0.231	0.099

Table 2: RMSE values of the night-time models

Month	SHA	HKS	LFS	TKL
Jan	0.369	0.331	0.206	0.442
Feb	0.315	0.238	0.283	0.200
Mar	0.098	0.189	0.141	0.251
Apr	0.228	0.231	0.266	0.297
May	0.180	0.081	0.066	0.210
Jun	0.252	0.198	0.150	0.275
Jul	0.207	0.142	0.131	0.577
Aug	0.208	0.290	0.162	0.160
Sep	0.193	0.290	0.209	0.356
Oct	0.220	0.690	0.113	0.274
Nov	0.268	0.169	0.217	0.111
Dec	0.350	0.170	0.258	0.414

Table 3: Trends of daytime temperature series for urban, rural and reference stations

Month	40-yr	30-yr	20-yr	10-yr
Summer				
HKO	0.0031	0.0028	0.0047	0.0080
SHA	0.0078	0.0118	0.0472	0.0523
HKS	0.0105	0.0171	0.0465	0.0107
LFS	0.0020	(0.0010)	0.0181	0.0514
TKL	0.0004	0.0018	(0.0069)	0.0261
Winter				
HKO	0.0283	0.0448	0.0203	(0.0048)
SHA	0.0305	0.0500	0.0654	0.0769
HKS	0.0209	0.0427	0.0553	0.0793
LFS	0.0355	0.0625	0.0730	0.0681
TKL	0.0306	0.0491	0.0184	0.0418

Table 4: Trends of night-time temperature series for urban, rural and reference stations

Month	40-yr	30-yr	20-yr	10-yr
Summer				
HKO	0.0168	0.0084	0.0015	(0.0274)
SHA	0.0161	0.0124	0.0320	0.0302
HKS	0.0160	0.0162	0.0275	(0.0106)
LFS	0.0135	0.0037	0.0121	(0.0061)
TKL	0.0112	0.0055	(0.0258)	(0.0117)
Winter				
HKO	0.0408	0.0549	0.0227	(0.0453)
SHA	0.0387	0.0523	0.0623	0.0535
HKS	0.0499	0.0719	0.0613	0.0566
LFS	0.0447	0.0626	0.0607	0.0103
TKL	0.0499	0.0632	0.0086	0.0290

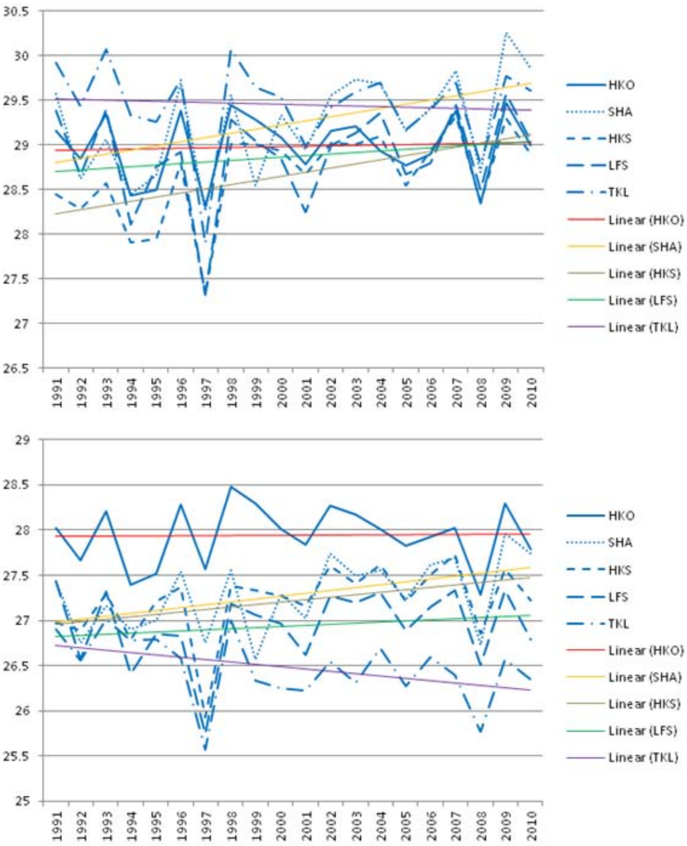

Figure 1. Temperature series of the 20-year summer mean (Top: daytime; Bottom: night-time)

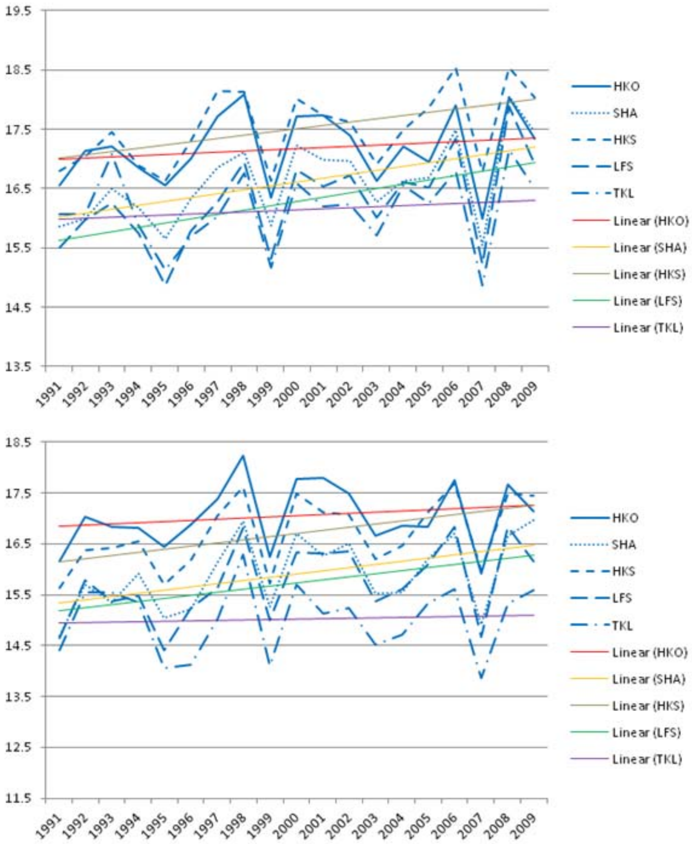

Figure 2. Temperature series of the 20-year winter mean (Top: daytime; Bottom: night-time)

Winter – Warming trends, both daytime and night-time, were found to be the highest in winter except for the short-term trends observed at the reference station (Fig 2). The long-term increasing trends of mean daytime temperature ranged from 0.0209 (HKS) to 0.0355°C per year (LFS). The 30-year trend showed a higher rate of increase with the highest rate observed at LFS station. Such a high increasing rate was also observed in the last 20 years. The highest rates for urban and rural stations were 0.0654 and 0.073°C per year respectively. In the last decade, a decrease in mean temperature was observed at the reference station. The rates of increase at SHA and HKS (urban stations) were 0.0769 and 0.0793°C per year respectively while those observed at LFS and TKL were 0.0681 and 0.0418°C per year respectively.

For night-time temperature, the increasing trends were higher than those of the daytime temperature. The long-term increasing rates were higher than 0.04°C per year except SHA. The 30-year increasing trends were the highest among the four periods concerned with the highest rate observed at HKS station. A reduction in increasing trend was observed at the reference and TKL station in the last 20 years while those of the other three stations remained at a rate of about 0.06°C per year. The warming trends were found to be reduced at all stations with those of LFS and TKL stations reduced to 0.0103 and 0.029°C per year. Furthermore, a cooling trend was observed at the reference stations.

4. Discussion

The impacts of climate change on mean air temperatures vary across seasons and local urban settings. The warming trends of the two urban areas in the last 20 years were particularly higher in summer, which was primarily due to the extensive development of residential estates in these urban areas in the 1980s. Such residential developments are characterized by high building volumes and coverage in order to accommodate the rapidly increasing population in city centres. The urbanization process involves extensive transformation of rural villages into high-density residential sites which caused an exacerbating urban heat island effect which was reflected by the higher increasing rate of the night-time temperature.

In the rural areas, both stations (LFS and TKL) have exhibited a warming trend since the 1990s due to various reasons. For Lau Fau Shan, it has long been a rural village and was developed into a tourist spot in the 1960s. Urban effects were limited in the district. As the population of Hong Kong grew, the government announced the development of a new town, Tin Shui Wai, in the northeast of Lau Fau Shan which accelerated the warming trend and altered local climatic characteristics. The rapid urbanization in Pearl River Delta in the last 20 years also influenced the local climate of Lau Fau Shan. In contrast, the mean air temperature of Ta Kwi Ling (TKL) increased steadily despite the rapid urbanization of Shenzhen which has turned into a special economic zone in the 1980s. It was likely due to the rapid release of radiative heat absorbed during daytime as the area is dominated by low-lying plains and extensive vegetation. Such a relatively natural environment is preserved since it is located within an administratively closed area with minimal urban footprint.

In addition, the decreasing trend, particularly at the reference station, is primarily due to the canyon effect which is a result of intensified high-rise development nearby. Solar radiation is blocked by high-rise buildings nearby and results in a reduction in ground-level temperature which is generally measured by ground-based meteorological stations. However, it does not reflect the actual situation of the street-level environment since the canyon effect also influences local ventilation and dispersion of in-situ pollutants which have a significant effect on local microclimate.

5. Implications on urban planning & design in Hong Kong

Urban climatic issues were not sufficiently considered, especially in the context of urban planning and design, until the implementation of the air ventilation assessment (AVA) system in Hong Kong in 2005. A technical guide was released to provide a framework to facilitate better air ventilation in compact urban areas (Ng, 2009). Various urban issues in Hong Kong were evaluated and experts' comments were provided on several aspects of urban conditions, including the importance of breezeways (air paths) in dense urban areas, the effect of podium coverage on ventilation, the orientation and layout of buildings, and building permeability. All these issues were incorporated into qualitative guidelines which "offer useful design reference for better air ventilation and provide designers with a strategic sense of how to start off their design" (Ng, 2009 pp. 1485-86). These guidelines were further incorporated into the Hong Kong Planning Standards and Guidelines in order to improve air ventilation in densely compacted urban areas.

In addition to the AVA system, the Planning Department of Hong Kong Special Administrative Region Government started a feasibility study on using an urban climatic map (UCMap) to identify climatically sensitive areas and assess the impacts of urban developments on the local wind environment. The study was fostered by the preceding AVA study as a refinement to the existing AVA system by determining a general standard for the wind environment of Hong Kong. Ren et al. (Ren *et al*. 2011) reviewed the state-of-the-art of the UCMap and its applications in different countries with a wide range of climatic characteristics. The thermal environment and conditions of air ventilation within the urban canopy layer of the city are two major aspects analyzed in the study. Mitigation measures and planning actions will be provided, including increasing urban greenery, creating air paths, and controlling building morphologies. Future developments will therefore have to consider these recommendations in order to improve the urban microclimate.

The present study provides information about the effects of urban development on local air temperature. These effects were found to be varied across seasons as well as daytime and night-time. With increasing redevelopment of older urban areas and development of new towns in the next decade, urban climatic conditions and the effect of climate change should be incorporated into the planning and design stages. The observed effect of urban development on local climatic conditions provides information for urban planners and designers to estimate how local climate will be altered due to proposed developments. The multi-decade temperature series also provide baseline information for the study of the effects of future climate change on individual districts as the projection of future temperature requires extensive records of local climatic parameters. For example, statistical downscaling of particular climatic variables generally requires a minimum of 30 years of past temperature records. As the effects of future climate change on local climate may vary according to urban characteristics, further studies are recommended to examine how these urban characteristics, and the associated processes and mechanisms, affect local climatic conditions.

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Optimizing Natural Ventilation Performance in Subtropical Cities by CFD and Morphometric Methods

1. Introduction

With rapid urbanization, high-density living enables cities to be more efficient in land use and energy utilization. However, in subtropical cities, the congested urban areas block low-level airflow, worsening the outdoor urban thermal comfort. During hot and humid summer, considering thermal comfort as the standard, a decrease in wind speed from 1.0 m/s to 0.3 m/s is equal to a 1.9 °C temperature increase (Cheng *et al*. 2011). The outdoor thermal comfort under typical subtropical summer conditions requires a minimum of 1.6 m/s wind speed (Cheng *et al*. 2011). Wind data from an urban observatory station in Hong Kong indicate that the mean wind speed at 20 m above the ground level in urban areas has decreased by approximately 40%, from 2.5 m/s to 1.5 m/s, over the last 10 years (HKPD, 2005). Optimizing urban planning and design to ensure adequate natural ventilation in subtropical urban areas has already become a major design problem confronting city planners and architects.

The corporation of urban planning and architecture design in different scales is important to efficiently improve urban natural ventilation performance, taking large city areas as a whole. From the urban scale to the building scale, the present study provides practical and reliable knowledge to architects and urban planners to integrate strategies in different scales. First, a method that readily evaluates urban wind permeability is provided to urban planners. Second, the efficiency of different building design strategies to improve wind permeability in the neighbourhood scale is cross compared to provide guidance for architects.

2. Methodology

a) Morphometric method

The morphometric methods (z_0 and z_d) (Grimmond and Oke, 1999) can estimate the surface roughness of urban areas. To make the roughness modelling more accessible and practical to urban planners, the urban geometric parameters (nondimensional ratios) frontal area density (λ_f) are directly used, instead of z_0. Wind permeability can be projected and mapped based on a spatially continuous urban morphology data set and local wind frequency (Figure 1). This map can provide important information to identify the current and potential air paths during the urban planning process.

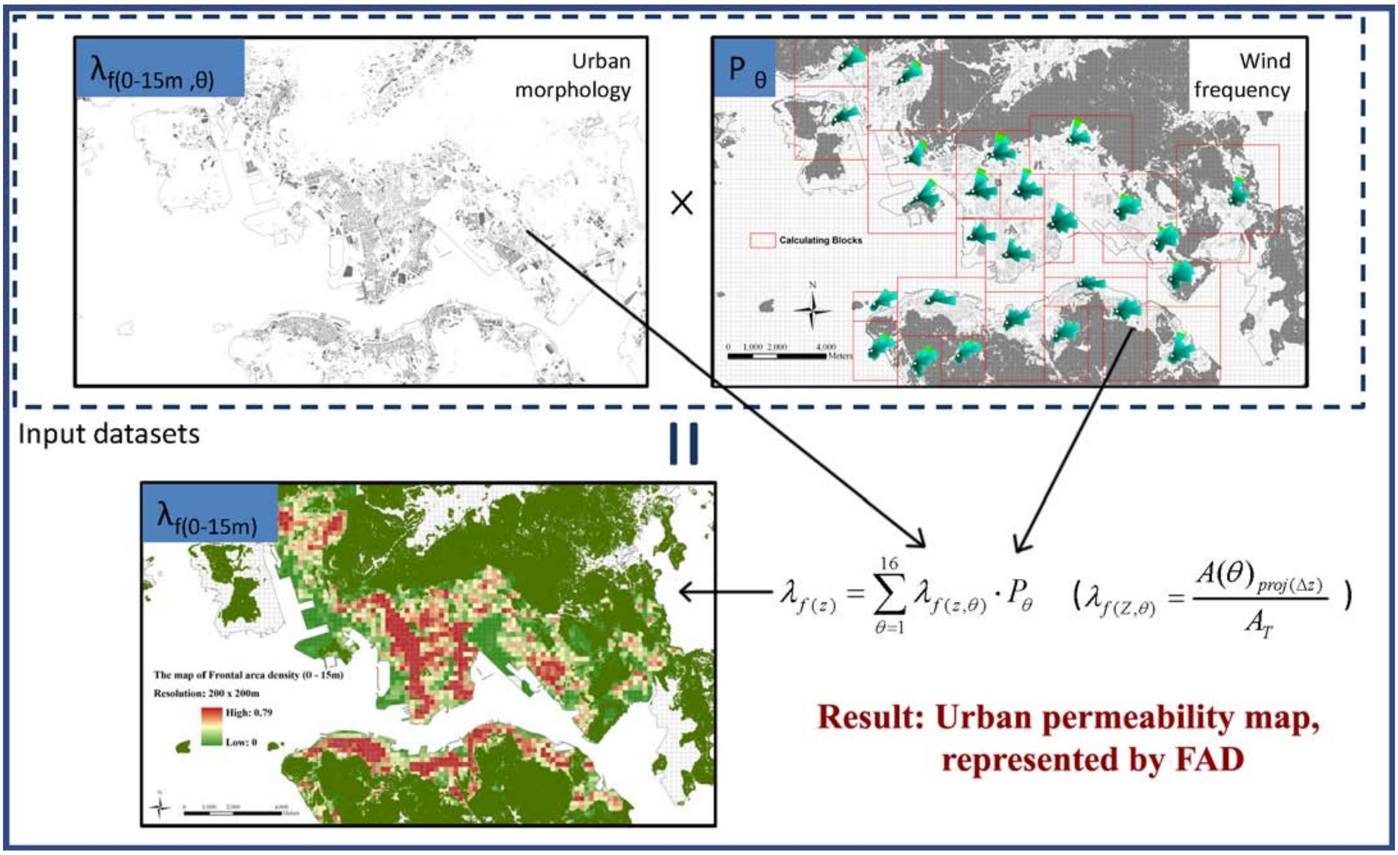

Figure 1. Morphometric method by using frontal area density (FAD).

b) CFD simulation (parametric study)

With regard to the building design, high resolution of several meters is needed for wind environment mapping to determine how the building morphological details affect the immediate wind environment. The CFD simulation is used in this study to solve highly unsteady turbulent flow in the street canyon. All modelling settings follow the Architectural Institute of Japan (AIJ) guideline (Tominaga *et al*. 2008). The results of the average roughness estimation calculated in a hundred-meter resolution from the morphometric methods are not suitable in this scale.

The neighbourhood-scale parametric approach with generic building configurations is used to cross-compare the efficiency of the different building-scale design strategies. Mong Kok in Hong Kong, which has a grid street plan, is chosen as the target area to establish the parametric model matrix (Figure 2).

Figure 2 shows that eight scenarios for cross comparison are designed and successively input into the above matrix to run the CFD simulation to evaluate the corresponding natural ventilation performance.

Among them, two scenarios (i.e., Cases 1 and 2) represent the urban morphologies of the present and future Mong Kok area in Hong Kong. Six scenarios (i.e., Cases 3 to 7) represent the corresponding mitigation strategies, such as setting back buildings, separating long buildings, stepping the podium, creating a building void between towers and podiums, and opening the permeability of towers and podiums. The building volumes in Cases 3 to 7 are similar to that in Case 2 to avoid future reduction in the land-use efficiency.

3. Validation

a) Validation of the roughness estimation

The wind tunnel data [wind velocity ratio (VR)] provided by a wind tunnel benchmark study by HKUST are used to validate the efficiency of λ_f in three height increment layers, namely, 0–15 m, 15–60 m, and 0–60 m, to estimate the VR.

The validation results are shown in Figure 3. R2 in the different layers indicate that the VR is highly correlated with λ_f at the podium layer (0–15 m, R^2=0.96). This result illustrates that the wind VR at the pedestrian level is more dependent on the urban morphologies at the podium layer (0–15 m) than at the building layer (15–60 m) or the whole canopy layer (0–60 m).

Because of the high density and tall urban morphology in Hong Kong, the airflow over the top of the urban canyon may not easily enter into the deep street gaps (skimming flow). Thus, the pedestrian-level natural ventilation performance mostly depends on the horizontal airflow dispersion in the podium layer.

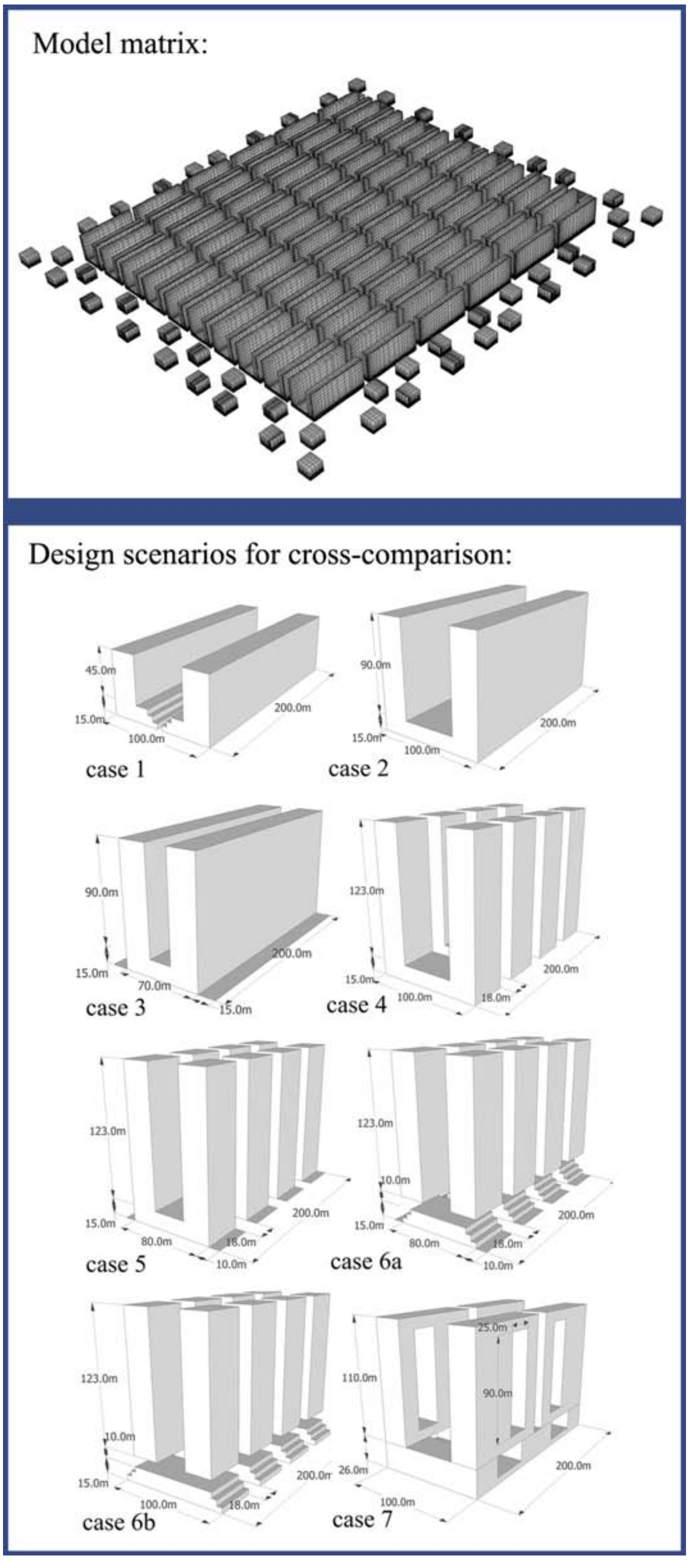

Figure 2. Parametric model matrix, surrounding random buildings, and design scenarios for cross-comparison (Yuan and Ng, 2012).

b) Validation of the turbulent model

For the CFD simulation, to choose the appropriate turbulence model, the accuracy of the LES and four RANS models (Reynolds stress, κ-ε SST, realized κ-ε model and RNG κ-ε) is cross compared with the wind tunnel data provided by AIJ (single building case) (Tominaga *et al.* 2008).

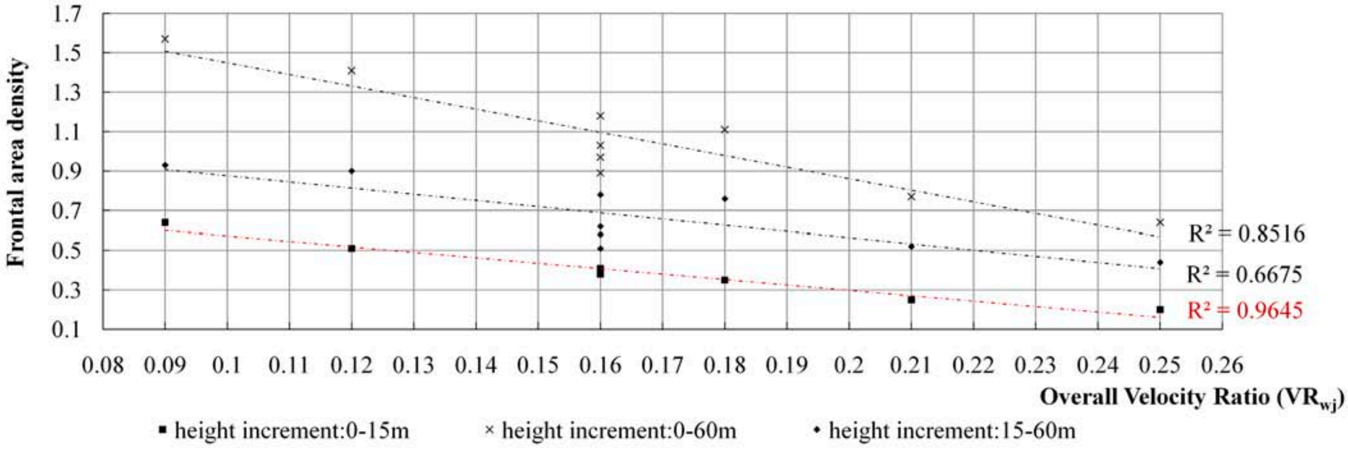

Figure 3. Linear relationship between the VR and the frontal area density calculated at different height increment layers (Ng *et al.*, 2011).

A user-defined function (UDF) is used to set the input boundary conditions, including both the wind speed and turbulence kinetic energy profiles (Figure 4), as similar as possible to the profiles in the wind tunnel experiments.

The cross-comparison results of the wind velocities in the stream-wise direction are also shown in Figure 4. The wind directions at the leeward areas are adverse due to the longer reattached length behind the building (the plotted points in quadrant IV in Figure 4). This result is consistent with the relative statement of Yoshie *et al.* (2007). The RANS model evidently cannot simulate the wind field behind the building as accurately as the LES model. Because the present study is only concerned with the pedestrian wind speed, after balancing the accuracy and computational cost, the κ-ε SST model is used in the CFD simulation.

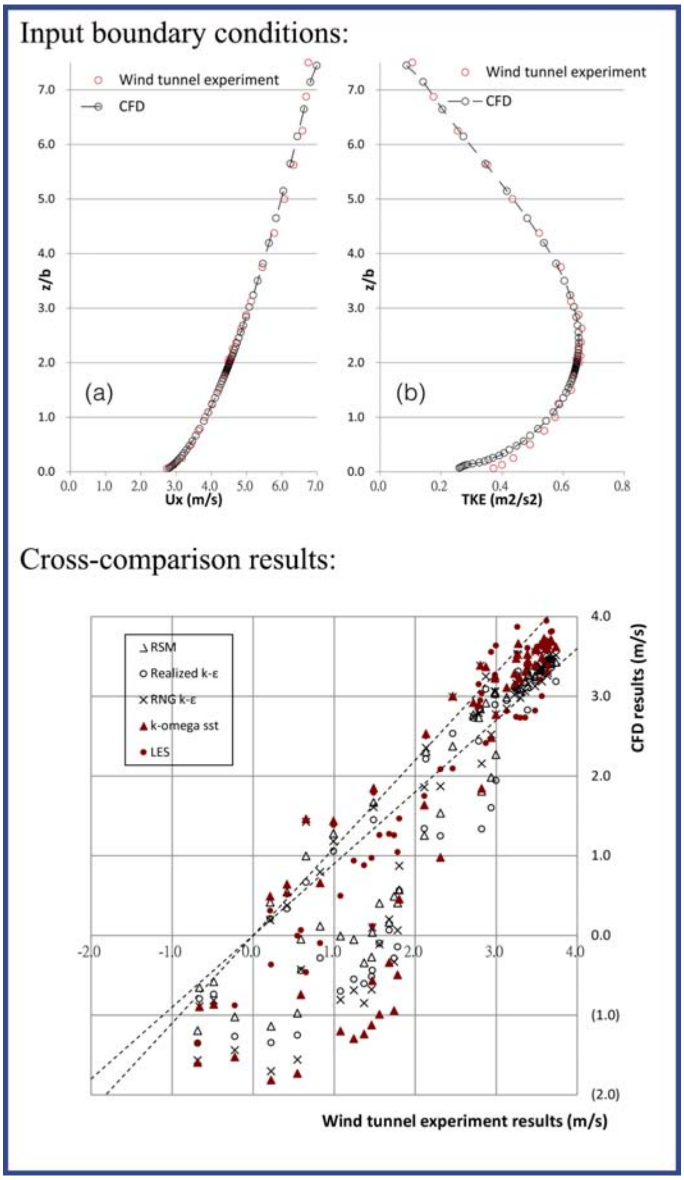

Figure 4. 1) Input boundary conditions. a) Wind speed profile. b) TKE profile. 2) Cross-comparison results: The wind velocity in the stream wise direction (positive values: input wind direction). Two dash lines: mean ± 10% accuracy.

4. Results

The result consists of two parts: a) evaluation of the local-scale urban permeability for urban planners, and b) evaluation of the efficiency of the building-scale design strategies for architects.

a) Local-scale wind permeability

From the complex input condition, which includes the spatially continuous urban morphology data set provided by the Hong Kong Planning Department and the MM5 data provided by the Institute for the Environment at HKUST (Figure 1), the urban permeability is mapped by λ_f (0-15 m) in the nested grids, as shown in Figure 1.

To simplify further the local roughness calculation for implementation in urban planning, the ground coverage ratio (R_g) is directly used to map the urban permeability as a user-friendly planning index because of the strong linear relationship between R_g and λ_f (0-15 m) (Ng *et al.* 2011) (Figure 5).

b) Building-scale natural ventilation

The result, which comprises eight test scenarios (Figure

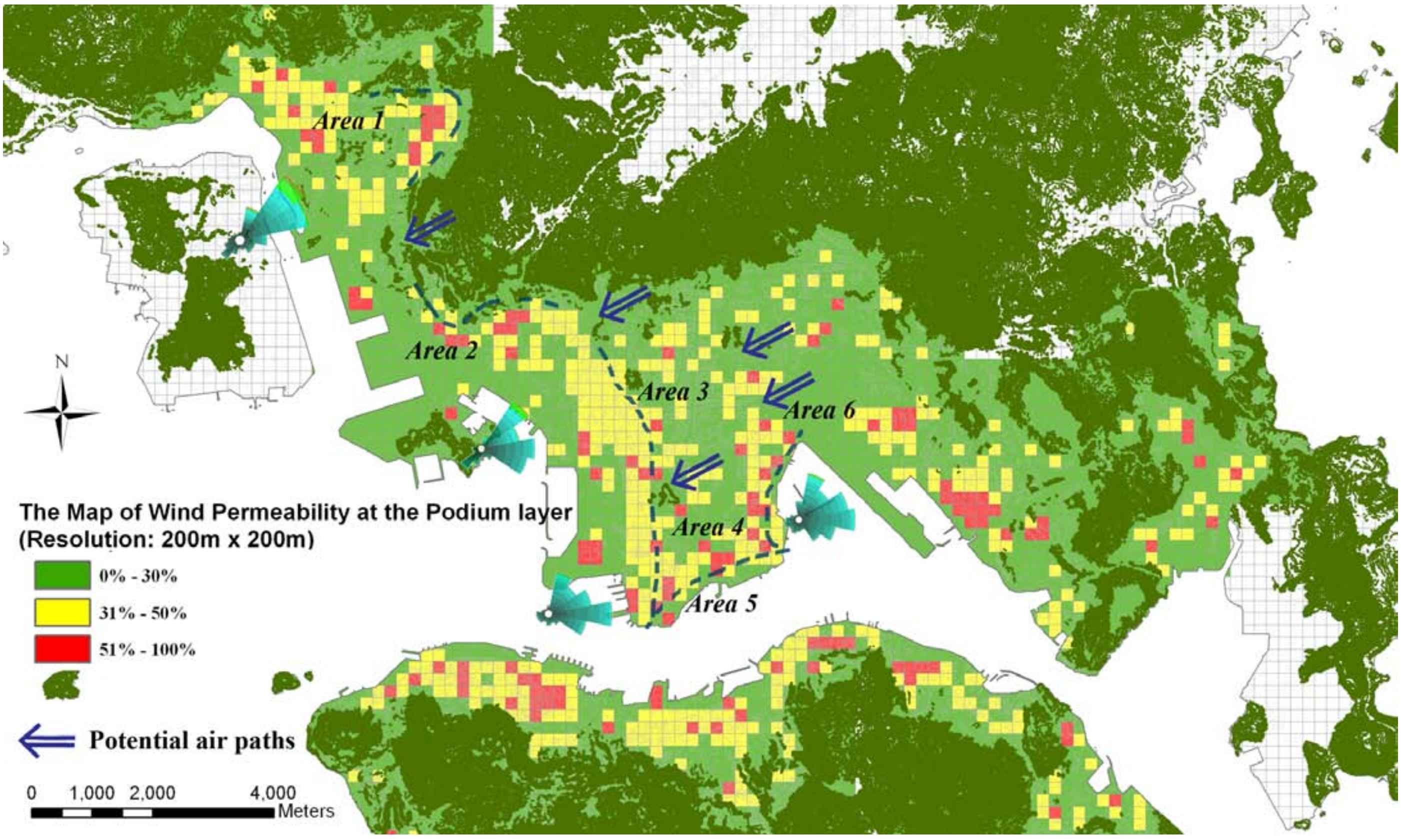

Figure 5. Pedestrian-level urban permeability, represented by ground coverage ratio. Based on the respective annual prevailing direction, the areas with low wind permeability are identified. These areas could block the natural ventilation and worsen the leeward districts' wind environment at the pedestrian level. Potential air paths in the podium layer are also marked out in this map (Ng *et al*. 2011).

2) in one input wind direction (prevailing wind direction), is presented in this section. The simulation results are organized by the relative frequency of the pedestrian-level wind-speed distribution to evaluate the natural ventilation performance under different building morphologies (Figure 6a). As shown in Figure 6a, the cross-comparison of the natural ventilation performance indicates that all of the building setback, separation, building void, and permeability are helpful to improve the pedestrian-level wind permeability. However, the levels of efficiency of these strategies significantly differ.

Architects should choose the appropriate strategies according to the actual design requirements and knowledge gained from this section.

Building permeability should be arranged as close as possible to the pedestrian level. In Case 6, the airflow across the building void (10 m) is numerically shown by blue lines in Figure 6b. By contrast, the large wind permeability in towers does not improve the pedestrian-level wind environment in Case 7. This knowledge is consistent with the discussion in Section 3a.

5. Conclusion

The natural ventilation performance in urban areas significantly depends on the coordination between city planners and architects. Urban planners should evaluate the existing urban wind environment and establish corresponding guidelines (Section 4a). On the other hand, architects should refer to the urban-scale permeability information provided by the urban planners to decide whether the issues of building porosity in their projects are important or not; if important, they should identify the optimal design strategies that should be chosen (Section 4b). Thus, the urban area can be considered in totality. New air paths can be efficiently established and organized in existing urban areas by applying different strategies in different scales. It is also helpful to avoid worsening current air paths by new projects in the rapid urbanization.

Second, in practice, the "scale" is critical in choosing the appropriate modelling methods and in applying the knowledge into the implementation of planning and design. For the urban-scale implementation, the average estimation by the morphometric method is appropriate (Section 3a). Even though the urban-scale numerical modelling can provide more detailed and accurate information, it requires far higher computational ability and complex field observation information for the input boundary condition settings. On the other hand, for building-scale implementation, to evaluate the difference in wind speed resulting from the building morphology, high-resolution numerical or physical modelling is needed (Section 3b). The wind permeability estimated at the urban scale by the morphometric method is not suitable for building-scale application, as it could cause significant errors.

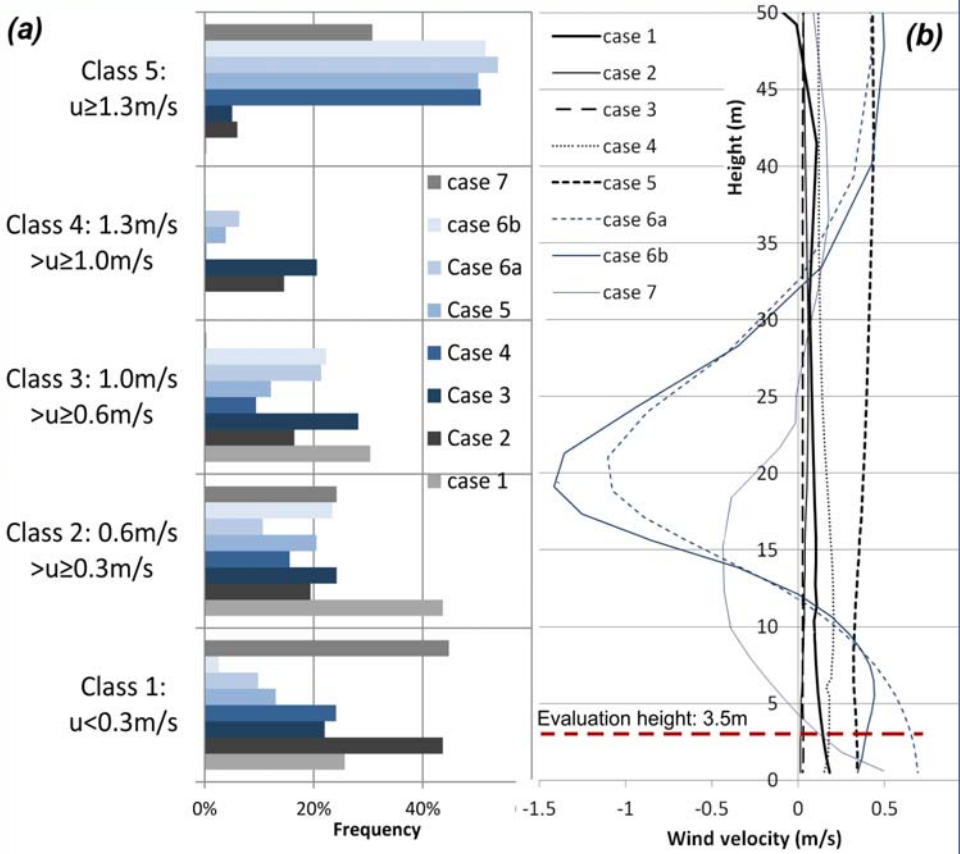

Figure 6. Cross-comparison results : a) relative frequency of wind speed; b) wind velocity vertical profile (negative values mean input wind direction).

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Influence of isoprene on ozone formation in an urban environment

1. Introduction

To form ozone in the troposphere, two types of precursor substances are needed: NOx (nitrogen oxides) and VOCs (volatile organic compounds). Whereas NOx are mainly emitted by anthropogenic sources, VOCs have anthropogenic and biogenic sources, resulting in the classification of AVOCs (anthropogenic VOCs) and BVOCs (biogenic VOCs). On the global scale, BVOC emissions exceed AVOC emissions by a factor of eleven (Kansal, 2009) and it is well-known that BVOCs are the dominant VOC type in rural areas. On the other hand, the impact of BVOCs in urban areas still needs to be researched. Only a few studies were performed to investigate this issue worldwide (e.g. Chameides *et al*., 1988; Taha, 1996; Benjamin and Winer, 1998; Im *et al*., 2011; von Schneidemesser *et al*., 2011; Hellén *et al*., 2012). Due to the fact that high AVOC emissions occur in urban areas and vegetation density is much lower in comparison to rural areas, the importance of BVOCs may be underestimated in urban environments. However, being more reactive than AVOCs, BVOCs react more quickly than the latter in the atmosphere and can rapidly contribute to ozone formation (Table 1). As a result, the higher reactivity can compensate the lower concentration and a thorough investigation of the VOC composition in the urban atmosphere is necessary to assess their impact on urban ozone chemistry.

The most abundant BVOC is isoprene (C_5H_8), one of the most reactive VOCs (Table 1). During the afternoon on summer days, when OH radical concentration is high, the lifetime of isoprene can be less than one hour, much shorter than many other organic ozone precursors. As it is dependent on temperature and light intensity (Guenther *et al*., 1991, 1993), isoprene emission – unlike AVOC emissions – reaches its maximum around the noon and afternoon hours, especially on hot and sunny summer days. These conditions are also favourable for ozone formation (Lee and Wang, 2006; Melkonyan and Wagner, 2013).

Isoprene is mainly emitted by deciduous tree species, but not every deciduous tree emits isoprene. However, some species which are characterized by high isoprene emissions are popular urban trees (Table 2). That is why isoprene should be analyzed in urban areas.

2. Study area and method

VOC measurements were carried out in the city of Essen (570,000 inhabitants), Germany, which is part of the metropolitan Ruhr area (approximately 5.2 million inhabitants). Concentrations of isoprene and important AVOCs (benzene, toluene, m,p-xylene) were measured with two GC-PID systems (GC 5000 of AMA Instruments, GC 955 of Synspec b.v.). Ambient air was sampled over

Table 1: Atmospheric lifetimes of selected AVOCs and BVOCs with respect to the reaction with OH radicals; assumed 12-h daytime average OH concentration of $2 \cdot 10^6$ radicals cm^{-3} (Atkinson, 2000; Atkinson and Arey, 2003).

Anthropogenic VOCs	Atmospheric lifetime
Benzene	9.4 day
n-Butane	4.7 day
Toluene	1.9 day
Ethylene	1.4 day
m-Xylene	5.9 h
Propylene	5.3 h
1,2,4-Trimethylbenzene	4.3 h
Biogenic VOCs	**Atmospheric lifetime**
Methyl vinyl ketone	6.8 h
Methacrolein	4.1 h
α-Pinene	2.6 h
β-Pinene	1.8 h
Isoprene	1.4 h
Limonene	50 min
Myrcene	39 min

Table 2: Selection of urban tree species and their isoprene emission rates at standard conditions where leaf temperature is 30°C and photosynthetically active radiation is 1000 µmol photons m^{-2} s^{-1} (this corresponds to a global radiation of approximately 530 W m^{-2} under natural daylight conditions). The emission rates were adopted from the database of Hewitt and Street (1992), available at http://www.es.lancs.ac.uk/cnhgroup/download.html, and are given in µg isoprene per g dry leaf weight (dlw) and hour. Note that the emission rate of a species is influenced by many biotic and abiotic factors, therefore data can only been seen as semi-quantitative.

Tree species	Common name	Isoprene emission rate (µg dlw^{-1} h^{-1})
Platanus x hybrida	London plane	10.68
Platanus occidentalis	American sycamore	24.29-27.6
Populus nigra	Black poplar	29.23-76
Populus tremula	Aspen	51
Robinia pseudoacacia	Black locust	10-13.5
Quercus robur	English oak	40-76.6
Quercus petraea	Sessile oak	>0.61-45
Quercus rubra	Red oak	14.8-61
Salix alba	White willow	37.2

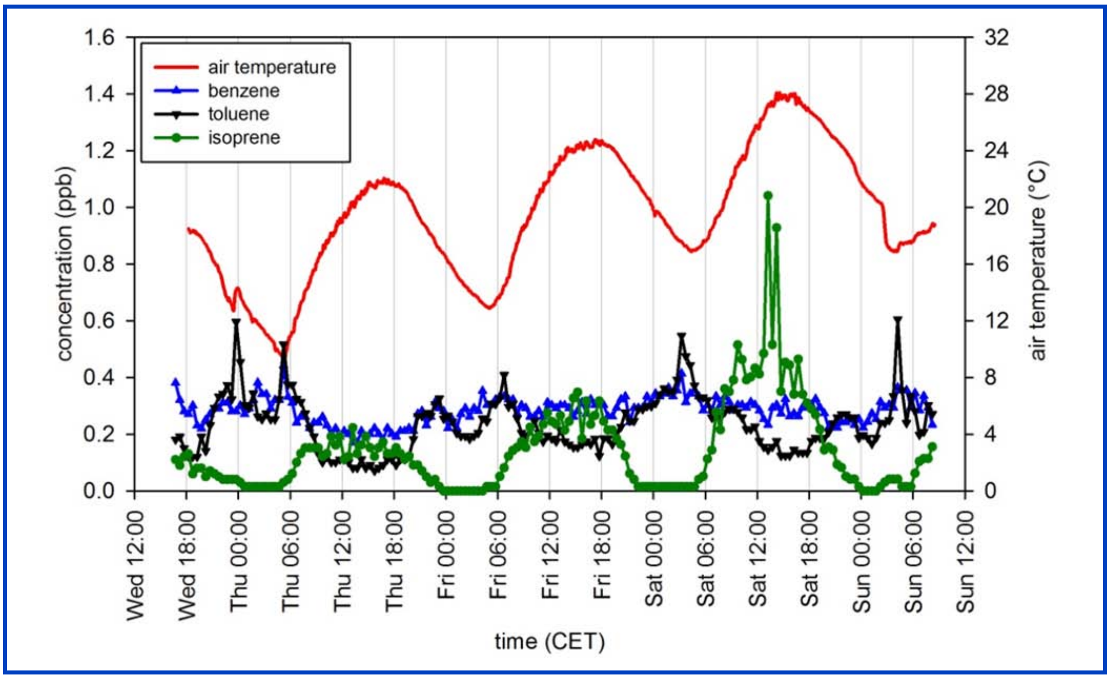

Figure 1. Diurnal variations of isoprene, benzene, toluene and air temperature during the measurement period in the Grugapark between 1 and 5 June 2011.

10 min (GC 5000) and 20 min (GC 955), respectively, and VOCs were enriched on adsorbents prior to analysis. The duration of each measurement cycle was 30 min, resulting in half-hourly data.

To investigate the importance of isoprene, VOC concentrations were measured at different sites, mainly during the summer months in 2011 and 2012. The measurement duration depended on the weather situation and the site and varied from several hours (from morning to evening) to a few consecutive days. Spatial and temporal variations of VOC concentrations were analyzed and isoprene was compared to typical AVOCs (benzene, toluene and m,p-xylene).

3. Results

Diurnal variation

The isoprene emission rate is strongly dependent on light intensity and temperature (Guenther *et al.*, 1991, 1993). At night, plants do not emit isoprene. During the daytime, however, emissions are exponentially dependent on leaf temperature up to a maximum of emission rate at about 40°C (Monson *et al.*, 1991). Leaf temperature is similar to air temperature in many cases (Meier and Scherer, 2012). The mentioned dependencies cause a pronounced diurnal variation in isoprene concentration. Figure 1 shows the results of a measurement in the largest park of Essen, the Grugapark. Isoprene concentration reached its maximum during the afternoon hours when air temperature also reached its maximum. At night, isoprene concentration dropped to zero because remaining isoprene from daytime emissions is diluted rapidly by chemical reactions and mixing. In contrast to isoprene, benzene and toluene do not show dependences on temperature and light; their diurnal variation is less pronounced. The concentration of benzene remained nearly constant during the whole period of measurement (Figure 1). Toluene indicates an inverse diurnal variation to isoprene with higher concentrations during the night and a minimum in the afternoon. Concentration peaks occurred in the late evening and early morning hours, typical of anthropogenic pollutants due to the combination of high traffic emissions, low wind speed and low mixing layer height. These conditions promote the accumulation of pollutants in the atmosphere. The higher levels during the night are a result of low mixing and the missing photochemistry, although emissions are lower than during the daytime.

Since a strong correlation with temperature can be only found for isoprene (Figure 2), isoprene concentra-

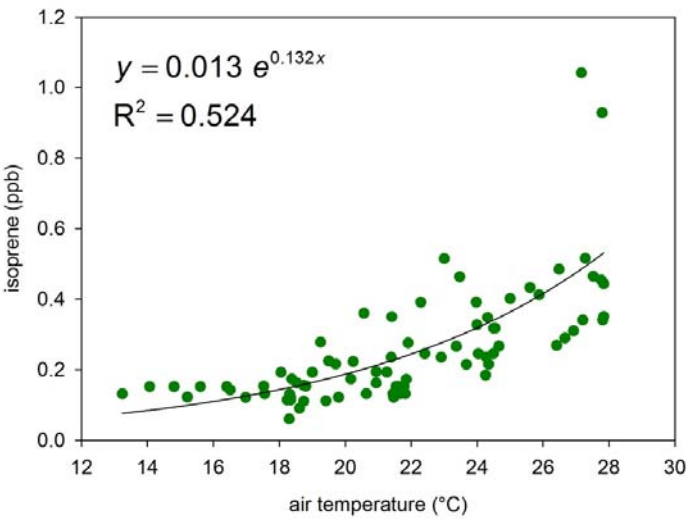

Figure 2. Isoprene concentration in dependence on air temperature for 7-19 CET data of the measurement period in the Grugapark between 1 and 5 June 2011.

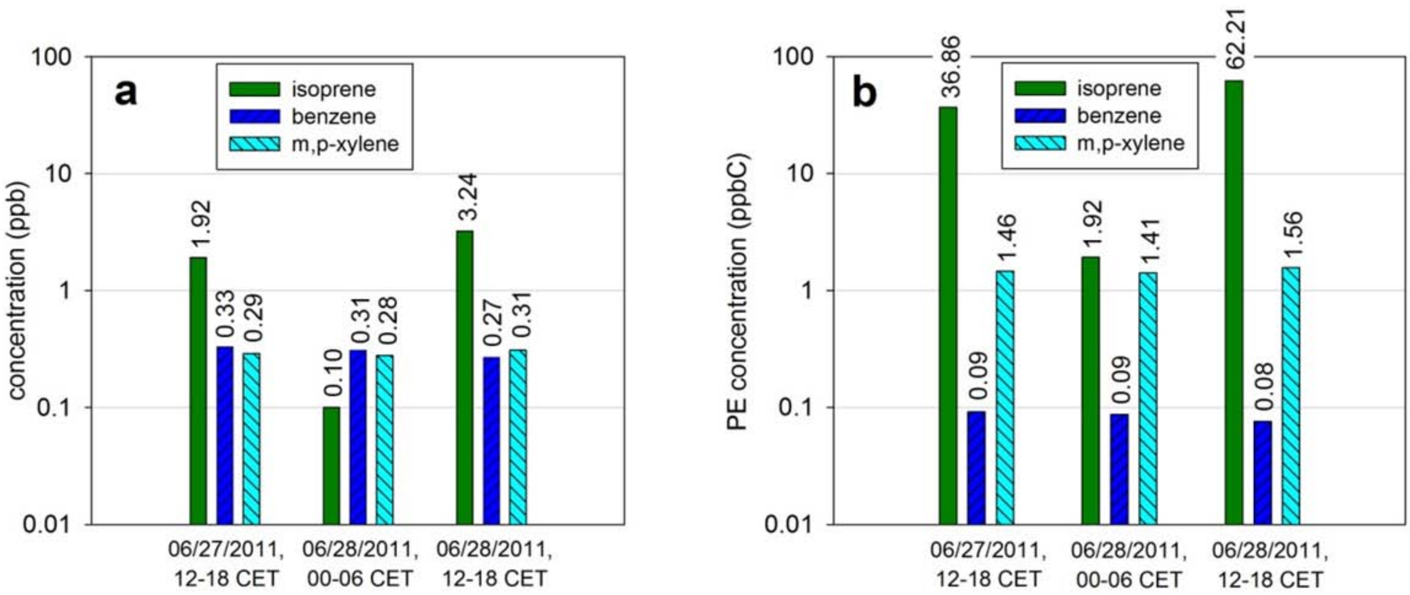

Figure 3. Average VOC concentrations during the night hours (0-6 CET) and the afternoon hours (12-18 CET) for the measurement period in the parking area in the city centre of Essen on 27 and 28 June 2011. Average values are given for concentration (a) and PE concentration (b), both on logarithmic ordinate.

tion can exceed concentrations of benzene and toluene on hot summer days, as can be demonstrated by the last day of the measurement period in Figure 1. Another measurement was performed in a parking area with numerous isoprene emitting trees in the city centre of Essen during the two hottest days in summer 2011. Air temperature increased up to 32.5°C and 35.8°C on the consecutive days, respectively. Isoprene maximum concentration was 2.82 ppb on the first and 5.68 ppb on the second day. During the isoprene peak on the second day, benzene, toluene and m,p-xylene concentrations were just 0.36 ppb, 0.82 ppb and 0.41 ppb, respectively. Considering average concentrations at night (0-6 CET) and in the afternoon (12-18 CET), once more the different pattern of diurnal variation of isoprene and AVOCs become visible (Figure 3a).

Estimating the impact of VOCs on ozone production

To estimate the importance of individual precursors for ozone chemistry, studying the concentration alone is not sufficient because it does not include information about reactivity. Therefore, a reactivity-based concentration should be used, called propylene-equivalent concentration (PE concentration - c_{PE}) (Chameides *et al*., 1992). It is calculated by Equation 1:

$$c_{PE}(VOC_i) = c(VOC_i) * n(VOC_i) * \frac{k_{OH}(VOC_i)}{k_{OH}(Propylen)} \qquad (1)$$

where *c* is the VOC concentration, *n* is the number of carbon atoms in the VOC molecule (e.g. five for isoprene, six for benzene) and k_{OH} is the rate constant with respect to the reaction of the considered VOC species *i* and propylene with OH radicals, respectively.

In the case of the measurement on 27 and 28 June 2011, benzene and m,p-xylene are almost on the same level in terms of concentration, but m,p-xylene/benzene ratio in terms of PE concentration is between 15 and 20, indicating the higher reactivity of m,p-xylene in comparison to benzene (Figure 3b). The reactivity of isoprene is even higher than that of m,p-xylene, resulting in PE concentration ratios of 778 and 40 for isoprene/benzene and isoprene/m,p-xylene in the afternoon of the second day, respectively!

Spatial variation

The aforementioned measurements were carried out in the vicinity of isoprene emitting trees to indicate the linkage between isoprene emission, isoprene concentration and environmental conditions of light and air temperature. The short distance to its emission sources causes high concentrations which are not representative for the mixed urban air. Therefore, further measurement sites were selected. Table 3 gives a short description of the sites and summarizes the mean PE concentrations in the afternoon. At some sites, the toluene concentration is higher than the isoprene concentration (not shown here), but the highest values of all PE concentrations were found for isoprene at all measurement sites.

Table 3: Average PE concentration and average air temperature in the afternoon (12-18 CET) at selected days and measurement sites.

Site description and date of measurement	air temperature (°C)	isoprene PE (ppbC)	benzene PE (ppbC)	toluene PE (ppbC)
Street canyon with many isoprene emitters in a residual area, 12 July 2011	26.9	30.3	0.1	2.6
Street with high traffic volume in vicinity to city centre, only a few emitters in the surrounding area, 4 July 2012	27.2	3.5	<0.1	0.9
Grugapark (under the canopy of some emitters), 4 June 2011	27.3	9.7	<0.1	0.2
Market place in a residual area, only three isoprene emitters within 100 m (none closer than 50 m), 24 June 2012	27.8	5.2	<0.1	0.3
Industrial area, no emitter within 200 m, 26 July 2012	28.8	3.5	<0.1	0.4
Park in vicinity to city centre with many emitters, but none within 50 m, 25 July 2012	29.7	8.8	<0.1	0.2
Parking area of the university with many emitters, 27 June 2011	31.4	36.8	<0.1	0.9

Conclusion

The analysis of isoprene concentration in the urban area of Essen indicates that isoprene can play an important role in the ozone chemistry of urban environments, particularly when urban vegetation includes a substantial number of isoprene emitting trees. The impact of isoprene becomes obvious when periods which are favorable for high ozone concentration are investigated, i.e. afternoon hours on hot and sunny summer days. Because photochemical reactions are needed to form ozone in the troposphere, it is necessary to assess the significance of individual VOCs for ozone formation on the basis of the concentrations during the hours with the best conditions for photochemistry. Furthermore, VOC reactivities have to be considered. However, the analysis of the 24-hour average concentrations leads to an underestimation of isoprene, because its pronounced diurnal variation with very low concentrations during the night and its high affinity to react with OH radicals during the daytime are ignored.

Due to climate change, stagnant high pressure conditions with high temperatures in summer are expected to occur more frequently in the future in many areas in the world, so an increase of isoprene concentration is to be expected while AVOC concentrations will decrease due to technological advances (Stemmler *et al*., 2005; von Schneidemesser et al., 2010). Therefore, isoprene emissions should be considered by urban planners and tree species that do not emit isoprene should be preferred as an ozone mitigation strategy.

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European partners launch COST action linking environmental and social challenges of urban forests and green infrastructure

By David Pearlmutter, Editor

"A well-structured urban forest decreases run-off and soil erosion, absorbs pollutants, and improves climatic conditions in the urban environment. By lowering air temperatures in the summer, indirect CO_2 savings are made through the reduction of energy consumption for air conditioning, and plants are also responsible for direct CO_2 savings through sequestration. It is this fact that is driving the post-Kyoto processes of afforestation and acquisition of credits throughout the world."

With this rationale as a motivating framework, a new European collaborative action was recently kicked off in Brussels to address the environmental and social issues surrounding the management and study of urban forests. The kick-off meeting, held on February 14, 2013, brought together representatives from the 36 EU member and partner states collaborating in the project under the European COST (Cooperation in Science and Technology) framework. An especially large consortium, COST Action FP1204 will focus on urban "green infrastructure" and will promote collaboration among specialists in fields ranging from forestry and plant ecology, to landscape architecture and urban planning – building bridges between the physical and the social sciences as well as between countries.

Coordination between this rich mix of actors will be headed by Dr. **Carlo Calfapietra** from the Institute of Agro-Environmental & Forest Biology (IBAF) of the Italian National Research Council (CNR). As outlined by Dr. Calfapietra, the COST action will embody two interests which are mutually reinforcing: understanding the effects of urban environments on the health of forests, and conversely, the effects of forests on the quality of urban environments. These mutual impacts are in turn expressed through a number of environmental aspects such as air quality, urban heat islands, energy demand and greenhouse gas emissions, as well as social aspects such as recreational services, cultural values and community access. At the same time, the successful management of urban forests as part of an integrated approach to green infrastructure hinges on issues of governance and calls for understanding the relationships between stakeholders, performing local cost-benefit analyses, and formulating policy road maps.

The added value of Europe-wide collaboration in addressing these issues is highlighted in the objectives of the action:

- compiling qualitative and quantitative findings from studies within European countries as well as international programs regarding the ecosystem services provided by green infrastructure and urban forests;
- comparing local approaches and conditions (climatic, socio-cultural, economic and urban planning) in the countries involved in order to develop 'best practice' guidelines for managers and decision makers;
- defining indicators (social as well as environmental) and thresholds for environmental quality in cities, to improve the quality of life for European citizens;
- gathering scientific evidence for the implementation of best practices through policy formulation and legislation at the local, national and European level; and
- identifying challenges and establishing priorities for future research.

To meet these objectives, the management committee members meeting in Brussels decided to establish four working groups (WGs), each of which will include representatives from participating countries and will tackle a particular area of the overall action. WG1 will address *environmental services*, WG2 – *social and cultural services*, WG3 – *governance of urban forests*, and WG4 will be an information dissemination task force comprised of representatives from the other three groups. This task force will set up an interactive web site targeting the scientific community, urban planners, government authorities and the general public, and publish a series of reports documenting the findings of the working groups.

The COST team's activities will continue at its next meeting in Milan, in tandem with the European Forum on Urban Forestry (EFUF) on May 7-11, 2013. This international conference is being organized by Prof. **Giovanni Sanesi** from the University of Bari, a member of the management committee who has been actively involved in an ongoing series of European projects on urban forestry and green infrastructure.

Recent publications in Urban Climatology

In this edition a list of publications are presented that have come out until the end of February 2013. As usual, papers published since this date are welcome for inclusion in the next newsletter and IAUC online database. Please send your references to the email address below with a header "IAUC publications" and the following format: Author, Title, Journal, Volume, Pages, Dates, Keywords, Language, URL, and Abstract.

Enjoy!

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6TH INTERNATIONAL CONFERENCE ON FOG, FOG COLLECTION AND DEW
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Newsletter Contributions

The next edition of ***Urban Climate News*** will appear in late June. Items to be considered for the upcoming issue should be received by **May 31, 2013** and may be sent to Editor David Pearlmutter (davidp@bgu.ac.il) or to the relevant section editor:

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