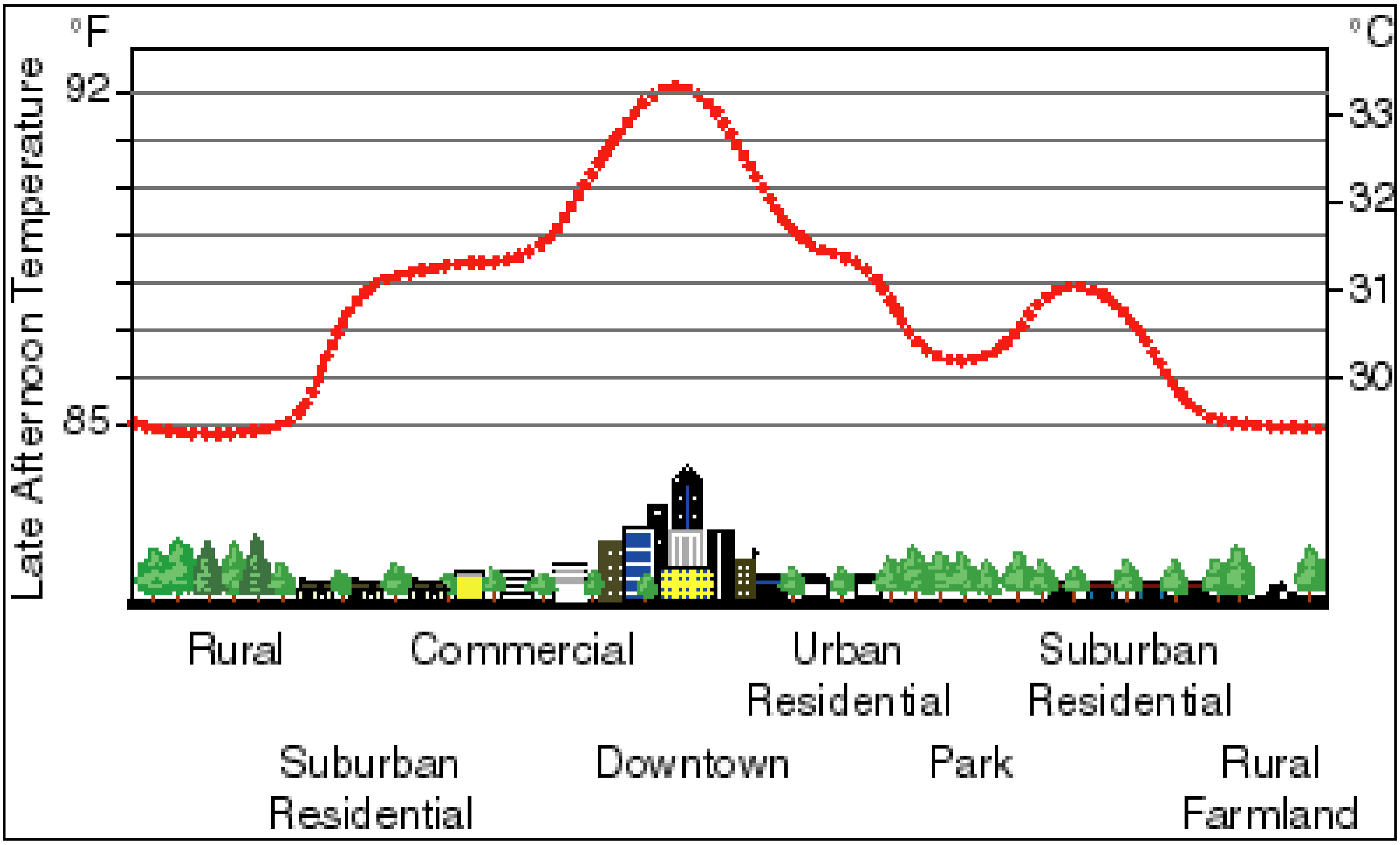


Guideline 2: Methodological guidelines for monitoring of temperature effects

Monitoring impacts of urban and peri-urban agriculture and forestry on climate change mitigation and adaptation

Francisco Escobedo and Marielle Dubbeling
With inputs from: Alejandra Coronel, Susana Feldman and Rubén Piacentini

RUAF

CONTENT

1. INTRODUCTION

The Intergovernmental Panel on Climate Change-IPCC Fifth Assessment Report (University of Cambridge and ICLEI, 2014) presents amongst its key findings that:

1. Many emerging climate change risks are concentrated in urban areas,
2. Rapid urbanisation will increase the number of highly vulnerable urban communities,
3. Key climate risks faced by cities include storm surges, sea level rise, droughts and water scarcity, excessive rainfall, floods and landslides, heat waves and urban food insecurity amongst others.

The same report forecasts that if emissions continue to rise at the current rate, impacts by the end of this century project an increase in global average temperature of 2.6–4.8 degrees Celsius (°C). Such temperature effects will directly affect urban areas, human comfort, related energy use (for cooling and refrigeration purposes) and heat-related diseases.

In general and with increased urbanisation and climate change impacts, built up areas are experiencing greater localised air and surface temperatures than surrounding open spaces (the so-called Urban Heat Island effects or UHI). The UHI effect is directly related to the modification of land surfaces, with decreasing green and open areas and increasing areas of built-up surfaces. Especially dark coloured buildings and impermeable surfaces (roads, parking lots, building roofs and walls, industrial and commercial areas) are responsible for absorption of solar radiation (Oke, 1987). In conjunction with the heat produced by transport, cooling systems and industrial activities, this contributes to a rise in ambient temperature in cities (American Meteorological Society, 2000).

Conversely urban and peri-urban vegetation and vegetated surfaces modify surface and atmospheric temperatures due to evapo-transpiration, shading and albedo effects. Increasing or conserving green infrastructure in urban areas has been proposed as a strategy to regulate urban temperatures (Cavan et al. 2014). Vegetated surface, such as green walls and roofs, gardens, green spaces, lawns and different forms of Urban and Peri-urban Agriculture and Forestry (UPAF) can contribute to reducing the UHI (http://www.epa.gov/heatisland/mitigation/trees.htm).

For example, Amiri et al. (2009) and Shashua-Bar et al., (2009) analysed the effects of vegetated landscapes on urban temperatures in Iran and Israel, respectively. Both studies found that urban vegetation can lower temperatures in cities in hot arid climates. Oliveira et al. (2011) and Lin and Lin (2010) in Portugal and subtropical China, respectively, also looked that the cooling effects of vegetated, urban spaces. Cavan et al. (2014) studied the role of different urban morphologies in regulating land surface temperatures in Addis Ababa, Ethiopia and Dar es Salaam, Tanzania. They found that residential land use types with large proportion of green space in both these cities had lower surface temperatures

This methodological guideline will provide measurement, quantification and monitoring methods to assess the hypothesis that current and increased UPAF area in urban and peri-urban area will reduce the UHI and contribute to energy savings. To do so, temperatures in current UPAF and green areas (specifically urban gardens, public parks and street trees) are compared to non-UPAF and built- up areas, preferably covering the period of one year to account for seasonal differences. Temperature data are used to determine air temperature in different UPAF and non-UPAF areas. Ambient temperatures are then related to thermal comfort. Thermal comfort is used as an international standard for evaluating the satisfaction with the thermal environment for occupants of buildings. Thermal comfort on its turn can be directly related to energy use. Air condition or cooling fans are used to reduce inside building temperatures and thereby increase thermal comfort. Alternatively, sources of heating are used to increase inside building temperatures and thus thermal comfort. Based on climate change and temperature projections, calculations can also be made for future situations. Taking current or projected energy prices, energy use can be translated into economic expenditures.

It is important to note that for these calculations, it is assumed that there is a direct relation between ambient air temperatures and thermal comfort inside buildings. In reality, this relation however is also influenced by amongst others the type of building materials used and their heat conductivity. Temperature monitoring inside buildings should be done to better assess this relation for specific types of buildings.
In an ideal situation, temperature monitoring data should also be done in various distances away from UPAF areas to assess the gradual extent to which air temperatures are affected in areas neighbouring UPAF towards areas that are located at larger distances from the UPAF areas. Based on these data, optimal "densities and distribution of UPAF areas" in the city could be better defined. This will allow to estimate what the much larger benefits would be if decision-makers up-scaled UPAF initiatives.

Specifically, this manual will provide the methods to:
- Identify and map representative UPAF and non-UPAF areas/types in the study city
- Measure urban temperatures and humidity for these representative areas
- Calculate degree days, thermal comfort and related energy use
- Develop future temperature and land use scenarios in order to guide urban development policies and planning.

Before such actual methods are described, first a short explanation is given of what is understood by the Urban Heat Island phenomenon.

2. THE URBAN HEAT ISLAND

The urban heat island (UHI) effect can either be manifested in a city's atmospheric layer (i.e. atmospheric UHI) or in the immediate surfaces of buildings and impervious surfaces (i.e. Surface UHI). The temperature differences between warmer urbanised areas relative to adjacent cooler, rural areas define the atmospheric UHI (http://www.epa.gov/heatisland/index.html). Surface UHIs are the difference between dry, exposed roofs, pavements, and other urban surfaces and shaded, moist, vegetated ones (http://www.epa.gov/heatisland/resources/pdf/BasicsCompendium.pdf).

Overall, the UHI is affected by the time of day, the season, and geomorphic and topographic location; for example surface UHIs tend to be strongest during the day when the sun is shining, but become more pronounced in the atmospheric layer after sunset due to slow heat emissions from heated urban surfaces. The UHI and an urban area's morphology will in conjunction affect the overall temperature and relative humidity characteristics of a city. The UHI's influence on temperature and relative humidity are particularly important in that they directly affect human well-being. This well-being can be measured in degree days and in terms of a person's thermal comfort, which is affected by temperature, wind speed, relative humidity as well as a person's metabolic rate and clothing type.

The growth of a city in particular changes its biophysical environment and results in local-scale climate modifications, thus creating a site-specific urban climate. Among the factors that lead to the development of UHIs are the reduction of green spaces due to urbanisation, the prevalence of impermeable surfaces in cities, the thermal and radiative properties of materials used in construction (concrete and steel retain and radiate more heat than do vegetation and soils), urban morphology (the layout of the city will affect wind flow and speed), the anthropogenic heat emission sources (cars and industrial sites generate heat), regional climate, weather patterns, and geomorphic and topographic location (UHI will be different between inland arid cities and coastal tropical cities for example).

The impact of increasing green as well as Urban and Peri-urban Agriculture and Forestry (UPAF) areas on reducing the UHI can be measured collecting onsite field data (localised temperature monitoring using thermo-hygrometers and data loggers) or using remotely sensed land surface temperatures using satellite images to characterise thermal behaviour of different areas in the city. These data can be used to calculate "degree days" that are compared to thermal comfort in order to arrive at the number of "cooling days" and "heating days" that impact energy consumption. In this way, scenarios can also be developed to show how increased UPAF area over time can contribute to percentage improvement in temperature and subsequent changes in seasonal thermal comfort (cooler day and night time summer temperatures), compared to a reference situation (for example, where UPAF and green areas are lost or there is no net increase in such areas).

3. TEMPERATURE MONITORING

Mapping/ description of UPAF types in the city

For monitoring purposes, it will be necessary to identify and select a range of different and representative UPAF types and areas in the study city. Each city will need to use and adapt a UPAF typology that accounts for its socioeconomic and biophysical conditions. These UPAF types can be selected based on either specific policy objectives (promoting productive green ways, gardens or reforestation projects) or more quantitative criteria such as the total area or proportion of specific UPAF types in the city, relative to other land use and cover types. Some basic UPAF types are presented below in Table 1 and can be used as a starting point, but need to be adjusted to reflect specific UPAFs found in the area of interest.

Table 1. Proposed Urban and Peri-urban Agriculture and Forest (UPAF) typology based on land use/cover types in Rosario, Argentina and Kesbewa, Sri Lanka.

City Zone (A = Inner city; B= Sub urban - less densely built up; C= Peri-urban -mainly open spaces)	UPAF type
A-B-C	1. Non-UPAF; Urban Core, densely built up: Impervious, high density residential, industrial, commercial, transportation, buildings
A	2. Backyard and community gardens
A-B-C	3. Green productive rooftops
A-B	4.Flood zones and other urban open spaces for conservation or food and biomass production: Inner city parks, wetlands, rice fields, pervious vacant areas, public green spaces, urban "greenways"
B-C	5. Urban, peri-urban and agro-forests: parks, low density residential areas with high tree cover, forest reserves, wooded hills and mountain slopes
B-C	6. Agriculture areas in city fringes/peri-urban areas, including wetlands
A-B-C	7. Street trees, street-side gardens

Selecting UPAF sites based using remote sensing

Different and specific UPAF types and sites for each city will need to be mapped, documented and used to locate temperature measurement and monitoring areas and plots. Such mapping can be done with use of land use maps and GIS, coupled to field observations (see further below). Alternatively, satellite imagery can be used. Although other satellites such as ASTER can also be used, the following methods will assume the use of LANDSAT satellite imagery.

The LANDSAT Program is a series of Earth-observing satellites that have continuously acquired space-based land remote sensing data since the early 1970s. Each of these satellites has different specifications and specific spatial resolutions, or measures of image clarity, that are key in selecting the minimum size of a UPAF area. Older LANDSAT (Multispectral Scanner) resolution was 79 x 57 meters and 120 meters for the Thematic Mapper (TM), but recent data is provided at a 60-meter pixels. Available LANDSAT Enhanced Thematic Mapper Plus data processed after 2010 is now resampled to 30-meter pixels. Finally LANDSAT 8 Thermal Infrared Sensor measures land surface temperature at a 100-meter resolution, but the product provided is resampled and delivered with a resolution of 30-meters (http://landsat.usgs.gov/band_designations_landsat_satellites.php).

Given these differences in LANDSAT specifications, the minimum size of a selected UPAF area will depend on the spatial resolution of the satellite image. If recent LANDSAT ETM+ or 8 images will be used, UPAF sites should be no less than 30 x 30 m in size to be visible on the images. But, to provide better flexibility in the use of different LANDSAT images, on average selected UPAF monitoring sites should have a minimum size of 60 x 60 m (by comparison 1 hectare is 100 x 100 m). They should at the same time have a maximum size and distribution in the city that makes the specific UPAF type representative of other UPAFs in the city. Additionally, the selected UPAF sites should be adjacent, minimum located at 120 to 240m (2-4 LANDSAT pixels) in distance to highly urbanised areas (high impervious and building cover) to compare temperature and UHI effects between UPAF and non-UPAF areas. Other considerations to be taken into account, are that during the analysis period the selected UPAF sites will be:

1. Accessible for monitoring purposes
2. Stable in terms of vegetation and ground cover types (consider seasonality of production)
3. Different from surrounding land use/cover types in terms of impervious surface and building cover
4. Relatively safe from vandalism and disturbance/rapid land use changes.

Identifying and mapping UPAF types and sites based on land use and GIS maps

UPAF areas can also be mapped using land use and topographic maps, spatial data and GIS software (ARCGIS or MapWindows). Satellite imagery classification can also be verified in the field by for example determining the surface area of each site using GIS and its GPS coordinates identified on a map.

Examples of spatial and GIS data include, but are not limited to soil, topographic, hydrologic, land use and Digital elevation models (DEM). Another possible method using Google Earth and GIS (ARCGIS-ArcMap 10) is outlined by Taylor and Lovell (2012) in Figure 1. Topographic maps, aerial images and planimeters or dot grids can be also used to identify, delineate, map and determine UPAF areas and relevant distances to other areas (http://www.youtube.com/watch?v=fnuRQE0_cIU; http://web1.cnre.vt.edu/forestcourses/Module4/dot_grid.pdf)

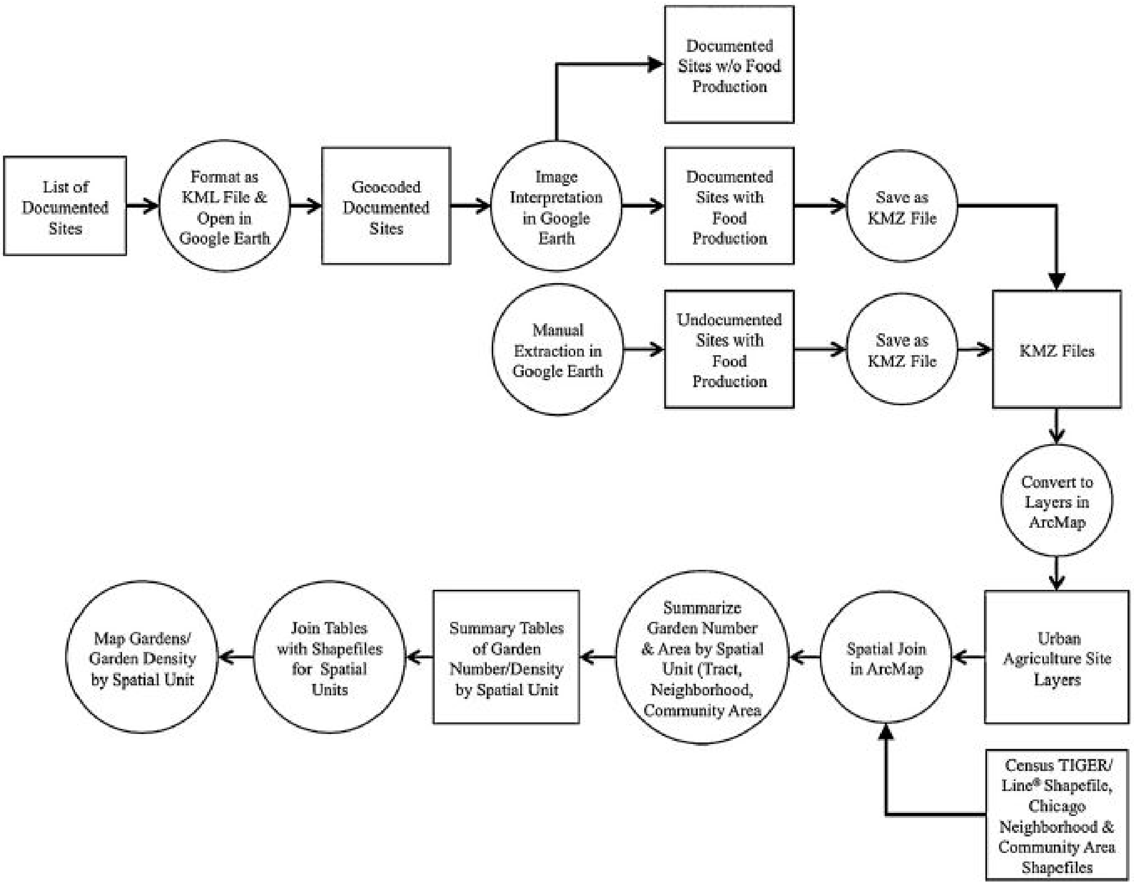


Figure 1. Taylor and Lovell's (2012) method for mapping urban and peri-urban agriculture and forestry sites using Google Earth and ARCGIS (ArcMap10). TIGER/Line refers to spatial data from the United States Census and KML and KMZ refer to Google Earth format files.

Selection/establishment of monitoring plots

Once representative UPAF and non-UPAF sites have been identified, temperature (and humidity) monitoring and measurements can be done by either field monitoring or analysis of satellite images. Monitoring should preferably be done for an entire year in order to capture seasonal (summer and winter) temperature differences. If localised field monitoring is applied, monitoring plots should be located in such a way so as to assess the hypothesis that urban surface summer, day and night time temperatures will be lower in UPAF – relative to non-UPAF areas (urban core, paved areas,) and that their mitigating effect will decrease as distance from UPAF and other green spaces to built-up spaces increases. The location and number of monitoring plots will need to account for the variation in main UPAF types, their size, location (inner city versus peri-urban, inland versus coastal, east-west and north-south orientation) and vegetation-soil cover as well as building density surrounding it. In general, the distance from a UPAF areas at which air temperatures begin to measurably change, can be considered as a starting point at which non-UPAF measurements and monitoring data can be collected. This distance can either be measured using temperature maps or based on satellite imagery thermal analysis. Typically, the monitoring plots should be located in the centre of each UPAF (or non-UPAF) site and at different distances away from the centre of the UPAF site towards adjacent built-up areas.

Temperature measurements will be influenced by solar radiation being reflected. As indicated earlier, infrared radiation emitted from impervious ground (pavement, concrete, rock) and wall (concrete, block, concrete) surfaces and will likely result in higher temperatures. Conversely, shade from trees and buildings will effect and subsequently reduce measured temperatures. Temperature monitoring can already be done comparing a minimum of 2 representative monitoring areas and plots (1 UPAF and 1 non-UPAF) in a given area in the city. But ideally and for statistical purposes, it is recommended to monitor at least 3 plots within each UPAF and non-UPAF area and to compare at least 10 different UPAF/non-UPAF types per city.

The following are two examples of how representative UPAF types and field monitoring locations in Rosario, Argentina (temperate climate, located in the Southern hemisphere) and Kesbewa, Sri Lanka (tropical humid climate) could be selected.

- Street trees: Specific street segments with, and without, street trees can be selected along streets aligned along east-west directions to maximise the hours of sunlight and minimise shading from taller buildings. Monitoring plots are either randomly located or subjectively located in sites that represent and capture specific UPAF types and used to collect temperature data using thermometers and data loggers. For example, street segments with different types and size of trees, streets with different building heights and characteristics, or streets with different amounts of over-story tree cover can be selected. Monitoring plots are assigned a unique identification number and used for measurement and monitoring purpose. Periods with and without tree leave cover (leave shedding trees) should be differentiated.
- Parks and gardens: Specific monitoring plots can be located within these UPAF areas in sites that best characterise the vegetation of this UPAF type (for example under a tree and/or in the middle of a garden) and at such a distance where temperature effects form adjacent urban areas are minimised (this distance can be determined using satellite images). The measurements should be collected at the centre of the selected UPAF area and in locations where people or animal traffic can be kept away from the equipment. Wire mesh or netting can be used as long as it does not affect wind flow into the solar shield. (See: http://gaw.empa.ch/gawsis/images/sites/172.jpg or http://www.did.sabah.gov.my/index.php?q=hidrologiukur). On UPAFs with trees; the equipment and its solar shield should be located directly under the tree crown at the halfway point between the edge of a tree's crown edge or dripline and its stem.
- Residential areas: Specific residential areas with and without UPAF and shade producing

tree cover can be used to characterise the temperature effects of UPAF on homes/buildings and energy use. Data can be collected both outside and inside of each home/building. Indoor thermometers/data loggers, 'units' hereafter, should not be located directly on the walls that receive the most sunlight for prolonged periods of time due to the sun heating the wall and affecting the unit. The SunCalc application (http://suncalc.net/) can be used to determine the sun's position for specified hours during a given day for different locations. The temperature units should not be directly affected by open windows, air conditioning, ovens, kitchens or other cooking areas, etc. Homes and outdoor sampling locations should be selected based on the following criteria:

- Find homes with at least 1 or more trees and another without trees, ideally with trees greater than 6m tall and within 18 m of the home that are shading the wall of the home that receives the most sun during the day. Larger, taller trees are better. Since the objective of this sampling is to assess the effect of tree shade on building temperature and home energy use, so presence of tree shade on the house from 1 or more trees during the hottest days of the year is more important than the specific number, type, species and size of trees. This tree data will be recorded in the field form in Appendix 1 but should not be used for selecting the monitoring site. The control home should not be affected or influenced by tree shade during the measurement period.
- Selecting the type of homes/buildings: homes/buildings should be categorised according to the building and roofing materials used, colour, as well as their number of floors and locations to other buildings. All these factors influence heat flux and transfer from outside to inside areas. For monitoring inside temperature effects, thinner roof and wall types are better as well as homes/buildings that are less than two floors high. Ideally all mentioned characteristics such as colour, roof type, building material types, number of floors, location to other buildings, etc. should be recorded to account for specific influences on outside to inside temperature relations.

- Forests, plantations, treed areas and parks, wetlands: The location of monitoring plots where the units will be placed should be limited to those areas where the units will not be vandalised, stolen or damaged. Religious sites, government buildings or private, fenced areas are examples. The plots should be located well within the UPAF area and its centre and the unit should be located at least 1.5 m above the surface and in a place that best represents over-story conditions. Other monitoring plots can be located at specific distances away from such areas to monitor related temperature effects.
- Non-UPAF sites: Monitoring plots will be located in highly urbanised sites such as urban cores that have little to no vegetation thereby best characterising non-UPAF conditions. These sites will be used as control areas to compare the temperature effects of UPAF sites to these non-UPAF sites.

In selecting and comparing monitoring plots and different UPAF-non UPAF areas other aspects affecting temperature should also be taken into account and recorded. These include the building density of the different areas and surrounding land uses. These data are needed to assess for example if temperatures in study locations in the peri-urban are lower than in the sites close to the city centre because of the surrounding land uses, rather than the presence of UPAF on the property/ in the area itself.

Field measurements of temperature and humidity

Field data can be used to determine UHI effects on temperatures by measuring and monitoring temperature and humidity at different UPAF and non-UPAF sites (and different distances away from UPAF sites) in the city's urban and peri-urban areas, as indicated above. Since temperature and humidity vary during the day and season, this temporal variability should be measured as well as the spatial variability of temperature and humidity across the city in representative UPAF and non-UPAF sites).

Air temperature and humidity measurements should preferably be made for at least one month periods in different seasons (summer and winter for example) and for 24 hours/ day to at least capture solar noon time of the day and midnight to assess night time UHI impacts.

It is recommended that outdoor (or respective indoor) thermo-hygrometers with data loggers be used to measure ambient temperatures and humidity. Thermo-hygrometers with data logger can take continuous measurements (for example every 15, 30 minutes or hour) and record data for various months. Data are captured by computer and data logger information will be collected or downloaded biweekly or monthly during the year. Examples are the HOBO data logger and sensors (http://www.onsetcomp.com/\). Some HOBO sensor data loggers also measure global solar radiation.

Thermo-hygrometer measurements collected every 15 minutes beginning at the top of the hour, will result in 4 hourly and 96 daily readings, accordingly. If possible a trial run for few days can be made to asses if these 15 minutes are sufficient to characterise measurement trends for a specific site (high temperature/humidity variability). Measurement readings adjustments can then be made accordingly. Data monitoring logs should be protected from direct rain and sunlight and calibrated as indicated in Appendix 2. A solar protection shield can be used for protection. Leaf litter, dust, and other detritus should be cleaned from the solar radiation shield periodically.

Solar radiation shields

A simple solar radiation shield was designed (see Appendix 2) according to the thermo-hygrometer data logger manufacturer's specifications and based on the following criteria: simplicity of construction (with materials made from mostly wood, a commonly available, renewable resource), use for outdoor conditions and protection from heavy rains, strong winds, ability to protect the sensor from nesting birds, ability to protect the unit from direct solar radiation even during sunset and sunrise, easy access for periodic maintenance, cleaning, data collection/download, etc. (Figure 2).

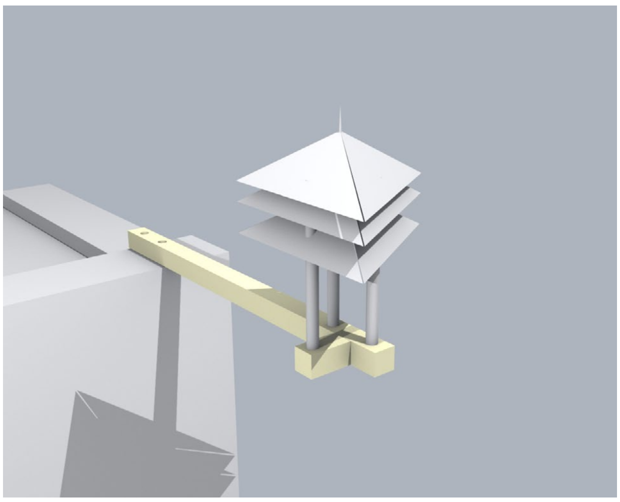


Figure 2.The solar radiation shield.

Characterising UHIs using satellite images

Infrared satellite imagery is a second method that can be used to map urban/non-UPAF and UPAF surface temperatures. Thermal bands in the 10.40 -12.50 µm range from LANDSAT7, and 8 ETM+ can be used to measure urban and vegetation cover surface temperatures. These bands can easily be converted to temperature using LANDSAT 7 and ETM+ methods. Thermal analyses can then transform pixel-level radiance and reflectance characteristics to radiant surface temperatures. Other satellite data such as Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) can also be used to create detailed maps of land surface temperature, reflectance, and elevation at no cost (http://asterweb.jpl.nasa.gov/).

Satellite images should be obtained for specific rain and cloud free days that ideally meet the following criteria:

- The day and time that correspond to the periods where the average highest and lowest temperature have been measured (http://www.weatherbase.com/)
- The capturing of data of different UPAF and non-UPAF sites of sufficient surface area (see indications provided earlier)
- One winter and one summer day that corresponds to the same temperature characteristics as mentioned above, that represent land uses and covers or periods in the city with UPAF compared to none or few UPAFs (UPAF cover may vary over time in different years).

In the case of Rosario, Argentina, "with UPAF" land uses were urban gardens, urban parks, and streets with street trees for example. "Without UPAF" land uses were different areas in the urban core characterised by commercial areas with tall buildings, impervious surfaces and no vegetation. As the city started to promote UPAF since the economic crisis in 2001, images from before this period can be compared with current images over time.

Images can be processed using software such as ENVI (http://www.exelisvis.com/ProductsServices/ENVI/ENVI.aspx), ERDAS Imagine (http://geospatial.intergraph.com/products/ERDASIMAGINE/ERDASIMAGINE/Details.aspx) or ILWIS (http://www.ilwis.org/).

Other statistical software such "SAS" (http://www.sas.com/software/sas9/) or "R" (http://www.r-project.org/) and commercially available tools such as FLAASH and QUAC (http://www.youtube.com/watch?v=4fiPRWixykU&noredirect=1; http://exelis.http.internapcdn.net/exelis/pdfs/Slick_ENVI_ACM_Module.pdf) can be used to develop and adjust algorithms that correct for atmospheric conditions and error. Processed imagery depicting surface temperatures can be used to develop isotherm maps for the specific periods of interest and scenarios (http://www.epa.gov/heatisland/about/measuring.htm).

The effects of UPAF and non-UPAF, or pre and post-UPAFs, on UHI will be determined by analysing statistical relationships between UPAF temperature and other remotely sensed or field measured variables from the monitoring such as UPAF area, tree/shrub/soil cover, number of trees on plot, etc using statistical tests such a multiple regression analyses and an alpha of 0.05. For example a sufficient, number of random geo-referenced points in the satellite image will need to be established and along with ancillary GIS/spatial data be used to estimate pixel level (60m resolution) relationships between temperature and: vegetation and soil cover (NDVI), distances to water bodies, building density, population density, distance where temperature effects are well way from a UPAF's influence, etcetera.

Box 1. Using remote sensing to determine effects of UPAF on UHI in Bobo Dioulasso. A study implemented in Bobo-Dioulasso, Burkina Faso (tropical-savannah climate) in 2013-2014 analysed the role of urbanisation and green infrastructure on increased surface temperatures in the city, using available satellite imagery and remote sensing techniques to spatially and temporally quantify urbanisation and land surface temperatures (LST) effects over 20 years. The effect of specific green infrastructure areas in the city on LSTs were also quantified. Results show that increased rates of urbanisation have resulted in increases in temperature trends across time and space. Temporal differences in LST between urban and peri-urban areas increased over the analyses period by approximately 6% per year. The study also found that mean LST over a 10 year period were consistently cooler (0.3 °C) in these green infrastructure areas than in adjacent built-up areas.

Although this was not specifically quantified in the present study, these green infrastructure areas are also providing other services (carbon sequestration, reduced storm-water runoff, (food and fuel and income from urban agriculture recreation) to urban citizens. Studies such as these can support evidence-based policy formulation on preservation, increase and management of green and UPAF spaces in a city, as in contrast many cities regularly encourage infill developments and higher housing densities that lead to the reduction or loss of green spaces and gardens (Di Leo et al, forthcoming).

Calculating the indicator values

When local field monitoring is implemented with use of thermo-hygrometers, for every hour of the day, the difference in temperature and humidity between UPAF and non-UPAF areas (or at different distances way from UPAF areas) can be calculated (24 data points per monitoring site per day) and the daily means for the months can be averaged. Again, data should preferably be collected for a one year period to account for all the different seasons. This will result in T for each month of the year (n=24 data points per month).

ΔThour, month, UPAF type = $(T_{\text{without UPAF}} - T_{\text{with UPAF}})$ hour, month, UPAF type
ΔHR hour, month, UPAF type = $(HR_{\text{without UPAF}} - HR_{\text{with UPAF}})$ hour, month, UPAF type

For each UPAF type, the hourly temperature range at which the influence of UPAF on temperature and humidity during specific hours of the day is greatest can be determined using measurement data. Since daily variation is determined for different months during the year, hourly variability, or stability, in temperature and humidity trends during the year can also be assessed.

Hourly and monthly differences in ΔT between the measured UPAF types and the representative non-UPAF type need to be assessed as to their overall impact on mitigating temperatures. These can be determined quantitatively using spreadsheets such as Microsoft Excel and a statistical student T-test with a significance level of 5% (http://www.youtube.com/watch?v=D_j-0gNh6Kw) or other statistical software. The effect of other UPAF site characteristics can also be determined by using data collected from the site and applying other more advanced statistical tests such as regression or multivariate statistical analyses.

Users of this manual need to determine what is and is not locally "significant" as this can be a statistical value or policy goal. The definition of significance in turn will determine what statistical test or performance standard (UPAF surface area or vegetation cover goal, formulation of a UPAF ordinance, level of financial investment in UPAF) will be used. For example a target of 10% green area land use cover can be set or the WHO target of 10-15 m^2 of green area/inhabitant used. Alternatively, specific human comfort levels or acceptable ranges can be defined for a specific situation.

Temperature effects on human comfort

Thermal comfort represents the temperature at which a building (residential, commercial, industrial, etc.) does not require energy-based cooling or heating to achieve a level of human occupant comfort (see Figure 3.). Thermal comfort does not solely depend on temperature, but also humidity, on heat flux/transfer into a building and on other factors that are directly or indirectly related to temperature as discussed earlier. The presence of UPAF can also influence humidity levels. Specific air temperatures coupled to higher humidity will have a larger impact on thermal comfort as compared to the same air temperatures with lower levels of humidity. It should be noted that humidity levels are not taken into account in the calculations below, as it is assumed in this study that UPAF impacts on humidity levels will be too small to have significant impacts on thermal comfort. This assumption however needs to be assessed in future studies.

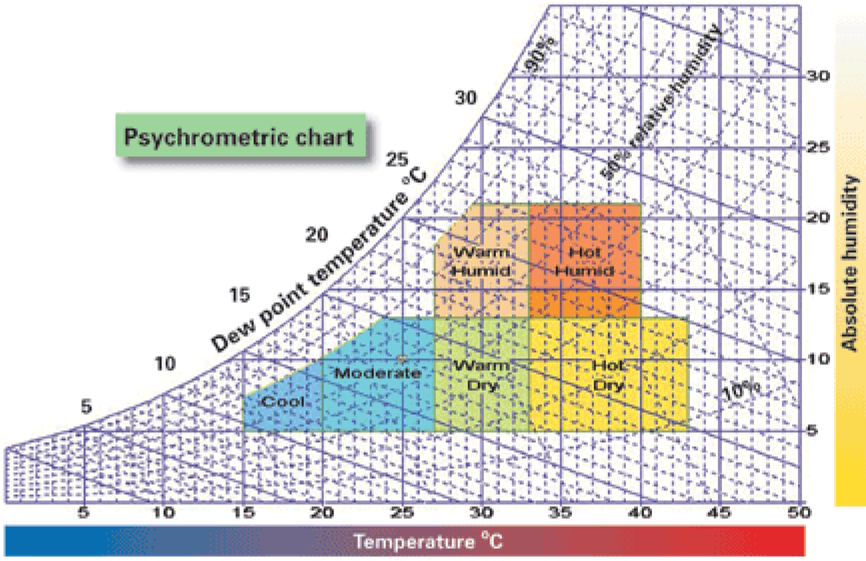


Figure 3. Psychrometric Chart (Source: http://www.kuulpads.com/charts.html).

"Degree days" is a method that can be used to determine the difference between air temperature and thermal comfort temperature; which depends on specific locations such as tropical versus arid regions, and individual living and working environments (office versus rural agriculture worker). This results in two conditions:

1. Heating degree days (HDD) in which thermal comfort temperature (Tb) is greater than actual air temperature (Ta) with (HDD = Tb – Ta), which represent the degrees needed to obtain thermal comfort using energy-based heating
2. Cooling degree days (CDD) in which thermal comfort temperature is less than air temperature (CDD= Ta – Tb) or the degrees that need to be lowered or cooled to achieve comfort using refrigerated based cooling.

Cooling and heating degree days for each month and for different UPAF and non-UPAF temperatures can be determined using:

$$CDD_{\text{month without UPAF type}} = \sum (T_{\text{hour, day, month}} - T_{\text{comfort}})$$
$$T_{\text{hour, day, month}} - T_{\text{comfort}} = Dh$$

Dh: degree hour

∑: The sum of the first to last day of the month or,

$$CDD = 0 \text{ if } T_{\text{hour, day, month}} \leq T_{\text{comfort}}$$
$$CDD \neq 0 \text{ if } T_{\text{hour, day, month}} \geq T_{\text{comfort}}$$

Or

$$HDD_{month,\ UPAF\ type} = \sum (T_{comfort} - T_{hour,\ day,\ month})$$

Dh: degree hour
∑: The sum of the first to last day of the month or,

The sum of the first to last day of the month or,

$$HDD = 0 \text{ if } T_{hour,\ day,\ month} \geq T_{comfort}$$
$$HDD \neq 0 \text{ if } T_{hour,\ day,\ month} \leq T_{comfort}$$

Degree day ranges can then be used to determine a range of different thermal comforts for different UPAF and non-UPAF areas. As previously mentioned, human comfort (T comfort) is affected by temperature and humidity and is context specific. For example in the tropics it is set at 26.2C, in Denmark at 25.7C, and in the United States at 25.6C according to:http://aldebaran.feld.cvut.cz/vyuka/environmental_engineering/lectures/L10%20Thermal%20Comfort.pdf. Emmanuel & Johansson (2006) report that thermal comfort is set at 26.1–26.7 C in Colombo, Sri Lanka and 27.2 C in Singapore, 26 C in Calcutta, India and 31.1 1C in Roorkee, India.

The degree days need to be calculated to determine the effects of UPAF and non-UPAF areas on cooling and heating needs, and related impacts on energy use.

These effects can be calculated using the following indicator:

$$\Delta CDD_{month,\ UPAF\ type} = (CDD_{withoutUPAF} - CDD_{withUPAF})_{month}$$
$$\Delta HDD_{month,\ UPAF\ type} = (HDD_{withUPAF} - HDD_{withoutUPAF})_{month}$$

Alternatively the Relative Strain Index (RSI): (t-21)/(58-e); t= temp; e vapour pressure (partial pressure of the water in the gas phase when at equilibrium)according to Emmanuel & Johansson (2006) can also be used to estimate thermal comfort as well as the International Standards Organization 7730-193 calculator (see also http://www.healthyheating.com/solutions.htm, or http://www.cbe.berkeley.edu/comforttool/).

As indicated before, a direct relation between air temperature and inside building temperature is assumed, while in reality this relation is influenced by building types, materials, densities etc. Calculations thus have to be adjusted for different building types. Inside temperature monitoring can be sued to do so. Inside and outside temperature monitoring done in Kesbewa, Sri Lanka for example showed that differences in outside temperature are higher than differences in inside temperature, showing that heat transfer is indeed dependent on building materials and structures used.

Effects on energy use, costs and emissions

Once heating and cooling demand are calculated, energy demand can be used to determine monetary expenditures or savings as well as emissions related to increased or avoided energy use.

Based on degree days and particularly degree hours, the cooling or heating energy needs of a building can be determined. According to Szokolay (2004) this energy need can be estimated by multiplying the degree hours by the building's conductance (Specific heat loss rate)

$$Ch = Dh \times q$$

where:
Ch= Heating/cooling requirement (Wh)
Dh= Degree hours (˚C h) (T hour, day, month– T comfort = Dh)
q =Building conductance (W/K)

If we assume that degree hours (Dh) are equal to degree days (DD) x 24, then the building's conductance value (W/K) is equal to 0.024 kWh for every degree day. Thus every $\Delta DD_{month, UPAF\ type}$ give the additional kWh that will be used in the case UPAFs would not present to reduce temperatures.

Depending on the energy source used and the respective emissions factors for each kWh used (such emissions factors can be found in international literature), the amount of emissions related to additional kWH needed can be calculated and compared for area with and without UPAF. Similarly related energy costs can be calculated.

It should be noted that emissions and energy demand and costs for cooling and heating days will vary according to the energy source used. Often electricity is used for cooling, while natural gas or fuel-wood may be used for heating. The calculations thus have to be adjusted for specific energy sources used (like fuel, hydro-powered electricity, gas or fuel-wood for example) and their specific emissions factors and prices for every city.

Scenarios for project climate change

With project climate change and increase in ambient air temperature, the number of cooling and heating days for such future situations might be also calculated, as well as related energy use, emissions and energy costs.

Box 2. Temperature monitoring for UPAF and non-UPAF areas with use of thermometers in Rosario, Argentina.

In Rosario, air temperature was monitored in different UPAF and non-UPAF areas during the period august 2013-august 2014. In Rosario, with its temperate climate, presence of UPAF statically lowered the UHI in summer with corresponding projected decreases in cooling days and energy demand for cooling. At the same time, vegetative tree cover in winter hampers soil radiation to reach the surface and building walls, and resulted in increase in heating days and thus energy demand for heating.

Comparing air temperatures with thermal comfort, the total average cooling degrees needed for the one year monitoring period (august 2013-august 2014) for all non-UPAF areas added up 482 as compared to 338 for all the UPAF areas in the city. The average total heating degrees for non-UPAF areas added up to 434 for the one-year period, as compared to 711 for all UPAF areas. However, and especially with projected temperature increase in the coming 25 years, future differences in cooling demand will become larger than differences in heating demand. Also considering that cooling energy in Rosario is principally based on electricity, while heating energy comes from a variety of sources (including natural gas, wood and electricity), emissions related to each Kwh of cooling energy are expected to be higher than for each kWh of heating energy used, although this has to be confirmed by further studies. With recent (December 2013, Rosario summer period) electricity cuts due to extreme cooling energy use related to high temperatures, findings of the study are relevant for municipal decision-makers.

Findings also interestingly illustrate that temperature effects of a small urban agricultural garden (1620 m2) where similar to that of larger garden and public park of 2 and 3 ha. respectively. This would imply that including small UPAF areas in new or upgraded housing and neighbour settlements would already bring desired effects on human comfort levels. Larger UPAF areas may however have temperature impacts on building areas located at farther distances away from the UPAF areas, as compared to smaller UPAF areas. Again, further study is needed to confirm such hypothesis (Coronel, Feldman and Piacentini, 2014).

REFERENCES

American Meteorological Society, 2000. Heat islands. Glossary of Meteorology 2nd edn. Cambridge University Press, Boston, USA

Amiri R., Wen, Q.H., Alimohammadi A., Alavipanah S. K., 2009. Spatial-temporal dynamics of land surface temperature in relation to fractional vegetation cover and land use/ cover in the Tabriz urban area. Iran. Remote Sensing of Environment. 113(12). 2606-2617. doi:10.1016/j.rse.2009.07.021

Cavan G., Lindley S., Jalayer F., Yeshitela K., Pauleit S., Renner F., Gill S., Capuano P., Nebebe A., Woldegerima T., Kibassa D., Shemdoe R., 2014. Urban morphological determinants of temperature regulating ecosystem services in two African cities. Ecological Indicators. 42:43-57.

Coronel, A., Feldman S., and Piacentini R., 2014. Efecto de agricultura y forestación urbana y peri-urbana sobre la mitigación y adaptación al cambio climático: impactos sobre la temperatura. Report prepared for RUAF Foundation and CDKN.

Di Leo, N., Escobedo, F., Dubbeling, M., forthcoming. The role of urban green infrastructure in mitigating land surface temperatures in Bobo-Dioulasso, Burkina Faso. Submitted to Springer publications.

Emmanuel and Johansson, 2006. Microclimate in hot-humid Colombo, Climate Research 30: 189–200.

Lin. B. S. and Lin. Y. J., 2010. Cooling Effect of Shade Trees with Different Characteristics in a Subtropical Urban Park. Hortscience. 45(1). 83-86.

Oke. T. R., 1987. Boundary layer climates (2nd ed.). Methuen, London, Great Britain

Oliveira. S., Andrade. H. and Vaz. T., 2011. The cooling effect of green spaces as a contribution to the mitigation of urban heat: A case study in Lisbon. Building and Environment. 46(11). 2186-2194. doi: 10.1016/j.buildenv.2011.04.034

Shashua-Bar L., Pearlmutter D., and Erell E., 2009. The cooling efficiency of urban landscape strategies in a hot dry climate. Landscape and Urban Planning. 92(3-4). 179-186. doi:10.1016/j.landurbplan.2009.04.005

Szokolay, S., 2004. Introduction to Architectural Science: The Basis of Sustainable Design Elsevier-Architectural Press. Great Britain

University of Cambridge and ICLEI, 2014. Climate change: implications for cities. Key Findings from the Intergovernmental Panel on Climate Change Fifth Assessment Report. Available from: http://www.iclei.org/fileadmin/PUBLICATIONS/Brochures/IPCC_AR5_Cities_Summary_FINAL_Web.pdf

Appendix 1. Field temperature-humidity data monitoring form

Enumerators								
GPS Coordinates								
Location								
Plot ID								
UPAF Type	Year	Month	Day	Hour	Minute	Temperature	Humidity	Notes (% clouds, rain, sun, specific tree characteristics)

Appendix 2. Solar radiation shield specifications for the digital thermo-hygrometers

A radiation shield should be constructed to protect the thermo-hygrometer from direct solar radiation and rainfall. The following shield is proposed which is easy to construct, resistant to outdoor conditions (heavy rain and strong winds, hail, intense solar UV radiation, dust deposition on the instrument, etc.). Its materials (mainly wood) can be easily obtained in different parts of the world. The construction method also allows for easy access to the instrument for periodic surveillance, cleaning, data extraction, etc.

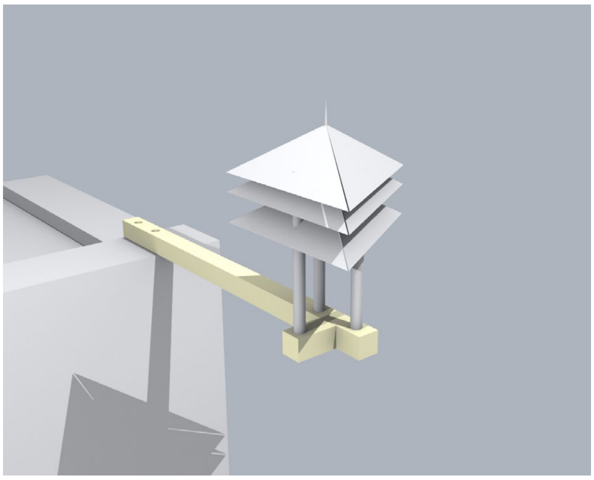
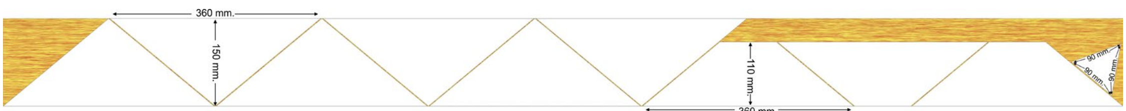


Figure 1.The solar radiation shield.

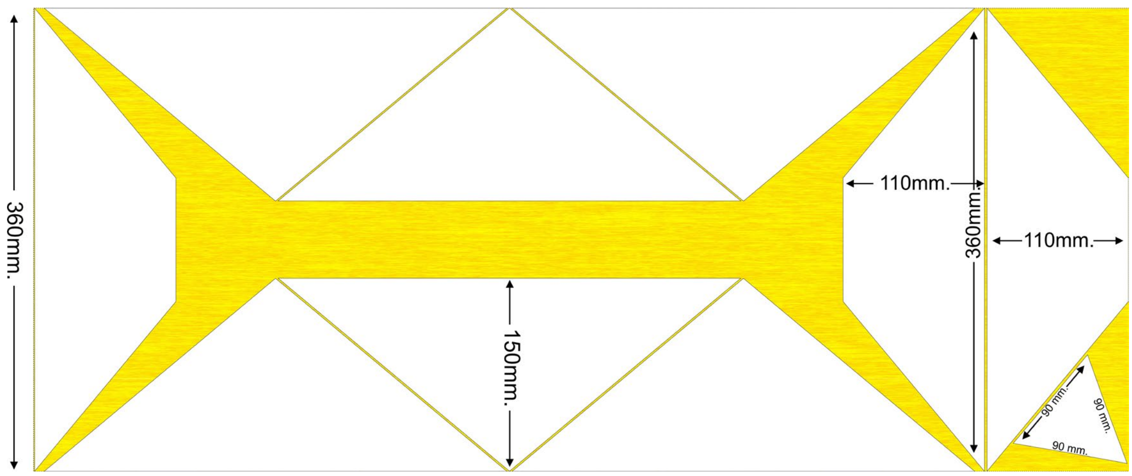
Construction

1. The topmost triangular-pyramidal roof: is made from 3 wooden triangles that are each 36 cm x 15 cm in size and approximately 8-12 mm or ½ inch thick. At the highest point on the roof, a screw or nail must be placed upwards in order to detract birds from nesting on the shield. The following 2 patterns can be used to obtain the necessary triangular-pyramidal roof sections:



Pattern Version 1: A piece of wood of 1912 mm x 150 mm (total area of 2868 cm²).

Pattern Version 2: A piece of wood of 852 mm x 360 mm (total surface of 3067 cm²).



2. The second triangular-pyramidal roof- is made from 3 wooden triangles that are 36 cm x 15 cm in size and 8 -12 mm thick. A hole needs to be drilled in each triangle, in order to place the corresponding support pole. As the roof is in an inclined position, the hole also has to be at an angle that is dependent on the angular position of the roof with respect to the horizon. This second roof needs to be located at, and a distance of, 4 cm from the topmost roof. Note: this particular roof is to reduce the sensor's heat gain due to solar radiation.

3. The base triangular-pyramidal roof- is also made with 3 wooden triangles that are 36 cm x 15 cm in size and 8- 12 mm thick. However, different from the topmost and second triangular-pyramids roofs, this base roof has a triangular, horizontal wood surface placed at the top at 5 cm below the extreme point of the base triangular-pyramidal roof (Figure 2). This horizontal platform is made to avoid potential contact between the sensor-data logger that will be placed above this base.

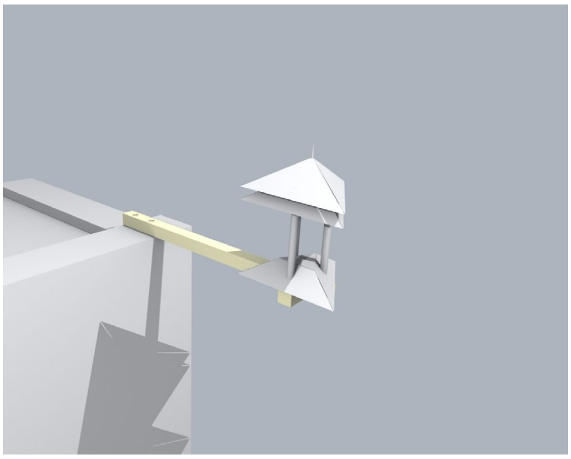


Figure 2. Horizontal wood surface at the top at 4 cm from the radiation shield's base triangular-pyramidal roof.

Thermo-hygrometer sensor-data logger (unit)

The unit should be placed between- not touching either - the second and third pyramidal roofs at a height of 1.5 meters above ground surface. Note again that the second pyramidal roof is 4 cm below the topmost shield and bottom base pyramidal roof is 5 cm below in the second pyramidal roof.

The unit's access to the temperature sensor is a small hole located the top of the unit that needs to be exposed to air. This hole is made since it needs to interact with the sensor so it must be placed in a "reversed" position (pointing downwards). By doing so, dust and water condensation will not be deposited on the sensor. The unit is then fixed to the 3 vertical supports using very resistant strings or white colour wires that are resistant to outdoor conditions (Figure 3). The USB wire (used to download data on the computer) should be connected to the instrument to avoid oxidation of the unit's contacts. Alternatively, the port can be sealed to avoid water and condensation from damaging the unit.

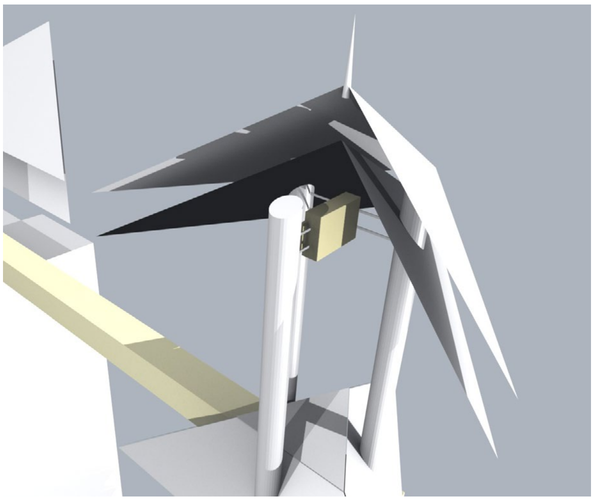


Figure 3.Location of the unit inside the radiation shield.

Shield supports
The shield supports consist of 3 vertical supports made of wooden broomsticks; one broomstick is sufficient for these 3 supports (Figure 3). The vertical supports should be about 2 meters in length assuming it is placed in the soil to a depth of about 40 cm. The upper part of each support needs to be cut at the same angle as that at which the topmost roof is placed. The bottom part must be cut horizontally.

In addition, one horizontal, 1 meter long (or more) wooden support pole is needed to separate the unit from the building walls (Figure 4) as these walls if heated by solar radiation can affect temperature. A small part of this horizontal support needs to be located in a perpendicular position in order to place one of the broomstick supports. Alternatively a vertical support of this same material can be used if the unit is placed away from a building, for example in the middle of a garden, below a tree, etc.).

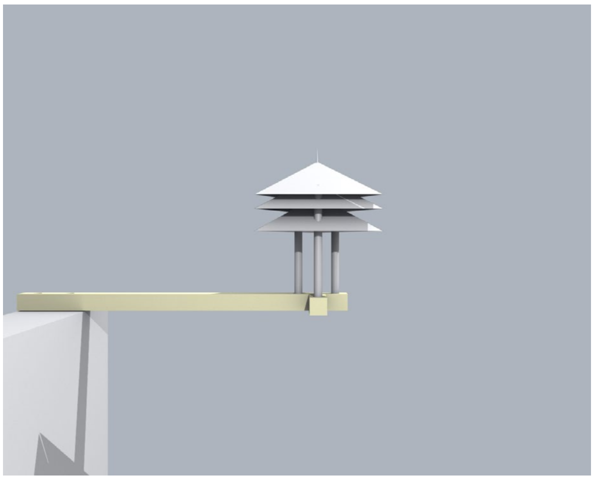


Figure 4.Location of the shield away from building walls.

Accessories and required building materials
Paint: The solar radiation shield need to be painted with several layers of bright, white paint since Ultra-Violet radiation can easily damage the unit and the shield's wood.
Carpenters' glue: Needs to be used with care to glue the 3 triangles together to form a pyramid as well as to fix the 3 pyramids to the 3 supports. If necessary, the glue can be mixed with sawdust in order to seal the slots between triangle-pyramids and to fix the vertical supports to the 2 roofs and the 1 base. This applies also to the slots between the verticals and horizontal supports.
Screws or nails: In order to secure the supports and triangles, screws or nails can also be used but care is needed since these can become oxidised. Rust proof material or several

layers of paint could also be used.

Unit maintenance
Several HOBO units are designed for use in indoor or outdoor conditions. Units with rapid response time, regular monitoring (every 15 min.), temperature ranges and resolutions can be found. When temperature changes are within 1˚C/hour, the less expensive HOBOS 23-001 and HOBOS 23-003 can well be used. Excessive moisture and mould/mildew can cause errors in measurements. Therefore, the units should be checked and maintained so as to not allow dust and water to settle on the instrument. If the monitoring site is susceptible to excessive insect activity, mosquito netting can be used to enclose the solar shield. The netting might affect wind flow and measurements might be slightly affected.

Calibration
Calibration and validation of temperature equipment should be used to correct for measurement error. For example in Rosario, Argentina, a temperature calibration procedure detected problems in the HOBO U23-001 used for the temperature and humidity measurements and conventional Maximum -minimum (max-min) thermometers. The variability and differences between outdoor equipment and a calibrated thermometer in a highly urbanised setting is shown in Figure 5. As seen, all HOBO equipment followed the same trends and presented mean and maximum temperature differences in the range of 0.5 ˚C while the reference thermometer presented lower values. In this case, this indicates that all units have a systematic error that needs to be corrected using a calibration technique.

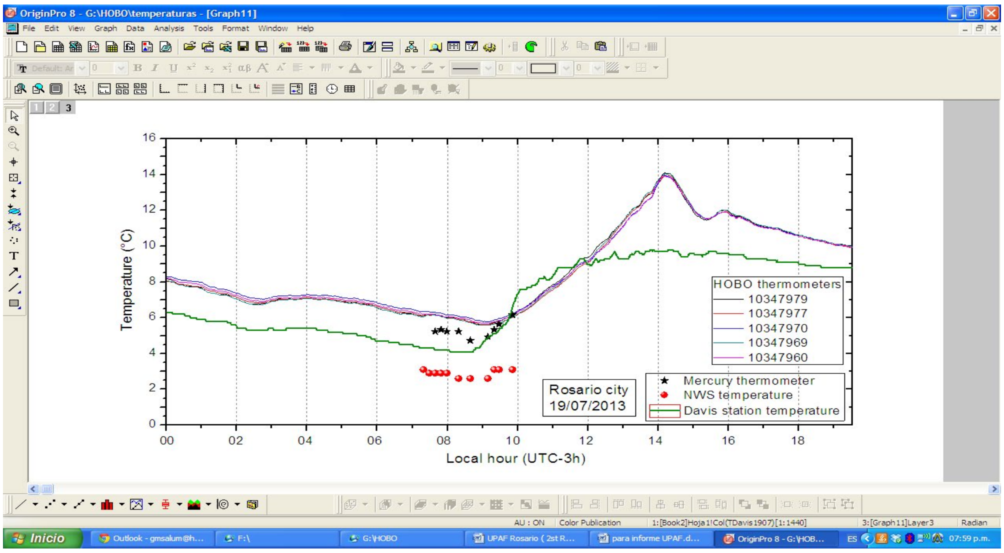


Figure 5. Time variation of the ambient temperatures measured in Rosario, Argentina on the 19th of July 2013 with: a) Five HOBO U23-001 thermometers (see details in the Figure), b) Davis station sensor (green thick line), c) mercury thermometer (black star) and d) National Weather Station (NWS) thermometer (red circle). The National Weather Station is located in Fisherton International Airport (near Rosario), the Davis station sensor in the Urquiza Park near the Paraná River, while the HOBO equipment and mercury thermometers were located about 1.9 km away from Urquiza Park.

One commonly used calibration method for temperature measurement using both conventional stem thermometers and thermistor based equipment (HOBO data loggers) is to use freezing (0°C) and boiling water (100°C) baths at sea level, adjusted for atmospheric pressure (See http://hyperphysics.phy-astr.gsu.edu/Hbase/Kinetic/vappre.html#c5 for adjusting boiling points to atmospheric pressures). First, place mineralised water and ice in a Styrofoam container with enough water to cover the ice, but not so much that the ice floats. Insert the bulb of the thermometer so that it is below water level, up to the immersion mark. Mix the ice water regularly at least every minute taking care not to damage the thermometer. Temperatures need to be measured every minute until a constant temperature is reached. Second, place boiling water in a separate Styrofoam container. Insert the thermometer, carefully mix the boiling water every minute and follow the same steps as for the ice-water mixture measurements. Use a magnifying glass for more precise temperature thermometer measurements, if possible up to 0.1˚C or even in smaller units. Make at least 3 constant freezing and temperature measurements to develop a calibration or correction curve using the following equation:

$$T_{actual,corrected} = a + bT_{measured.}$$

The resulting curve and its adjusted R^2 are specific to the thermometer and should be used for their calibration. For example, the following measurements and data (Table 1) are an example regression curve developed for a Mercury Thermometer (DIN 085). Using the measurement data the calibration/correction curve has the following form:

$T_{corrected} = 0.24791 + 0.98811^{*}T_{DIN085}$ and an adjusted $R^2 = 0.99$. (For specific steps and procedures see: http://infohost.nmt.edu/~chem/images/pdf/draltig/chem109_fall2011/ThermoCalibration.pdf)

Table 1. Measurements using a reference thermometer and the Mercury (decimal) thermometer DIN 085

Treference (°C)	**TDIN 085 (˚C)**	**Difference (˚C)**
10	9.9	**0.1**
20	20	**0.0**
30	30	**0.0**
40	40.3	**-0.3**

Weather station measurements located less than 12 kilometres from the data logger units can also be used to validate temperature measurements and data using calibration curves as shown in the previous example.

Data on temperature (T) and relative humidity (RH)

The units should be located so that temperature-humidity data are collected at 1.5 meters above the ground surface and that air is allowed to freely circulate around the unit. However, they need to be shielded from direct sunlight and high velocity winds. In cases where measurements cannot be collected at 1.5m above the surface, temperature will need to be corrected using a generalised thermal gradient correction of 0.65ºC/100m (Standard atmosphere: increasing height decreases temperature). Note: this correction can vary according to the time of day, season, climate, geographic location, but can be considered reasonable for these types of measurements.

Each plot will be measured and sketched for characteristics such as location, coordinates, data collectors, vegetation covers and types, buildings, etc site using field data collection form in Appendix 3.

When collecting temperature and humidity measurements, time and site-specific observations should be noted in the field form provided in Appendix 1. It is recommended to take photos for each site.

Appendix 3. Plot data information sheet

The temperature monitoring measurements must be collected at plot centre. Get permission to access the property if necessary (from resident or property owner). Locate the plot centre and plot boundaries using aerial photographs and/or maps and by use of GPS. Use a separate sheet per plot. Each plot will be given a unique 3 digit ID number (the same number as used in Appendix 1):

1. Plot ID number:
2. Type of UPAF or non-UPAF:
3. Date: date of data collection
4. Field staff: name of field staff that collected the data
5. Location of the plot/GPS coordinates of the centre of plot (in decimal degrees or Universal Transverse Mercator):
6. Plot sketch, landmark and pictures: Make sketch of the monitoring point/plot, measure distances and indicate orientation (using a compass) to landmarks and fixed objects (such as buildings and other permanent structures). Take pictures of the plot from the plot/point to north/south/west/east; Give digital photo file same number as the plot ID
7. Plot contact information: Include name, address and –if available- telephone number of the contact person to access the plot (if such permission is required)).
8. Describe plot vegetation and other ground covers. Estimate: 1.Overstory tree, 2 understory shrub and 3. ground covers (black areas on the scale represent the specific cover type that you want to estimate; see categories below while the white areas represent the sum of other covers on the plot). A tree is a woody plant or palm with a diameter at breast height (dbh; stem diameter at 1.4 m above the ground surface) greater than 2.5 cm;

   8.1 Overstory plot tree cover (%): the amount of tree crowns covering the plot. When looking upward from within the plot, one will either see tree canopies or open sky areas between the canopies. This datum is the proportion of the sky that is obscured by tree crowns within the plot and will range from 0 to 100%. Tree cover can come from trees located outside the plot; so plots not containing trees could still have tree cover. Record to nearest 5% unless cover is minimal. If amount less than 5% are present; entering 1,2,3%, etc. is acceptable.

   8.2 Plot Shrub Cover (%)* –Understory shrubs (Woody plants or palms less than 2.5 cm DBH and taller than 30cm in height). Look down from above. Record to nearest 5% unless cover is minimal. If trace amount present; 1, 2, 3%, etc. is acceptable. Any woody vegetation (Tree/palm or shrub species) with a DBH = 2.5 cm is considered to be a tree, for measurement purposes. If DBH does not equal 2.5cm, then the plant is considered a shrub. If woody plant does not reach 30 cm height, then that plant is considered herbaceous cover. The tree/palm's centre of the stem or pith must be within 11.3m (plot boundary) from plot centre for it to be considered inside the plot.

   8.3 Ground cover: the % various ground surface cover types on the plot. Within the plot, various materials will cover the ground (trees and shrubs are considered separately; tree stems as a ground cover are ignored). Record to nearest 5% unless cover is minimal. If trace amount present; 1,2,3%, etc. is acceptable. The sum of these proportions above must add to 100% per plot. Use the following cover classes as given in Figure 1 and the plot sketch to visually estimate the certain percentage of:

   - Buildings, asphalt and cement: % of plot area covered by buildings and pavements of asphalt and cement as well as other pavements made of brick, flagstone, gravel, etc.
   - Bare soil: % of plot area covered by soil that is heavily compacted due to human or animal activity (e.g. used for parking, markets, walking area, grazing area etcetera).
   - Leaf litter, mulch, compost: % surface litter and organic matter
   - Cultivated cropland: % of plot area in use for cultivation of crops other than wet rice. Land planted with non-woody trees (banana, papaya, etcetera) is included

in this category shrub cover).

- Grass/vegetation: % of plot used as pasture, meadow or lawn or other natural vegetation.
- Rock fragments: % brick, blocks, cobbles, etc.
- Water: % of plot area: water bodies, including pools, ponds and wetlands with surface water

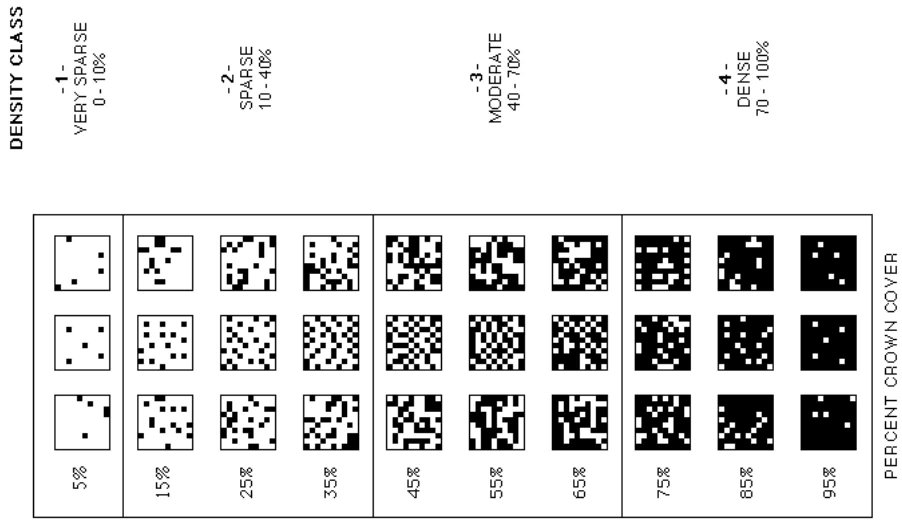


Figure 1. Percent cover and density classes .

FIELD FORM

PLOT ID	DATE AND TIME	CREW	GPS CORRD	PHOTO#	
			X Y	N NE	S SW

Plot address =
Notes:

Plot sketch:

UPAF Type		**Crop Types**	**Tree/ Palm cover (%) Tree Species: Number of trees*:**	**Number of trees in the following DBH sizes: <2.5 cm 2.6-10 cm 11-20 cm 21-30 cm 31+ cm**	**Woody Shrub cover(%)**		**Other**	
Ground cover (Sum to 100%)	% Building	%Cement and pavement	&Bare Soil	%Leaf litter, mulch, compost	% Crops	% Grass/ Veg.	%rock frag.	%water

*Number of trees (>= 6m. tall) that are located within 18 meters of the selected residential buildings.

November 2014

This document is an output from a project funded by the UK Department for International Development (DFID) and the Netherlands Directorate-General for International Cooperation (DGIS) for the benefit of developing countries. However, the views expressed and information contained in it are not necessarily those of or endorsed by DFID, DGIS or the entities managing the delivery of the Climate and Development Knowledge Network, which can accept no responsibility or liability for such views, completeness or accuracy of the information or for any reliance placed on them. This research was funded by The Climate and Development Knowledge Network (www.cdkn.org).

RUAF Foundation
RESOURCE CENTRES ON URBAN AGRICULTURE & FOOD SECURITY