499: Use of simplified tools to evaluate thermal comfort in urban spaces in the teaching experience

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Abstract

The role of physical elements and interactions among them, which influence people behaviour and liveability conditions in urban spaces, is usually not correctly evaluated in environmental urban design in the Italian School of Architecture.
The performance of basic physical elements in urban spaces – morphology, materials and the effect of environmental forces – are mainly designed to support functional and visual needs and requirements, while environmental comfort is often underestimated.
Students attending the Master degree course "Environmental Design" at the Faculty of Architecture "Architettura e Società" - Polytechnic of Milan – implemented methods and tools to evaluate environmental performances in urban design, mainly focusing on thermal comfort needs. Some of these students use the same methodology for their thesis.
This paper shows a work for a thesis describing four different squares in the dense central area of Milan having comparable characteristics such as morphology, e.g., shape and orientation materials.
Microclimatic measurements have been done during a summer day, while comfort conditions have been calculated through the COMFA+ model.

Keywords: thermal comfort, field survey, teaching, evaluation tools

1. Introduction

Urban spaces appreciated by users from different point of view, not only aesthetic, are perceived as places belonging to their everyday life, and nowadays represent a very urgent requirement. It means that in our schools we have to introduce again typical Mediterranean architecture models, suitable for ensuring high standard liveability in our urban spaces.
The public space use is a contribution to the urban life and it is strongly related to the environmental liveability.
The improvement of that will need innovative approaches in order to reconfigure the complex system of the environmental needs.
The general urban climate worsening has highlighted these needs, felt by all citizens from children to eldest ones.
This paper introduces a teaching experience related to the environmental design course.
This final year course is aimed to students nearing in completion of their Master degree, and with a good experience in conventional urban and architectural design.
The synthetic design approach guides students to practise the implementation of control of shapes, materials and spatial relationship at different scales, and constantly checking by calculation tools and 2D/3D models at different levels of the problem.
Indeed urban space design promotion goes also through evaluation tools allowing designers to foresee performance, in terms of thermal, acoustic and luminous comfort, i.e. polysensorial environmental comfort of urban spaces in the different phases of the design process.

2. The implemented methodology

2.1 The environmental design course

The short (60 hours) course is articulated in two modules; one is devoted to bioclimatic approach to Architectural Design and the second focus the attention on bioclimatic approach to small urban scale.
As the course is scheduled on the second semester from March to June, it is possible to evaluate the environmental performance of the selected open spaces in the summer climatic conditions.
The course is oriented to evaluate summer comfort conditions in outdoor urban spaces which are commonly used in Italian context especially for settled activities like reading, meeting between friends, consuming food and drinks.
We usually take into consideration different typologies of urban spaces around the Faculty, a pedestrian street, a urban park, where the historical entrance of the Politecnico is located, small urban squares in the City, covered spaces, patios.
The first day approaches two topics.
The first is an introduction to the concept of "liveability" in the urban spaces and to the role of physical elements in urban space design.
The second topic focuses on how the urban structure and its elements define the specific microclimate of the urban space, with particular focus on the radiant field.
The elements are morphology, paving and façade materials, shading devices, vegetation and water.

The second day is devoted to refresh concepts and tools already known by the students from previous courses, but now they are asked to focus in the context of the urban space.
Basic knowledge on thermal comfort and indicators are extended to the outdoor spaces (i.e. the Thermal Balance, the modified PMV and PET).
The second part is devoted to evaluation tools for outside thermal comfort.
The main focus is on tools and simulation methods with particular reference to one simplified tool: Comfa+.
The work of the students starts in the third day, with the field survey in three selected places.
Students already know the meteorological physical climate variables (i.e. air temperature air and radiant temperature, air velocity, radiation and humidity) conventionally used in environmental design, but they do not have knowledge of the effects of solar radiation on different morphology, materials, vegetation and water in term of surface temperature and radiant field.
They are guided to verify the variations of microclimate variables due mainly to the effect of solar radiation (wind in Milan is very weak).

Fig 1. The day of the field survey with the students, in a outdoor place near to the Polytechnic

This kind of field survey represents the knowledge background of the site before students work on environmental microclimatic improving site design without giving much attention on aesthetic aspects.
At the next lesson the students come with all the data set down, and at this time they are able to read for every site how the comfort conditions change in relation to parameters variation.
The students can select the site to design and often they decide to work on sites already analysed in other courses, and they are able to visit the place in order to observe the physical characteristics and the sun/shadow patterns, as well as the activities and the people behaviours, in terms of their favourite paths, the most frequented areas, an so on. It means that the students are now able to roughly describe the microclimatic performances and the thermal comfort conditions of the site.
In parallel to the microclimatic measurements students have to answer to a sort a questionnaire based on thermal comfort perception and they repeat it every time the situation and location changes.

	Location:	real state	Air velocity	water	shadow	materials
1	Sun exposition (S= sun, O= shadow					
2	How long have you been outdoor? (min.)					
3	clothes (Clo)					
4	Activity (Met)					
5	Air temperature (measurement)					
6	Relative humidity (measurement)					
7	Air velocity (measurement)					
8	Surface temperature (measurement)					
9	How do you feel in this moment? Very cold(-3) Cold (-2) A bit cold (-1) Neutral (0) warm(1) hot (2) very hot (3)					
10	Do you feel in comfort? (YES=1 NO=2)					

Fig 2. The questionnaire used by the students in the field survey relating to the comfort perception and microclimatic measurements, sun/shade position, clothes and metabolic rate, comfort perception and measured data.

2.2 The thesis

One of the students decided to analyse in detail the topic of the course for her thesis.
The aim of the thesis was to evaluate thermal comfort conditions of four squares in the dense central area of Milan, by trying to point out the effect and the weight of several parameters.
In particular the four squares were seen both in terms of morphology -orientation and dimensional ratio between paving and facades- and materials (albedo).
Materials should be considered in terms both of albedo and heat capacity. During the day the albedo is the main parameter affecting the paving or façade thermal performace. On the other hand if we considered the nocturnal comfort conditions, i.e. without solar radiation, the heat capacity would be the most important factor. We consider only daytime and the lack of detailed information about urban elements. For this reason we only take into account the albedo.
The field survey analysed two squares at the same time and was carried out in two days at the almost the same conditions, at three different stage of the day e.g., morning, lunch time, afternoon. The four squares were selected in order to get the possibility to compare each parameter, such as orientation, square shape and the paving and buildings colour, one by one.
Pio XI and Mercanti squares, on the NW-SE axis, are both rectangular with very long and with narrow shape. The first one (18x69x19) can be described as a square with dark colours, where else the second one (20x64x16/18m) is light coloured.
San Fedele square(26x68x16m), on the NE-SW axis, has a rectangular shape with light coloured.
Affari square (62x51x24m), on NS axis, has almost a square shape with dark colours. The

analysis results were compared each others in order to provide a clear frame of microclimate differences produced by the square features.

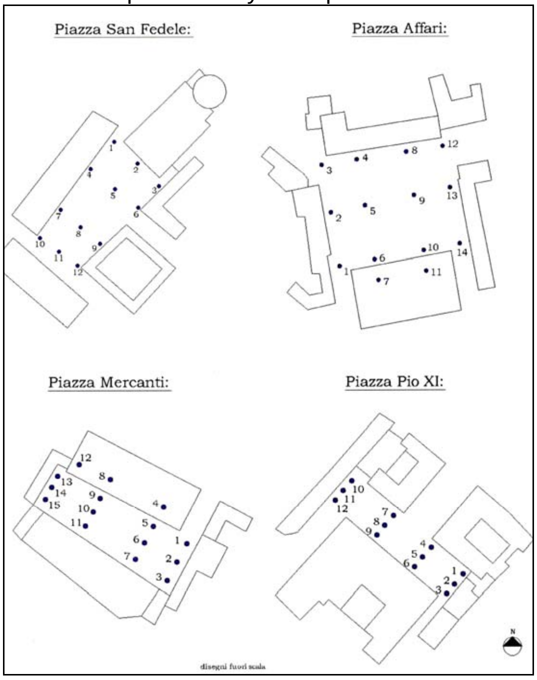

Fig 3. The four squares analysed and all the points that have been measured during the field survey

By identifying relevant variables it is possible to calibrate the design actions oriented to improve microclimate as well as comfort conditions, especially for those areas characterized by walking through and situated people activities.
The analysis was done with the same criteria used during the course. First step people movements, paths and favourite sited areas.

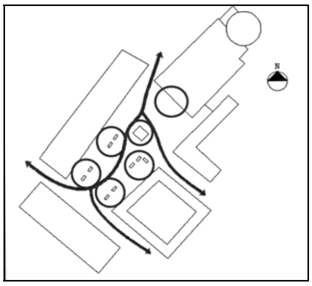

Fig 4. Favourite paths and sitting areas of the users of San Fedele square

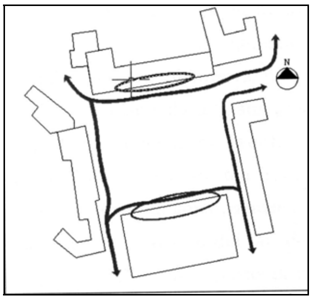

Fig 5. Favourite paths and sitting areas of the users of Affari square

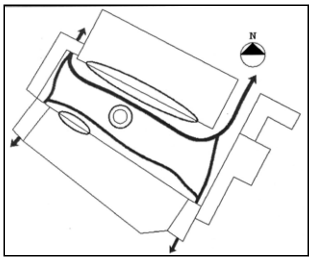

Fig 6. Favourite paths and sitting areas of the users of Mercanti square

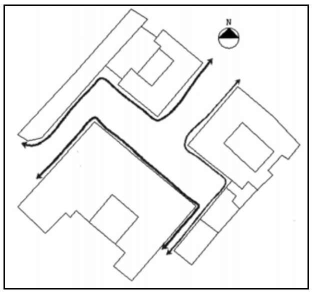

Fig 7. Favourite paths and sitting areas of the users of Pio XI square

Second step microclimate measurements, e.g. air and surface temperature, relative humidity, wind speed in some points in every square, combined with others such as beam and diffuse solar radiation, from the near microclimatic station of the Università Statale and with the shadow pattern in three moments of the day.

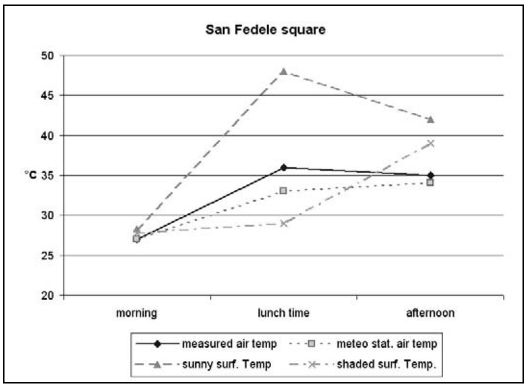

Fig 8. Differences in air temperature measured and from meteorological station, and of surface temperature in sunny and shaded areas in San Fedele square

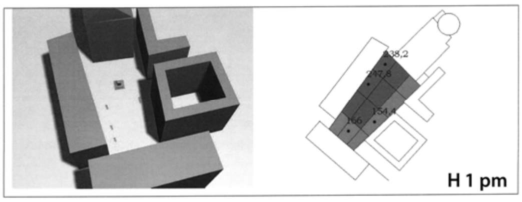

Fig 9. Shadow pattern and BT at 1 p.m., in different areas of San Fedele square

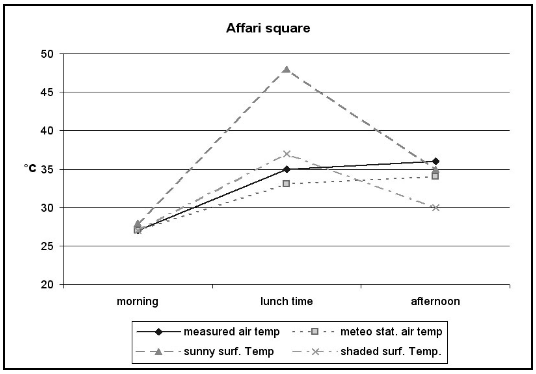

Fig 10. Differences in air temperature measured and from meteorological station, and of surface temperature in sunny and shaded areas in Affari square

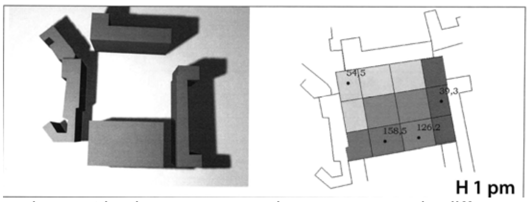

Fig 11. Shadow pattern and BT at 1 p.m., in different areas of Affari square

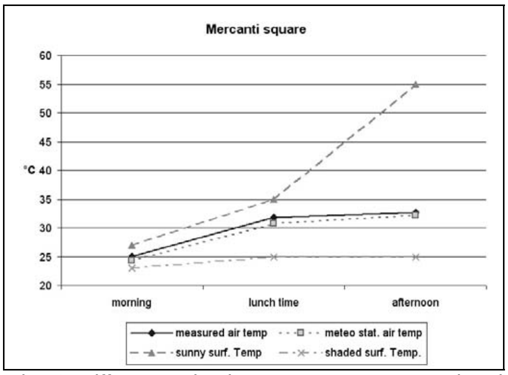

Fig 12. Differences in air temperature measured and from meteorological station, and of surface temperature in sunny and shaded areas in Mercanti square

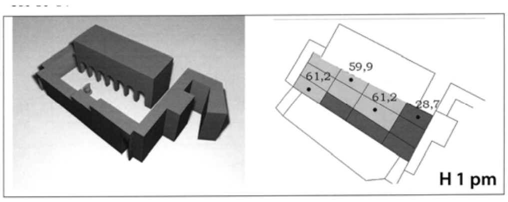

Fig 13. Shadow pattern and BT at 1 p.m., in different areas of Mercanti square

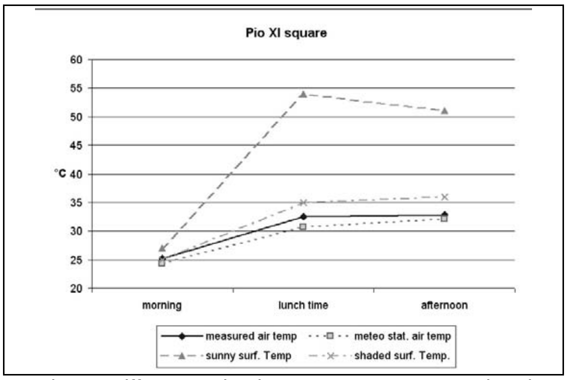

Fig 14. Differences in air temperature measured and from meteorological station, and of surface temperature in sunny and shaded areas in Pio XI square

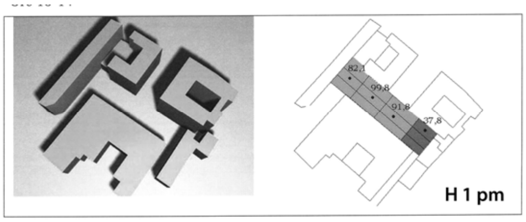

Fig 15. Shadow pattern and BT at 1 p.m., in different areas of Pio XI square

Third step the evaluation of the physical characteristics of paving and façades, especially materials, in particular thermal conductivity (w/mK), emissivity and albedo.

Table 1: Physical characteristics of materials in San Fedele square

Materials	**Thermal conductivity**	**Emissivity**	**Albedo**
Marble	2	0.93	0.7
Stone	1.4	0.9	0.55-0.75
Cobbles	1.3	o.9	0.55-0.75
Travertine	1.5	0.9	0.55-0.75

Table 2: Physical characteristics of materials in Affari square

Materials	**Thermal conductivity**	**Emissivity**	**Albedo**
Porphyry	1.54	0.93	0.9
Stone	1.4	0.9	0.55-0.75
Bricks	0.8	0.93	0.26-0.3
Asphalt	1.23	0.9	0.1-0.2
Marble	2	0.93	0.7

Table 3: Physical characteristics of materials in Mercanti square

Materials	**Thermal conductivity**	**Emissivity**	**Albedo**
Stone	1.4	0.9	0.55-0.75
Bricks	0.8	0.93	0.26-0.3
Plaster	0.8	0.9	0.58
Marble	2	0.93	0.7

Table 4: Physical characteristics of materials in Pio XI square

Materials	Thermal conductivity	Emissivity	Albedo
Stone	1.4	0.9	0.55-0.75
Porphyry	1.54	0.93	0.9
Plaster	0.8	0.9	0.58

All this data have been later used to calculate comfort conditions with the COMFA + model.

3. The COMFA+ model

The COMFA model, originally proposed by Brown and Gillespie (Brown, 1986; Brown, 1995), has been developed for landscape evaluation and is one of the simplest model for outdoor comfort evaluation based on the energy balance approach. The comfort sensation is evaluated trough the value of the energy budget TB.

Table 5: comfort sensations and energy budget

Energy budget	Sensation
TB<-150 W/m^2	very cold
-150 W/m^2<TB<-50 W/m^2	cold
-50 W/m^2<TB<50 W/m^2	comfort
50 W/m^2<TB<150 W/m^2	hot
TB>150 W/m^2	very hot

The energy balance equation, giving the person thermal balance TB, is:

$$TB=M+K_{abs}+L_{abs}-(Conv+Evap+TR_{emitted})$$

where:

- M is the net metabolic rate;
- K_{abs} is the solar radiation absorbed;
- L_{abs} is the thermal radiation absorbed;
- Conv is the heat lost by convection;
- Evap is the heat lost by evaporation;
- $TR_{emitted}$ is the emitted thermal radiation.

In order to evaluate comfort conditions in urban spaces an evolution of the original model has been developed at the department BEST of the Polytechnic of Milan, as described in [1].

The main difference between the landscape and the townscape is the presence of buildings. Buildings may intercept, absorb and reflect solar radiation, obstruct a part of the sky view and emit thermal radiation. All these effects are taken into account within the COMFA+.

Solar radiation absorbed by a person in the landscape K_{abs} may be calculated as:

$$K_{abs}=(1-A_p)(T+D+S+R)$$

where:

- A_p is the person albedo;
- T is the beam solar radiation incident on the person;
- D is the diffuse solar radiation incident on the person;
- S is the diffuse solar radiation reflected on the person by objects in the sky, like trees;
- R is the global solar radiation reflected on the person by the ground.

In order to take into account the effects of buildings on solar radiation, a new view factor between the person and the building, named BVF_i has been introduced.

The buildings and the ground reflect both the diffuse and the beam radiation incident on them. Depending on their orientation and on the time, a given fraction of the building surface will be exposed to the sun. Moreover the buildings may in case shade partially the ground.

For this reason it's necessary to define the solar radiation reflected by buildings on the person, considering in particular the sunlit fraction respectively of the building and of the ground area. The solar radiation absorbed by a person in the urban space becomes:

$$K_{abs}=(1-A_p)(T+D+S+R+B)$$

The view factor between a person and a building (BVFi) and the ground view factor GVF may be derived by the view factors diagrams by Fanger (Fanger, 1970).

The view factor between a person and a rectangular wall, and the floor in an enclosure, have the same behavior indeed.

The thermal radiation absorbed by a person in the landscape L_{abs} is:

$$L_{abs}=\varepsilon_p (V+G+F)$$

where:

- ε_p is the person emissivity;
- V is the thermal radiation emitted by the sky incident on the person;
- G is the thermal radiation emitted by the ground incident on the person;
- F is the thermal radiation emitted by the objects in the sky incident on the person.

In a urban space, equations have to be modified to take into account the new view factors, as it was done for the solar fluxes.

Moreover, the thermal radiation emitted by the buildings and incident on the person, named U, must be added:

$$U=\Sigma_i BVF_i \cdot \sigma \cdot \varepsilon_{bi} \cdot T_{bi}^4$$

where:

- ε_{bi} is the i building emissivity;
- T_{bi} is the i building absolute temperature. The Thermal radiation absorbed by a person in the urban space becomes:

$$L_{abs}=\varepsilon_p (V+G+F+U)$$

4. The results from the thesis

Environmental performance evaluation of an urban space consists in reading the combination of parameters.

All of those define the specific microclimate as well as comfort conditions perceived by users, and environmental performance is calculated through the only one comfort indicator.

Even if lots of points were measured, in the paper only one point is taken into account, usually the central one.

The first comparison was made between Mercanti square and Pio XI square. The two squares were found similar between them in terms of dimension and orientation, but different in materials and colours. Except for the morning, the comparison shows that, Mercanti square, even dough it has lower surface temperatures, it has higher thermal balance. This is due to the highest albedo value which generates a greater reflected solar radiation quantity on walking or seated people.

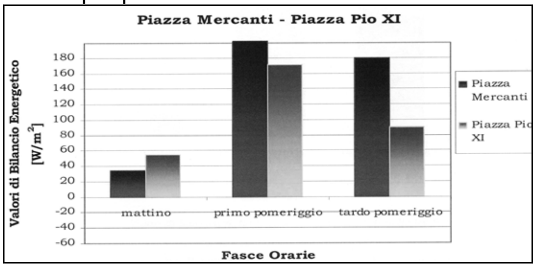

Fig 16. Comparison between thermal balance of Mercanti square and Pio XI square

By comparing the two light coloured squares, Mercanti and San Fedele which is slightly different in dimension and orientation, it comes out that San Fedele square receives and then reflects on the users a greater amount of solar radiation increasing the thermal balance.

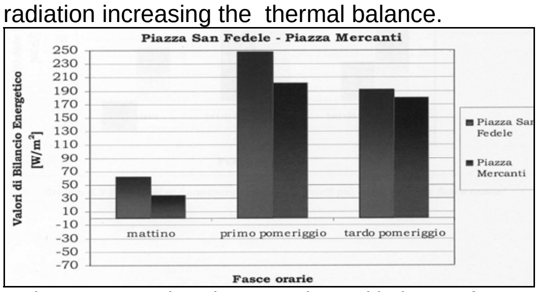

Fig 17. Comparison between thermal balance of San Fedele square and Mercanti square

The comparison Affari square and Pio XI one is referred to the morphology. The two squares are both dark coloured but really different in dimensions and orientation. Affari square is almost twice Pio XI square, and the dimensional ratio (H1/D, H2/D) is quite different too. By this comparison it comes out that Affari square has a better thermal behaviour, because only a smaller portion of the surfaces gets the solar radiation, in the morning and in the afternoon. Moreover in the afternoon in Pio XI square there a lot of “trapped” solar and thermal radiation, that can be more hardly re-emitted to the sky vault. In midday, when the solar radiation is the highest in the sky, the greater contribution to the thermal balance is due to the beam solar radiation. For this reason Affari and Pio XI squares have a similar thermal balance.

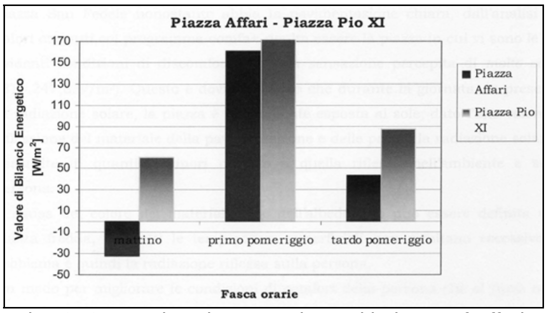

Fig 18. Comparison between thermal balance of Affari square and Pio XI square

The comparison between Affari and San Fedele squares shows clearly a big difference between them. This difference is due to both morphology and materials, and it shows worse thermal balance in San Fedele square.

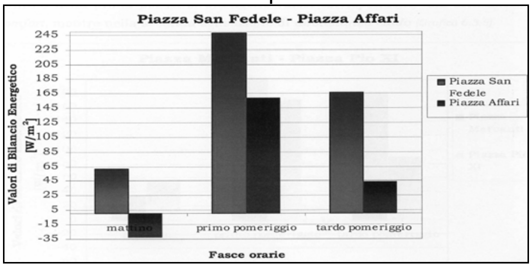

Fig 19. Comparison between thermal balance of Affari square and Pio XI square

5. Conclusion

With this thesis, based on the field survey of open spaces, it is possible to evaluate the importance of each parameter on comfort conditions. The limit of this approach is that not all the real variables can be considered. It would be necessary to analyse more urban spaces having some similarity, with at least one comparable parameter. It should be possible thus to evaluate the influence of the vegetation and the water, more deeply the differences of materials, the traffic, and so on. Such evaluations will be done in the future with much more analysis and field surveys, eventually combined with thermal simulation in dynamic regime. However the result analysis of the four squares suggests some strategies that can be carried out to improve the microclimate. Nevertheless the project thesis following this evaluation would be the chance to carry out improving measures with the aim to reduce negative effects of some specific parameters. Another important aspect is that in this way students are able to size the strategy and then the comfort evaluation represents a check of their working in progress. It is very important, after the field survey and the use of simplified tools to calculate thermal comfort, that students become confident with microclimate variables. These aspects in combination with the urban space use, will guide the design process.

6. References

1. Angelotti A., Dessì V., Scudo G., (2007), “The evaluation of thermal comfort conditions in simplified urban spaces: the COMFA+ model”, in: *Proceedings of the 2nd PALENC & 28th AIVC Conference*, Crete.
2. Bacchi C., *Valutazione del benessere negli spazi aperti. Quattro casi studio a Milano*. Thesis at Polytechnic of Milan, 2006-2007
3. Brown R.D. & Gillespie T.J. (1986). Estimating outdoor thermal comfort using a cylindrical radiation thermometer and an energy budget model. *Int. J. Biometeorology*, vol. 30, no.1
4. Dessì V., (2007), *Progettare il comfort urbano. Soluzioni per un’integrazione tra società e territorio*. Esselibri, Sistemi Editoriali, Napoli
5. Grosso M., Peretti G., Riardi S., Scudo G., (2005) *Progettazione ecocompatibile dell’architettura*, Esselibri, Sistemi Editoriali, Napoli