Chapter 2
Keynote Chapter—Bioclimatic Design in Architecture: A Research and Didactic Experience

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Abstract  This essay intends to outline a synthetic excursus on my research, didactical and consultancy experience in the field of bioclimatic design for architecture. The aim is to highlight the milestones of my academic and professional career with regard to interrelationships between the bioclimatic approach and the design process in building design as well as landscape and urban design.

2.1 Academic Experience

2.1.1 Theoretical Background

Before entering the research team formed by Lorenzo Matteoli, a professor who was a pioneer in Italy for the integration of environmental and bioclimatic issues in architecture, at the Institute of Built Environment of the School of Architecture, Polytechnic University of Turin in 1977—an action which initiated my experience on the bioclimatic issues—I had been contract researcher since 1974, and teaching assistant since 1972, for Leonardo Mosso. He was Professor of Architectural Composition and Social Architecture as well as the main Aalto’s scholar in Italy and founder of the still active Aalto’s Institute. This activity was permeated by a ‘structuralistic’ approach, based on the philosopher Pareyson’s ‘Theory of formativity’ (Pareyson 1954) as well as an ecological and social attitude towards the field of architecture in its widest meaning including historical compound renewal and regional planning. The combination of Pareyson’s aesthetic theory, for which a work of art needs to be analysed and perceived in its autonomous and intrinsic values out of the influence of its author’s historical context, with the ecological approach to the analysis and planning of the territorial transformations, had facilitated my conversion to the bioclimatic field in architecture. Mosso’s ecological thinking was pioneering for that
time within the University faculty and rather consistent with the ’68 student movement, which I experienced fully since my second year of study in 1967, when the school of architecture in Turin was occupied. During those years of protest—I have to highlight that it was very peaceful in our School at that time, and only later on it would have changed to violent actions, sometimes leading to rioting against the police and the Government—there was a lively exciting debate on the urban development model driven by unregulated industrialisation and land use, and causing environmental and social distress. A few years later, the awareness of an incumbent ecological crisis became apparent in the first of a series of UN assemblies dealing with the environment(1).

In addition, that students’ movement set the foundation for a radical transformation of the method of teaching and learning in the architecture field, from a traditional dogmatic strictly disciplinary approach to a multi- and interdisciplinary one, by which theoretical knowledge, social aspects, and professional practice would have been interconnected.

A witness of that unrepeatable period was an exhibit-roundtable held in Bologna in October 1972, which saw the participation of people from any part of the world and all sort of fields—moviemakers, theatre actors, artists, sociologists, politicians, musicians, scientists, teachers, architects, farmers, citizens. My contribution was a written text on the role of the architectural designer as an intellectual figure influencing the ongoing social and territorial transformation (Grosso 1972). My main point-of-view was to emphasize the need for overcoming both the prevailing ideological and utopian approaches through a science-based methodological and structuralistic one, implying the involvement of all actors in the incumbent revolutionary (so we thought to be at that time) social and territorial transformation of our environment.

This approach was my reference line in both didactical and research activities I carried out in collaboration to Leonardo Mosso from 1972—just after been graduated—to 1974, when I won a 4-year contract research position at the School of Architecture. During that period, my activity was more autonomous and was characterise as well by a collaboration with Prof. Ciribini, one of the founder of Architectural Technology as a transformation of the previous “Construction Components discipline. In that period, my research activity was strictly interconnected to a professional practice as a free-lance architect. This experience had been focus-sing on ecological and social territorial analysis and planning as well as on a historical urban recovery project(2). However, even in the professional activity I always tried to apply a ‘scientific’ methodological approach and, reversely, I have taken the impact on the real social and territorial context into account in my research and didactic experience.

1The 1972 UN summit in Stockholm set for the first time rules and recommendation for the recovery of the Earth environment, endangered by unregulated urban sprawl and industrial development.

2In 1973, just two years after graduation, I won, together with my colleagues Guido Laganà and Carla Barovetti, the first prize in a competition for the restoration planning of the historical centre of the city of Vimercate, in the Milan Province. That prize represented the beginning of a professional appointment by the Municipality of Vimercate, which lasted up to 1980, having as a objet the completion of an executive planning framework for the refurbishment of all historical centre as well as a detailed project related to a specific urban block of that area.
2.1.2 **Origin of the Bioclimatic Approach**

After the above-described experience, I entered Matteoli’s research team, where there was an exciting and growing development of activities linked to both the National Plan for Energy, just implemented at that time after the ’73 oil crisis, and the lab for testing air infiltration windows performance founded by Matteoli himself. Various projects were developed since, leading to national seminars and conferences\(^3\) as well as publications. Amid the latter, it is worth to mention the following: two books on the interrelationships between energy and buildings, authored collectively (Matteoli et al. 1981a, b); an article on the development of windows’ frame industry (Grosso 1980); a contribution in a special issue of a Journal on the integration of solar energy in school buildings (Matteoli et al. 1981c); a paper for a Conference on the application of renewable energy sources in the Pantelleria Island (Matteoli et al. 1981d).

Within that environment, two personal lines of research were present in a nutshell: the first regarding solar radiation, the second related to air infiltration and natural ventilation. Both topics would later been developed in a wide spectrum of aspects, all connected to their interrelationships with building and urban design as well as regional planning and landscape architecture. Key objectives of my research work have been, since the beginning, modelling and simulate the effects of those two main climate factors—solar radiation and air movement—on the built environment as well as developing simplified methods and tools to support the building, urban and landscape design processes towards a bioclimatic approach.

In addition, even after the conclusion of my practice as an architect and urban planner in 1984, all my research work have been always integrated to a professional activity as a consultant of architecture and engineering offices. This have been carried out in relation to my competence sectors, in particular, energy efficiency in buildings, natural ventilation control, passive ventilative cooling, solar energy applications, and use of sustainable materials. The most significant of these experiences are described in the last part of this contribution, after the description of the main line of research just following.

2.1.3 **Research on Solar Aspects and Didactic-Related Tools**

**Dynamics of shadowing**

My first approach to the solar-related research was a study on the dynamics of shadowing cast by any obstacle on a horizontal surface. An article published on Solar Energy (Appelbaum and Bany 1979) was the base of this study, and its aim

\(^3\)One of the most interesting event was the Sogesta Summer School, where experts from various Universities and ENEA (an Agency for Alternative Energy sources, re-founded from the previous Nuclear Energy Agency)—including prof. Federico Butera, as the coordinator of the task group “energy for limited resources’ areas”—gathered to discuss about the new perspective of the Energy National Plan as well as to practice an experimental study workshop on a bioclimatic project.
was to develop a method to draw shadows, cast from a peg on a horizontal surface at any hour of the day and day of the year, while changing location, i.e., latitude and longitude of the given place. It was a method analogous to the one applied for constructing a sundial, but referred to a horizontal instead of a vertical surface, and with a different aim: not time measuring, but modelling the effect of obstacles in a built environment on the effective solar radiation of a surface at a given time and location.

The outcome of this study was my first published book (Grosso 1982). This included an original approach, never developed before: a calculation routine, made using a pocket calculator by Bruno Caudana—a brilliant just graduated student at that time—able to simulate the horizontal projection of the shadow cast by a peg high one unit of measurement at any given time and location (Fig. 2.1). Through this calculator was possible to draw the hyperbolic-shaped shadows’ daily profiles for each of the twelve monthly-reference days of the year at the local time of any location in the Earth, by imputing latitude, longitude and hourly angle. Its output considers the solar local time, including the effect of the equation of time (‘analemma’) (Fig. 2.2). Using the graphical shadows monthly profiles was then possible to draw the hourly shadow field cast by a solid parallelepiped obstacle on the horizontal surface by considering its envelope surfaces as made by the sum of infinite vertical parallel segments with the same dimension and position as the peg of the profiles. An evolution of that method, developed mainly for didactical purposes, allowed for the graphical elaboration of the shadow cast by an obstacle on any vertical surface intercepting that projection. This was made based on the horizontal shadows profiles, by a technique overturning the triangle peg-beam-shadow from the vertical to the horizontal plane and again on the vertical plane containing the receiving surface.

An algorithm was further developed to calculate the area of the shadow projected from a solid parallelepiped obstacle to another parallel surface, such as the one of a building façade intercepting that projection. This simplified calculation method was presented at an international energy-related congress (Grosso and Pacini 1984).

**Solar irradiation at territorial scale**

A calculation programme at territorial scale was developed in collaboration to the CSI—a Piedmont Regional Centre for Information Services—with the aim of mapping the daily monthly-averaged solar irradiation of mountain land areas, taking their surfaces slope orientation and tilt into account. As a reference case study, the Val Chisone valley was considered. Monthly maps with zoning classification of solar irradiation were produced (Fig. 2.3) and shown at an exhibition-congress (Grosso et al. 1984). Methodology and results were presented in papers for both a Journal (Grosso 1984) and an International Conference (Grosso et al. 1983).

The main use of such a tool would have supposed to be for regional framework planning of building development location at Municipality scale, based on solar access criteria. However, this approach was too advanced for that time, and it had no
impact on the urbanisation plans elaborated since by the Municipality administrations of Piedmont.

**Solar residential buildings**

The most concrete and effective application of the above mentioned technique on solar dynamic shadowing was on the EC co-funded Project UPSE comprising the design and constructing 457 solar dwellings in 17 locations on Piedmont. The aim of this project was to demonstrate that it would have been possible to reduce consistently the space heating energy consumption in multi-storey residential buildings, which used current construction technology, by applying solar active and passive systems as well as increased insulation with respect to the standards of that time. In particular, a mechanical ventilation system with supplied air heated by solar collectors was installed, in addition to sunspaces and, in a few cases, solar storage walls (Trombe-Michel type). Main result of this project was an energy saving for space heating ranging from 35 to 55% of the consumption of similar residential buildings, which did not have the systems implemented by the project.

The shadow dynamic method was used for placing the passive systems on the South-oriented façades of the buildings, in such a way that they would not be on the shadow of sur-rounding solid obstacles during the winter season, hence exploiting solar radiation as much as possible. An example of this application is the façade design of Grugliasco’s building (Fig. 2.4), which was based on the analysis of the

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**Fig. 2.1** Flow-chart of the procedure developed on a Texas Instrument Calculator for calculating the shadow relative length at a given location and time (Grosso 1982, p. 88)
Fig. 2.2 Daily profile of the shadow cast by a peg on winter solstice at a location of Latitude 45°N (Grosso 1982, p. 40)

Fig. 2.3 Map and 3-D view, representing classes of solar radiation for March 21 on Val Chisone (Piedmont, Italy) (Grosso 1984)
shadows cast in the winter solstice by surrounding buildings, as represented in the graphical representation of Fig. 2.5.

A didactical tool: the Heliodon

While graphical shadowing analysis methods, as the one above described, are very useful for bioclimatic design purposes, so as the computer-aided simulator developed commercially after the early '90 s of the XX Century—see, as an example, the ECOTECH model, later incorporated by the AUTOCAD software—, a physical model as the Heliodon is far more effective for didactical aims. As Lechner wrote (2009), “Experience has shown that although computer models are powerful, physical models are still better. It is well known that a picture is worth a thousand words, but it is less well known that a model is worth a thousand pictures”.

There are three types of Heliodons (Lechner 2009, Appendix I): Sun Simulator, Sun Emulator, and Tabletop. The first simulates the sunrays by lamps installed at regular intervals on 180°-span parallel metal circular arches, tilted as to simulate a specific latitude, although it can be adjusted for a range of latitudes plus or minus 5° from the constructed latitude. At the centre of these arches, a plane is located to place a scale model. The second is similar, but the lamps are installed on a 360°-circular span parallel arches, which can rotate along the diameter to simulate latitudes from equator to the pole. The third has a fixed lamp, reflecting light on a parabolic foil in order to simulate the parallel solar beams, and a movable separate table composed of a plane, which can rotate to simulate hourly angle and tilt to simulate latitude and solar declination, on which a scale model is placed.
After having supervised a thesis on solar design tools, within which the student developed an ingenious Leonardo’s-like tabletop Heliodon (Fig. 2.6), built in wood, I decided to design and have constructed a prototype of tabletop Heliodon, in 1987. It was based on a technical drawing table, a tool that had been in use by all designers using graphical output until the CAD software replaced it in any offices. This was used for a thesis, but remain abandoned during my study period abroad.

Following that application, this tabletop Heliodon was replaced by a more complex tool of the sun simulator type, design and made built by Valentino Manni, a technician at that time of the DINSE Department.

The tabletop Heliodon was composed of two following main elements.

(a) A concave circular aluminium plate with a parabolic section, in the focus of which a lamp projected light towards the inner surface of the plate in order to reflect light beams as much parallel as possible, within a radius able to include the normal projection of the table on which the models were paced.

(b) A round wooden table (Fig. 2.7) supported by a steel structure, characterised by a motorised mechanism allowing three types of movements: (1) vertical tilt to simulate Latitude from 0° (pole) to 90° (equator); (2) adjustment of this tilt to
consider the sun declination angle, i.e., the day of the year; (3) a 180° rotation around a vertical axis to simulate the hourly angle (solar hour of the day).

The sun simulator Heliodon (Fig. 2.8) is still working in the LaSTin (Laboratory of Technological System Innovation) as a didactic support for the courses of both the Master Degree Programme on Architecture for a Sustainable Design and the Bachelor Degree in Architecture, at the Polytechnic University of Turin.

It is composed of the following elements.

(a) A 3-m long steel arm rotating 180° for hourly movement around a motorised hub, which, in turn, can tilt vertically to simulate latitude and sun declination angles.

(b) A concave circular Aluminium plate with a parabolic section with a lamp on its focus, similar to the one described above of the tabletop Heliodon, but with a special finishing of the inner surface for an optimal light beams reflection; it is attached to the top extreme of the arm with the concave plate facing the table on which the model is placed.
Amid others, this sun simulator Heliodon has been used in the course Environmental Technological Design of the Bachelor Degree Programme in Architecture, English curriculum, which I was initiated in 2015 and taught until my retirement (November 2018). My former teaching assistant, Giacomo Chiesa, have held this
course since then. In particular, the Heliodon has been used as a test exercise for checking the location of virtual building units and outdoor activities in the design of a students’ residential building, in relation to optimal winter solar access and summer solar control. Pictures of the hourly shadowing conditions of the proposed initial project solution within the built context, in the two reference days—winter and summer solstices—for the latitude of Turin, were compared to the shadows simulation made using a CAD software. This comparison helped students not only to validate the simulation analysis, but also to better understand, through the 3-D close-to-reality Heliodon visualisation, the dynamics of the solar irradiation on the envelopes of the designed buildings as well as on the outdoor spaces of the project lot. This check allowed for changing the initial design solution depending on the critical points highlighted by the Heliodon results (Fig. 2.9).

A calculation tools for solar active systems
Consistently to my proneness towards modelling the effects of the main climate factors on building and urban design, back home after the international COMIS experience (see below), I developed, with the collaboration of a brilliant student whose final Master Degree thesis I supervised—Luca Raimondo—an EXCEL sheet for calculating the energy contribution of active thermal and Photovoltaic solar systems to the total load of a building. This tool (SolDim), which had been upgraded several times during the years, is based on monthly average temperature and solar radiation data—direct and diffuse—to be inputted for a given location. The energy calculator uses simplified algorithms for space heating in stationary regime as well as parametric values for the thermal losses through the envelope (for the main 4 orientations and the horizontal roof), and DHW and electricity needs dimensioning.

SolDim was applied to both my didactic activities and the consultancy practice, when appropriate.

Fig. 2.9 Test of the dynamic shadowing for a preliminary design layout on the sun simulator Heliodon at LaSTin: winter solstice (left, 10 a.m.; right, 2 p.m.) (picture by the author)
2.1.4 Research on Airflow Aspects and Didactic-Related Tools

Window draught elimination
My first airflow-related research experience was the scientific and technical direction of a project funded by an oil-based utility Company in Rome, under the general responsibility of Lorenzo Matteoli. That project aimed at evaluating the energy saving effect of the reduction of draught through windows in an existing school building, taken as a reference case study representing a large majority of the existing buildings at that time (1983–85). Those buildings had a rather high air infiltration rate in winter due to old wooden frame windows without weather-stripping. The retrofit operation consisted on the application of silicon mastic along the joint between any operating window sash and its frame, using a special technique in order to avoid the bonding between the two.

This technique consisted on the placement of silicon mastic on the stop bead of the frame and a light gluing scotch tape on the corresponding rabbet bead of the sashes (Fig. 2.10). Hence, the windows are kept closed for 24 h, allowing the mastic to fit any impervious gap between sash perimeter and frame. Once the silicon mastic hardened, windows could be opened thanks to the tape, which avoided the two wooden elements bonding. The result was a perfect fitting built-in weather-stripping, much more effective than a commercial strip with constant section.

The school building had a traditional hot water heating system with a central boiler and wall cast-iron radiators in any classroom. To demonstrate the effect of draught reduction, a heat-flow meter was installed on the boiler and measurements were taken before and after the above-described operation. The outcome was an energy saving of approximately 20% of the total consumption for space heating. The methodology and results of this project were published in a scientific international Journal (Grosso et al. 1985) as well as in a research summary book (Grosso 1985).

The C.O.M.I.S. experience
As a consequence of the published results on the draught elimination project, I was invited in 1987 by Helmut Feustel to join an year-long international workshop—Conjunction Of Multi-zone Infiltration Specialists (C.O.M.I.S.)—to be held at the Lawrence Berkeley Laboratory of the University of California, Berkeley, CA, USA, starting from September 1988. I was able to accept this invitation and participate to the workshop due to the possibility, foreseen by the Italian law for senior researchers, of spending a sabbatical period abroad of a maximum of two years. I exploited all this possibility and, in addition, I got a research grant by the CNR (National Research Council) and a financial contribution by an Italian windows manufacturing Company, allowing for an extension of 6 months of my stay in California.

The aim of the COMIS workshop was to develop a Multizone infiltration and ventilation model, the first of the kind, through the contribution of top International experts in the field, coming from various Countries: Helmut E Feustel (USA), Francis Allard (France), Viktor B Dorer (Switzerland), Eduardo Rodriguez Garcia (Spain), Magnus K Herrlin (Sweden), Liu Mingshen (Peoples Republic of China), Hans C Phaff (Netherlands), Yasuo Utsumi (Japan), Hiroshi Yoshino (Japan). The
results of the COMIS workshop were published by the Air Infiltration and Ventilation Centre (AIVC), with the support of the International Energy Agency (IEA), Energy Conservation in Buildings and Community Systems Programme (Feustel et al. 1990, 1993).

My specific contribution was the development of a module of the COMIS model related to wind pressure distribution around buildings. Wind pressure coefficients are an essential input of any multizone ventilation programmes as well as related energy simulation software. Up to the date of the COMIS workshop, such an input were usually taken from tables of façade-average values, dependent on wind angle and building aspect ratios, or needed to be measured on purpose for any specific project by wind tunnel tests or calculated using CFD simulations. Both latter solutions are very time consuming and costly and need expert competences not usually present in a building design office even today.

Instead, my aim was to develop a procedure to calculate automatically wind pressure coefficients (CpCalc), which did not exist at that time and could be applicable to any project in a simple and straightforward mode. The intent was to supply a general
tool to support both scientists and building/urban designers in getting a necessary input for assessing the effect of air movement on air infiltration as well as the potential of natural ventilation for IAQ and passive cooling. CpCalc was deemed to be part of the COMIS model under development, but also to be run stand-alone. It would have been lately linked to the main international energy simulation programme: DOE—the ‘father’ of EnergyPlus—TRNSYS, and ESPr. A flow-chart of the programme is shown in Fig. 2.11.

Before developing the routines CpCalc is composed of, using the FORTRAN 77 language, I analysed thousands of pressure coefficients data from wind tunnel tests on rectangular shaped models, with the intent to perform on them fitting regressions. This was necessary to correlate Cp values to several wind environmental and building parameters, which characterise any design context and process: terrain roughness, plan area density, average height of surrounding buildings, wind incident angles, relative building height, frontal and side aspect ratios, and element positioning on the facades. For this purpose I had to select wind tunnel test Cp databases with results

![Flow-chart of the CpCalc programme](image-url)
for modular models with a range of values as wide as possible. The Cp databases from the following authors were then chosen: Hussein and Lee (1980), Akins and Cermak (1976) (Fig. 2.12). In addition, the equation for calculating surface-averaged pressure coefficients for low-rise buildings by Swami and Chandra (1987) was used as a reference evaluation tool in same cases. The methodology used, the flow-chart and structure of the algorithms developed, and all results from the regression analyses were presented in an AIVC workshop, held at LBL, and lately published, after an

Fig. 2.12 Allocation of the reference data sets in the CpCalc programme development
extensive and thorough peer review by three reviewers, on the International Journal Energy and Buildings (Grosso 1992).

**European Projects using CpCalc**
Thanks to the development of CpCalc, I had the opportunity to participate as a unit research responsible to the following EC-funded projects: PASCOOL, AIOLOS, and PRECIS.

PASCOOL (PASsive COOLing of buildings) was co-funded by the European Commission, DG XII, Joule II Non Nuclear Energy Programme, Sub-programme: Energy Conservation and Utilisation. Its main objective was to develop a model for simulating the energy performance of passive cooling systems in buildings. The project was coordinated by M. San-tamouris and A. Argiriou of the University of Athens, Physics Department and was carried out from 1992 to 1995.

My contribution was related to the development of an upgraded version of CpCalc (CpCalc+), which was translated in VISUAL Basic Language and was completed with the correlation of wind pressure data on roof (Figs. 2.13 and 2.14). This was made possible by wind tunnel tests performed at the INETI Laboratory in Lisbon (Marques da Silva and Saraiva 1994).

My contribution in PASCOOL was included in the sub-group Climate—coordinated by Servando Alvarez—whose main topics were: (a) procedure and evaluation of methods for generating TMYs (Typical Meteorological Years) and their application to selected European localities; (b) characterisation of environmental heat sinks (sky temperature depression, psychrometric, sol-air temperature, ground temperature); (c) wind effect—pressure distribution around buildings; (d) performance of natural cooling techniques (underground pipes, direct and indirect evaporative cooling, radiative cooling).

![Fig. 2.13 Cp variation with wind direction on the centreline of a flat roof along the wind flow](image-url)
The results of my work were presented in various international Conferences (Grosso 1993; Grosso et al. 1994, 1995; Grosso and Parisi 1995), and laid the foundation for the publication of my second single author book, a handbook on passive cooling in buildings for Italian students, researchers, and professionals (Grosso 1997, and further editions).

AIOLOS was a project carried out within the framework of the ALTENER Programme of the European Commission, DG XVII for Energy. Its main goal was to create a specific material on the efficient use of passive ventilation for buildings than could be transferred to education activities and be used by all the professionals involved in the field of buildings.

My contribution was to write design guidelines and technical solutions for natural ventilation as well as to include CpCalc+ in the software AIOLOS, which calculates multizone natural ventilation airflow rates. A publication, edited by Francis Allard, includes the outcome of the project, including a chapter on my contribution and a CD on AIOLOS software (Allard 1998).

PRECis (assessing the Potential for Renewable Energies in Cities) was co-funded by the European Commission, DG XII, Joule III Non Nuclear Energy Programme, Sub-programme: Energy Conservation and Utilisation. The Project was coordinated by The Martin Centre for Architecture and Urban Studies, University of Cambridge, UK, and involved: the research Institute for CFD in Trondheim, Norway; the Fribourg School of Architecture, Switzerland; and my research unit at Polytechnic University of Turin. It was carried out from 1997 to 2000.

The main project goal was to develop methods and tools for assessing the potential use of renewable energy sources in urban planning and regulations. It included solar energy and daylight as well as wind effect as a potential natural ventilation driver. I was involved in the latter, through the utilisation of CpCalc+ as a tool for calculating
the wind pressure coefficients on the envelope of a reference building in relation to its location in a theoretical urban block with varying form and layout. Hence, the correlation analysis of the CpCalc+ output allowed for evaluating the wind-driven airflow rates due to cross natural ventilation through a double room unit of the reference building, by applying Ansley’s equation (Ansley 1982) with the calculated Cp differences as an input.

The results of my research for the PRECis Project were published in a paper on an International Journal (Grosso 1998) and in various International Conferences (Grosso et al. 2000a, b, c; Grosso and Banchio 2000).

Within the PRECIs Project, I commissioned to TNO—an Institute and Laboratory of the University of Delft, Netherlands—an analysis of the effect of a single obstacle in various positions on the wind pressure distribution on a building’s envelope. This analysis was carried out using their Cp-generator based on wind tunnel test results. My intent was to complete the CpCalc+ programme with a correlation of data on the effects on the wind pressure distribution on a building’s envelope of a single obstacle, which I could not include neither in the original COMIS CpCalc version nor in the upgraded PASCOOL’s one, both considering only the effect of terrain roughness and plan area density. However, the amount of data and their characteristic stochastic variation would have not made possible a fitting linear analysis as had done before, but a different probabilistic approach should have been applied. Unfortunately, I have not be able since to find resources and personnel to carry out this task and that database is still there waiting to be elaborated and linked to CpCalc+. A hope comes from the perspective of the development of a future new version of the programme using the Python language (Chiesa and Grosso 2019a).

A didactic method: the wind-wake core projection and microclimate matrix

Based on the wind tunnel test diagrams representing the wind wake cores (calm zones) on the leeward side of parallelepiped modular models, elaborated by Boutet (1987), I developed a simplified method to draw such calm zones in any urban context. I did it by correlating the varying values of the relative width and length of the models with respect to their height, to the depth of the wind wake core of each model. The resulting fitting curves allow for determining the depth of the calm zone of any parallelepiped-shaped building within the range of aspect rations variation of the Boutet’s models. Correction factors were then applied for different wind incident angles, with steps at 0°, 30°, 45°, and 90° and interpolating for values in between.

The combination of this method to the dynamic shadowing projection technique yielded the microclimate matrix tool, whose development was inspired by Brown and Dekay.

The microclimate matrix (Fig. 2.15), allows for assessing the optimal position of buildings and outdoor activities for a given project included in an urban context in relation to wind and solar access/protection, depending on seasonal thermal comfort and IAQ needs. This method was described in various publications (Grosso 2008b; Grosso et al. 2015; Nigra et al. 2016; Chiesa and Grosso 2017, 2019b).

Both the wind wake core and microclimate matrix graphical techniques have been applied in the course of Environmental Technological Design, which I taught in the Bachelor Degree Programme in Architecture, English curriculum, until my
retirement, and afterword by Giacomo Chiesa. I used as well this method in the same course within the Atelier on Sustainable Design of the Master Degree Programme in Architecture for a Sustainable Design, which I taught last year and I will be teaching next academic year.

**A tool to calculate the energy saving due to ventilative cooling**

From 2006 to 2009, I collaborated to the Municipality of Turin for the development and implementation of an Annex to the Building Code dealing with mandatory and voluntary requirements, aimed at improving energy efficiency, thermal comfort, and indoor air quality in buildings. The voluntary part of the scheme was to assign scores related to the application of the voluntary requirements in construction or refurbishment projects, presented for authorisation by the Municipality, and apply relevant reduction of the urbanisation charges.

In particular, I proposed and wrote the requirement related to passive cooling through con-trolled natural ventilation, i.e., controlling wind-driven and stack-driven airflow by letting it in a building through automatic opening devices, applied to windows and vents, at given indoor and outdoor air temperature conditions.

In order to check the energy saving performance related to the application of that requirement, I proposed and developed a software (EcoWind), calculating the potential energy reduction of the cooling annual need of a double-room building unit due to the application of controlled natural ventilation for the climate of Turin. The software was developed thanks to the collaboration of a team composed of an energy expert (Luca Raimondo) and two informatics professionals (Luca Colombo and Andrea Deganutti) (Grosso et al. 2009). It was based on the semi-dynamics hourly calculation of the sensible heat transfer through a building’s envelope, de-scribed by the standard EN ISO 13790:2008, Energy performance of buildings—Calculation of energy use for space heating and cooling, and empiric formulas for the airflow rate prediction (Grosso 2008b).

This software was further upgraded for various locations representative of the climates of Italy in both a web version (SPERAVent) (Grosso et al. 2010–11) and a compacted version on CD (WindChill) (Grosso et al. 2011), attached to the third edition of my book on passive cooling.
2.1.5 Research Projects Integrating All Aspects of Bioclimatic Design

Environmental evaluation for the 2006 Winter Olympic Games in Turin

The Turin Organising Committee for the XXth Olympic winter games (TOROC), held in 2006, appointed the Polytechnic University of Turin, Italy, Dept. Settlements Science and Environmental Technology (DINSE)—which converged into the Dept. Architecture and Design with the reform of 2012—to evaluate the environmental quality and compatibility of the projects included in the Olympic Programme (OP). This was done according to the recommendations issued on the basis of a Strategic Environmental Assessment (SEA), whose application represented the first case in Italy, and one of the first in Europe, for this type of events.

The projects assessed concerned land transformation and constructed assets, construction of new buildings, and refurbishment of old unused industrial and commercial structures.

Gabriella Peretti, a colleague of mine, and me, were the co-ordinators of the work, which was carried out through:

(a) guidelines for project sustainability as regards the construction and management of Olympic and Multimedia Villages;
(b) a system aimed at evaluating the Eco-compatibility Projects within the Quality Settlement Indicator as provided in the Monitoring Plan foreseen by the SEA.

Objectives, requirements and indicators used for the eco-compatibility assessment regarding use of climate resources, outdoor spaces, and control of resources consumption—all aspects related to the application of bioclimatic principles, are described in Tables 2.1.

The methodology applied was based, with adaptation to the client requirements, on the one elaborated within the Working Group ‘Sustainability in buildings’ of the Constructions Committee of UNI, instituted in 2000, and coordinated by Peretti from the inception to 2006, and by me from 2006 to 2019. It consisted of a multi-criteria method inspired to the one developed by iiSBE (international initiative for a Sustainable Built Environment): GBCtool, lateron SBTool. This is a spreadsheet for calculating several indicators, subdivided in issues, categories, and criteria, to which a weighted system is applied in order to obtain a final aggregated performance score. The UNI’s WG method—never converted into a standard due to the overlapping of an analogous CEN standard development process—was, instead, based on a subdivision of the performance indicators in ‘needs’ (objectives), ‘classes of requirements’, and ‘requirements’ as well as on the main phases of a building life cycle (Fig. 2.16). An example of the weighting system in Fig. 2.17.
Table 2.1  (a) Requirements and relevant indicators related to the use of climate resources and outdoor spaces, (b) requirements and relevant indicators related to the control of resources consumption

(a)

| Objectives | Requirements | Indicators |
|------------|--------------|------------|
| Use of climatic resources (UCR) | R1. Winter solar radiation use | (a) shape efficiency for solar access (b) ratio of shadows length to distance between buildings |
| | R2. Natural ventilation use | (a) ratio (%) of the number of dwellings with potential wind-driven and/or stack effect-driven cross ventilation to the overall number of dwellings (b) natural ventilation air flow rates in sample dwelling units |
| Environmental quality of external spaces | R3. Winter wind dynamics control | winter wind protection factor |
| | R4. Summer wind dynamics control | summer wind exposure factor |

(b)

| Objectives | Requirements | Indicators |
|------------|--------------|------------|
| Resources consumption control (rcc) | R8. Use of thermal insulation | Weighted average U-value of the buildings’ envelope |
| | R9. Substitution of fossil fuel with renewable sources in HVAC and electricity production | Efficiency Factor for primary energy loads related to HVAC and electricity production systems, defined as the ratio of the difference between a reference load and the project load to the reference load (range 0–1) |
| | R10. Summer radiation control | (a) percentage of the number of windows with fixed shaded glazed area greater than 60% of total glazed area between 15 h and 17 h, summer solstice, on the total number of windows oriented to SE, S, SW, W (sample buildings) (b) area-weighted average shading coefficient of the windows oriented to SE, S, SW, W (all buildings) |

(continued)
The methodology and results of the work carried out were described in a paper presented to the International Conference on Sustainable Buildings, held in Warsaw, 2004 (Peretti and Grosso 2004).

**PR.I.M.E.**

In 2010, I was contacted by Maria Irene Cardillo, an architect with office in Rome, who was looking for an expert on natural ventilation for answering to a “Call for proposals on projects of energy efficiency and use of renewable energy sources in urban areas”, opened by the Italian Ministry of Environment. My name was given to her by a German expert she contacted earlier.

I accepted her request for collaboration and we elaborated together a project proposal called PR.I.M.E. (Innovative procedures for energy-efficient and eco-compatible building modules).

The project was funded. It involved the Consortium So.Ri.Ser. (Society for Research and Services), which included Cardillo’s SME AE.C.I. (Architecture and
Construction), COR-MATEX—a company making machinery to treat recycled material, located in Prato (Florence)—and the Engineering firm INGE.CO, Rome. The Polytechnic University of Turin was involved through a research unit I coordinated, while holding also the role of scientific responsible of the entire project.

The project was developed from 2011 to 2013. Its main objective was to design and test a prototype of a movable prefabricated building module, with an Aluminium bearing structure, a highly insulated envelope and sustainable low-energy environmental control systems (ECS). The insulation layers were made of materials coming from recycling process of waste tires and industrial textile scraps, enclosed in Aluminium panels. The ECS included a hybrid passive air conditioning wall element, called H-NAC (Hybrid-Natural Air Conditioning) and a sanitary wastewater heat recovery system. The H-NAC was tested in the Laboratory of Technology System Innovation (LaSTIn) of the Dept. Architecture and Design, Polytechnic University of Turin, of which I was the scientific Director and which was just instituted at that time as a transformation of the a previous lab with had a different name, inherited by its founder (Laboratory “R. Mattone”).

The design and test of the H-NAC system represented the most innovative environmental-technological feature of the PR.I.M.E³ project. Its main purpose was to demonstrate that it could be conditioned indoor air both in winter and in summer, using a natural source as the outdoor air with a very low energy consumption. The main challenge was to apply the concept and functioning of a heat recovery system (HRS), whose commercial applications worked—and still work—only with controlled mechanical ventilation, to a system applying very low pressures, close to

**Fig. 2.17** Example of the weighting system used for the TOROC project
the ones of natural airflow. For that purpose a special metal ‘box’ with crossing channels, having sections much higher than the ones of mechanical HRS, was built and tested. After the first tests, spiral ‘turbolators’ were inserted in the channels in order to increase the heat exchange efficiency, which reached eventually a good value (50%) even not comparable to mechanical HRSs. The entire H-NAC system was conceived as a wall element (Fig. 2.18), composed of various elements, in addition to the HRS: a latent-heat adsorption transfer (LHAT) component for air de-humidification, where two types of adsorbing material were tested (zeolite and silica gel); a Direct Evaporative Cooling (DEC) system, called ‘rain-shaft’; and solar collectors, both air- and water-fuelled to heat air as well regenerate the LHAT system (Fig. 2.19).

2.1.6 Teaching on the Overall Bioclimatic Spectrum

Institutional Teaching at the Polytechnic University of Turin

Back from the experience in California, in 1992 I had the chance to start teaching courses at the School of Architecture of the Polytechnic University of Turin, as a course holder and no longer as an assistant like in the pre-American period. Since then and up to the curricula re-form of 1995, I held two courses on Architectural Technology, one in the School’s headquarter, at the Valentino Castle, the other in the decentralised site of Mondovi (CN). In both experiences, I applied all what I had learned during the period abroad, not only within the COMIS workshop, but also in the two years afterward, when I had carried out consultancy activities (see below in the relevant paragraph).

In that initial teaching experience as a course holder, I applied concepts and methods inspired by researchers and scholars, whom I mentioned in my other chapter of this book on the origin and evolution of bioclimatic approach in architecture. It was of a great help my association to the Society of Building Science Educators (SBSE), which includes teachers of ECS (Environmental Control Systems). They
come from architecture schools in the USA, rather than from engineering schools as it occurs, generally, in Europe. Since ECS at the Polytechnic University of Turin was, and has always been, a field held by Building Physics teachers, my approach at that time caused a conflict with the main representative of that field. He criticised, e.g., the use I made of the balance point temperature as a parameter for evaluating the contribution of passive systems to the energy need for space heating and cooling in a building, which I thought to be a good synthetic criterion more useful for architecture students than the more analytical one applied by the Building Physics teachers. The quarrel was then solved thanks to the mediation of the School’s Dean and based on the principle of autonomy and responsibility of teachers granted by the Italian Constitution. However, my belief on that interrelation between Architectural Technology and Building Physics as a plus for the effectiveness of a knowledge and methodological transfer of the bioclimatic approach to students would have had negative consequences on my career progress. This was, and still is, due to the characteristics of the Italian academic recruitment and career advancement, based on closed scientific disciplinary sectors, penalising candidates belonging to inter-boundary fields of research.

To be honest, my experience abroad had an important value for my career advancement when I obtained the role of associate professor on Architectural Technology
and Environmental Design in 1998 by winning a national competition for 10 openings to be allocated in all Italian Schools of architecture. That was the last call at national level. Afterword, all calls for openings were managed at local level.

Since the curricula reform of 1995 several other reforms were instituted for the Italian University, leading eventually, in 2003, to the $3 + 2$ format (Bachelor + Master degree), consistent to the European setting. Since 1995 up to my retirement, and now as a Contract Professor, I have been teaching mainly in architecture studios. From 1995 to 2002, I taught ‘Construction in Architecture’, in the 2nd year of the 5-year degree programme, a studio integrated to architectural design and structural engineering, with the last two academic years at the Mondovi site. Within the same Degree Programme, I taught in a ‘Final Synthesis Studio’ ‘Environmental Design (and Eco-Design)’ from 1998 to 2002, and an analogous studio at Mondovi in the academic year 2001–02. From 2002 to 2007, I taught ‘Technology Innovation’ and ‘Environmental Technology’, studios at the third year of the Bachelor Degree Programme Architecture for Design, with an integration of Material Science, respectively, in Turin and Mondovi. From 2004 to 2009, I taught ‘Eco-compatible Technology’ in a Studio Architecture and Urban Landscape Design for the Master Degree Programme Architecture for the Environment and Landscape at the Mondovi site, and ‘Environmental Technology’ for a studio on ‘Local Planning’ for the Maser degree Programme ‘Territorial, Urban, and Landscape Planning’ in the academic year 2004–05. From 2007 to 2011, I taught ‘Technology of Architecture II’ in a studio ‘Technological Design in Architecture’ for the Master Degree Programme in Architecture, with an integration of Structural Engineering. For the new Master Degree Programme ‘Architecture for a sustainable design’, I taught ‘Technology Innovation’ in a studio ‘Sustainability in the design of building-systems’, integrated with ‘architectural design’, from 2011 to 2014, and from 2014 to 2016, ‘Advanced Environmental Technological Design’ in a Final Design Studio, in English, integrating architectural design and building physics. All these studios were held in the 2nd (final) year of the Programme. In the first year of the same Programme, I have been teaching ‘Environmental Technological Design’ in the Atelier ‘The architectural sustainable Design E’ since 2018. In all these studios, I have based my teaching on a strict integration between knowledge, methodology, and tools related to environmental and technological aspects, with particular focus on the bioclimatic approach, and the architectural design process, through all its phases, from building programming to preliminary, schematic, and design development (Fig. 2.20).

I taught single courses on: ‘Environmental Technological Design’, in the third year, from 2012 to 2018, and ‘Fundamental of Architectural Technology’, in the first year, in the academic year 2016–17, both in English, for the Bachelor Degree Programme in Architecture; ‘Elements of Environmental Urban Design’, in the third year of the Bachelor Degree Programme ‘Territorial, Urban, and Landscape Planning’; ‘Technology for Building and Environmental Hygiene’, from 1998 to 2000, in the third year of a University Diploma I Building Constructions, an Architecture-Engineering interfaculty experience, ended with the $3 + 2$ reform.
At the third Degree level, I taught a Course ‘Design of indoor climate-control passive systems in buildings’ for the Ph.D. Programme ‘Management, Production and Design’, SCUDO, Polytechnic University of Turin.

**Thesis development supervision**

Thesis supervision had been always the most favoured didactic activity I carried out in my entire academic career. It allowed a special and deep link with a single student, who had chosen to be supervised by me because of my specific competence in relation to his/her scientific interest. Although several of the theses were of research nature, I generally preferred topics involving an integrated design development, including both technological (environmental) and architectural aspects. To cover the latter, I usually asked for a co-supervision by a professor on architectural design. This integration led most of the times to optimal results in demonstrating the potential and effective application of bioclimatic principles and methods to real project case studies. In this regard, amid the about 500 theses I supervised in my entire academic career, I would like to mention the ones supervised, in the academic years 2014/and 2015/2016, together with Marianna Nigra, a contract professor of architectural design at the time of the theses supervision, and later on a Ph.D student of mine. The theses’ subjects were about various design projects related to new building construction and refurbishment as well as infrastructure and urban scale, with location spanning all over the world. A synergic and deep supervising support action allowed those theses to be based on a common technological-architectural methodological approach, but with a specific original imprinting characterising each student. Due to the extraordinary results of this experience, 15 of those theses were selected for publication (Grosso and Nigra 2019).
**Bioclimatic approach to landscape architecture**

I was involved, from 2004 to 2009, in the organisation—together with my colleague Gabriella Peretti—and teaching of a Master Degree Course on Design of Parks, Gardens, and Landscape, established by the 2nd Faculty of Architecture, Polytechnic University of Turin, and the Faculty of Agriculture, University of Turin. I taught a Studio on Environmental Urban Design, focussed on the interaction between climate factors and urban design, concerning their impact on outdoor comfort, air quality, and energy conservation.

In 2009, that experience lead to the inception of a new agreement between the above-mentioned Faculties, extended to the Faculty of Agriculture of the University of Milan and the School of Architecture of the University of Genoa, which already had a Master Degree on Landscape Architecture. This inter-university Master Degree Course, which was titled Design of Green Areas and Landscape, went through a cumbersome Institutional process to reach an agreement amid the Faculties involved, with a strong opposition of the Territorial and Regional Planning Department of the Polytechnic University of Turin. It claimed to have a paternity on that field having a landscape related teaching module in its Master Degree Course on Regional Planning.

However, the battle I personally lead in my Faculty to win—successfully, at the end—the approval of that agreement, was based on the belief that landscape architecture had the legitimation as an autonomous discipline, being grounded on a design scale typical of urban and micro-territorial contexts, quite different from a regional planning scale. In addition, the new Programme was also focussed on gardens design, including restoration of historical gardens, a topic stranger to the regional planning course.

Within that inter-university Course, I taught a module on Environmental Technology within a 2nd year Studio on Landscape Design, held at the University of Genoa. This teaching was focussed on the bioclimatic effect of vegetation on outdoor comfort as well as on special materials, which could be used in landscape design to control and mitigate microclimate outdoor conditions. I used for that teaching also the outcome of a work carried out by Gianni Scudo and his team at the Polytechnic University of Milan—for which I had done a consultancy activity—within the European project RUROS (Rediscovering the Urban Realm and Open Spaces), funded under FP5-EESD and coordinated by the Centre For Renewable Energy Sources, Greece (2001–2004). I carried out that teaching up to 2013, when the Programme’s coordination was transferred to the Territorial Planning Department, within the new depart-mental asset of the Polytechnic University of Turin.

That experience lead as well to writing contributions for publications (Grosso 2012, 2014).

**Teaching in other Universities**

In my entire academic and professional career, I have always been inclined to apply my scientific and didactic expertise beyond the borders of my Institutional role with the aim of disseminating a ‘bioclimatic’ way of thinking within the professional world of architects and engineers. This have implied both, an active consultancy activity as described in the next para-graph, and hundreds of lectures and courses, I
held in other Universities as well for Public and private non-academic organisations. The following are some of the most significant and long lasting of them related to bioclimatic design for post-graduate Master Programme (MP).

For the MP “Bio-ecologic Architecture and Technological Integration in the Environment”, managed by the Inter-University Consortium A.B.I.T.A. (Architettura Bio-ecologica e Integrazione Tecnologica Ambientale) at the Dept. Architectural Technology and Design, University of Florence, I taught ‘Natural Ventilation and Passive Ventilative Cooling of Buildings’ from 2002 to 2013. For the MP “RIDEF (Renewable Energies, Decentralization, Energy Efficiency)—Energy for Kyoto”, at the Dept. BEST—Building Environment Science and Technology, Polytechnic University of Milan, I taught ‘Passive Cooling Systems’ from 2003 to 2014. From 2002 to 2006, I taught ‘Natural Ventilation and Passive Ventilative Cooling of Buildings’ for two MPs coordinated by late prof. Cristina Benedetti, an Italian Pioneer in Bioclimatic Design and friend of mine: ‘House-Climate’, at the School of Economy, Free University of Bozen; ‘Environmental Design’, at the School of Architecture ‘Valle Giulia’, University of Rome ‘La Sapienza’.

2.2 Extra-Academic Experience

As I already mentioned above, in my entire life-long work activity I always tried to combine theoretical investigation and practical application, possibly connected to the real professional design world. This came from a firm belief that the theoretical concepts I developed in the activities above described needed to be verified and tested through experiences concerning direct building and urban design applications. This occurred in both teaching and consultancy activity in support of architectural design offices. A synthesis of them are outlined as follows.

2.2.1 Teaching

I held hundreds of lectures and seminars on bioclimatic, energy and environmental related topics in professional updating and long-life learning courses, managed by public and private organisations. Amid them, it worth to mention the following: ANAB (National Association of Biological Architecture); INBAR (National Institute of Bio-architecture); ISES (International Solar Energy Society), WWF (World Wildlife Fund); Environment Park SpA, Turin; iiSBE (international initiative for a Sustainable Built Environment); CELIM Onlus, Milan, within a collaboration agreement Italy-Albany; the Italian Ministry of the Environment, Rome; the Chinese Ministry of Science and Technology, Beijing; and the Order of Architects, Planners, Landscapers, and Restorers, of Turin, Genoa, Aosta Valley, Lecco, Reggio Calabria.
2.2.2 Main Consultancy Projects

I will describe synthetically, in the following paragraphs, some of the main activities and projects I was involved in, the most significant from the point of view of thoroughness of the knowledge and competence applied. It will be clear from this description that my involvement was not only the mere application of a specific knowledge such as the one on airflow and solar control, but was a holistic experience characterising the complex interrelationships between science and technology expertise and the design process in the professional practice.

Architect Liebermann’s design
Just after the COMIS workshop in Berkeley, CA, USA, I had the chance to meet with the last F.L. Wright’s assistant, Daniel Liebermann. He was a fond of Borromini’s architecture and a theorist of the application of Fibonacci’s number series to architectural design. This theory was a way to give a sort of scientific validation to the form of his architecture within the tradition of Wright’s organic approach. I recall Dan, who died at 84 year old in 2015, as both a brilliant and unconventional man, even eccentric. He would comport himself in layers of wool clothing during summer heat, and kept a trove of artefacts—including old cars—at his home in Berkeley, and later, in Inverness. He was very intelligent, so multifaceted in his life experiences; sometimes you’d go crazy because he would kind of go off on tangents. But he was very passionate about his work and about doing things right. He was a pioneer of recycling by using scraps such as tires and metals in his architecture. I could visited some of his work, mostly residential houses, and I was particularly hit by the Radius House, designed in 1962 for his parents on two contiguous parcels in Mill Valley, Marin County, CA. The interior is completely open without separation between the two storeys, whose only connection is a spiral stair. All structure is made of timber beams getting off on a radius form (Fibonacci’s curve) by a central stone core. In addition, he introduced me to a completely unknown (for me) world of Californian architects followers of Bruce Goff, one of the major Wright’s disciple. Amid those, I was astonished by a tree house in the woods above the Big Sur cliffs, in the way from San Francisco to Los Angeles.

However, my collaboration with him ended up, in Berkeley, to a design of a rammed earth house, never built, and to the writing of a book (Liebermann was also a self-made publisher) on fire resistant architecture (Grosso 1991), where I could apply some of the results of the tests I carried out at the wind tunnel of the University of California, Berkeley. When I came back to my work as a researcher and teacher at the Polytechnic University of Turin, I was able to manage to invite him as a visiting lecturer for a period of two months, in 1995. His lectures were very successful among students of both technology and architectural design courses. All were excited by viewing the examples and learning the organic approach to architecture from an architect who had experienced directly Wright’s way of working. He was also surprise by Turin’s townscape, saying that “it was the best kept secret of Italy”. In particular, he was struck by Turin’s Baroque architecture and by the Nervi ‘Labour Palace’, which Daniel Liebermann considered an extraordinary example of application of Wright’s
organic theory with its structural reinforced concrete grid of modular tree-like pillars sustaining radial beams on their tops within a square framework.

The Consalud Headquarter Building in Santiago, Chile

In 1998, I participated through the Department of Science and Techniques for Settlement Processes, in which I worked as a senior scientist at that time, to an International Competition for the bioclimatic consultancy to the design of the headquarter building of Consalud, a Health Insurance Company in Santiago, Chile, which was commissioned to the architecture office May y Soler. In spite of the participation of much stronger competitors in terms of professional experience and staff dimension, such as Buro Happold Engineering from UK, I won, probably also for a higher proneness of the appointed Architects to a consultant coming from a “Mediterranean” area, culturally closer to the Chilean context.

This consultancy activity was carried out on site as a full time charrette lasting a week, during which I discussed continuously with the designer, with the help of a student of mine, Mario Voerzio, who would have lately developed his thesis on the same topic together with another student, Gianfranco Dell’aquila. The comprised two parts: a central gathering space and cafeteria, and an office wing. My contribution was focussed on the latter.

The first action I overtook was a sensitivity analysis on the thermal effect of the building orientation, considering an overhanging shading made of horizontal tilted slats at roof level on the top of placed all around the building, according to a concept inspired to the Chilean traditional of country houses (Fig. 2.21). This simulation, as all the others made in that experience, were carried out using the thermal model QUICKII (Mathews and Joubert 1989). Results from the simulation led to choose 20° East orientation as the optimal one in terms of balancing heating and cooling. In a second series of simulation, the width of the overhanging pergola was increased of one meter at each step, from the value considered in the above-mentioned sensitivity analysis, keeping the orientation at 30° from North eastward (the worst among the previously analysed as far as cooling loads are concerned). The advantage of increasing the overhang width resulted quite low in terms of both comfort and cooling loads. Since those decreases do not offset the increase in costs due to the relevant higher widths, a 6-m width for both northward and southward pergola was suggested. All other analyses and simulation regarded technologies for both the envelope and the environmental control systems (ECS).

As far as the latter are concerned, the most original and innovative solution I suggested was to combine the vertical bearing function and airflow transportation in one building element, a steel pillar-duct. This solution, whose only precedent dated back in a building of the late XIX Century in England, appeared to be rational and efficient, as long as all relevant joint thermal and structural stress problems were solved.

Based on the maximum airflow rates requirement for ventilation cooling, the pillar-duct constant inner cross section was 0.25 m². For thermal and acoustical insulation, a double insulation layer was applied: a rock wool matte of 5 cm thickness and an outer 2 cm thick gypsum board panel. A resilient material was inserted in
joints between pillar-ducts and floor slabs in order to avoid risks of sound structural transmission. The thickness of the pillar’s steel profile

had to be increased as compared to a similar conventional structural vertical framework of the same resistance, due to the holes foreseen for the attachment of the horizontal ducts at each floor. The overall ventilation and air conditioning system was conceived as a hybrid natural-artificial one, with a chiller and a heating boiler dimensioned only for occasional pick energy demand. It was realised through a 4-ways air flux mechanical ventilation system, whose Air Handling Units (AHUs) were connected to an Earth Heat Exchange (EHX) battery, made of horizontal buried pipes, for space cooling and pre-heating as well as air solar collectors on roof for space heating (Fig. 2.22). The horizontal airflow network was made of supply air ducts within suspended ceiling and extract air directly from under-floor plenum to vents in the pillar-ducts.

This configuration did not allow for flushing directly at night by external air the only massive elements of the building, the concrete floor slabs, being the envelope made of curtain all-glazed walls. Hence, a free-cooling was conceived by using the mechanical ventilation system, when outdoor air temperature is below a value set as a function of indoor comfort, net of the daily solar and internal heat gains.

The bioclimatic strategies and technologies applied in the office building of the Consalud facility can be summarised as follows:

1. linear building form;
2. building orientation of 20° from North towards East;
3. 6 m deep overhanging pergola;
4. double glazing with external reflecting pane;
5. thermal mass for floor slabs;
6. mechanical night ventilation of floor slabs by a flow rate of 3 air change per hour (ACH);
7. mechanical free-cooling when appropriate;
8. cooling by ventilation through EHX buried pipes of 20 cm radius;
9. heating by ventilation through solar collectors located on roof;
10. stack ventilation of entrance hall.

The overall annual energy saving for ventilation and air conditioning (cooling) due to the above listed measures related to cooling, was of 510.4 MWh, i.e., the 58% of the energy needs of a reference configuration of the same building, but with a conventional HVAC system, no shading, and clear single glass on the curtain walls, equal to 880 MWh.

The high school building “L. Orsini”, Imola (BO), Italy
In 2005, I submitted—together with colleagues operating in the professional fields of architectural design, mechanical engineering, structural engineering, geology, and construction works safety—an offer to a tender opened by the Municipality of Imola (BO), Office for Public Works, for the design development of the High School “L. Orsini”, located in the Pedagna district. This call was opened on the basis of a previously approved project at a preliminary design phase, and required the contribution of an environmental consultancy with a particular focus on airflow modelling and

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**Fig. 2.22** Scheme of the hybrid indoor climate control system of the office wing of Consalud building (cooling mode): red = exhausted hot air; orange = outdoor warm air; blue = cold air (on bottom-left: pipes coming from the EAHX system)
natural ventilation. My competence and experience in this field helped the on-purpose temporary associated professionals to win the tender.

This experience was characterised by an accurate and innovative design process integrating different architectural and engineering figures and technical knowledge, in order to design a building that was fully functional as well as a model of sustainability for students, teachers, and citizens as a whole. In order to achieve this goal, strongly required by the Municipality, the associated professionals were engaged since the design program in a collaborative process aimed at conceiving an innovative building-equipment system. As a consultant with a know-how bridging architectural design and mechanical engineering sectors, I plaid a fundamental role for the successful, not granted, outcome of that integration process.

Various design options were assessed from the performance and environmental point of views during the entire process. In particular, innovation involved construction technologies, materials, functions’ distribution, use of renewable sources, integration between mechanical and passive systems aimed at increasing energy efficiency, attention to maintenance and to waste disposal and recycling, design and installation of the monitoring sensors’ system.

The “L. Orsini” high school building, located in a lot used as a city park and has three stories plus a basement, was designed to accommodate 425 students. The shape of the building was conceived to optimise uptake of solar radiation as a source of direct heat gain in winter for classrooms as well as of energy collection for thermal water solar systems on roof and Solarwall® elements on the south façade (Fig. 2.23). The school building is composed by two bodies linked by a glazed atrium placed along the E-W axis, even if the body facing north opens like a fan towards the east. The atrium exerts various architectural-environmental functions, i.e., horizontal and vertical distribution, buffer space, stack-driven ventilation. The Southern body houses classrooms, while in the North side are located laboratories, offices and other complementary services. The building envelope is mostly opaque in the façade facing north, while, to the south, large floor-to-ceiling windows are fragmented by opaque vertical wall supporting the Solarwall® system and embedding vertical air ducts which connect batteries of Air Handling Units (AHU) from the technical basement to the roof. A shading system made of large metal blades movable mechanically in two position according to seasons (winter and summer) is located between the opaque elements in front of the windows and integrated by rolling blinds. Coat insulation layers are made of natural material, i.e., cork and wood fibres, and dimensioned to exceed standard transmittance requirements: 0.14 W/m²K on the North wall, a considerable performance considering the year of construction/design of this building. The roof is ventilated in order to disperse heat accumulated during summer (Fig. 2.24). Designers paid particular attention to compliance with regulations on sound insulation, using eight different types of wall to maximize acoustical performance in different combinations and functional modes. In particular, dry-assembled types were preferred for internal partitions. The lighting appliances installed in classrooms were subjected to a careful design, optimised by CFD analyses in the atrium-classroom system to assess the compatibility between lighting equipment and night cooling airflows (Fig. 2.25). The suspended lamps perform, in fact, several functions:
artificial lighting to compensate daylighting through photo-sensors, distribution of mechanically treated air inside classrooms, and improvement of sound absorption. The lighting system is also equipped with sensors of occupants’ presence to avoid waste of electricity. A great attention was paid to the design of the air conditioning system, in order to integrate it to the passive indoor climate-control techniques. In particular, it was adopted an approach able to maximise integration between the different systems of space heating, cooling and ventilation.

Equipment for the technical building systems are localised on the roof and in the basement. In particular, a 20 kWp photovoltaic array, vacuum solar collectors’, exhaust-air towers from the atrium, an outside air intake grid for AHUs, and two AHUs dedicated to the Solarwall® system, are located on roof. Other four AHUs connected to the Earth-to-Air Heat Exchangers (EAHX) are placed in the basement. Furthermore, the school building is equipped with a space heating distribution system through radiant floor panels, connected to Imola’s district heating, coupled with the mechanical ventilation system that allows for treating the latent heat component. In the heating period, the AHUs use, depending on the boundary conditions, air pre-treated by the EAHX system, mixed with outside air, or air heated by the Solarwall® elements (about 268 m² of collection surface). In the summer period, cooling is provided by the EAHX system injecting air into the mechanical ventilation network and the controlled natural ventilation by floor slab flushing and stack-driven flow through the atrium. In addition, an absorption chiller fed by the solar water collectors which over produced heat in summer, generate cold water to be brought to the radiant floor pipes in pick demand periods (Fig. 2.26).
Fig. 2.24  Inside view of the atrium of the ‘Orsini’ School building, with the top opening on the glazing roof

Fig. 2.25  3-D Representation of the CFD modelling of the controlled natural stack-driven airflow between classrooms and atrium in the ‘Orsini’ School building: after 5 s (top-left); after 35 s (top-right); after 1 h (bottom). Source Grosso (2017, p. 467)
The floor slabs, in pre-tensioned reinforced concrete, are left in view at ceiling in order to act as an exposed thermal mass to maximise the performance of the natural night cooling system, provided in the summer period. Cooler outside air enters the Southern classrooms through motorised openings embedded in the windows and flushes both concrete ceiling and floor slabs hence lowering their surface temperature and the relevant heat exchange toward indoor spaces the day after. Air is naturally moved by the temperature gradient between inside and outside and by the effect induced by the temperature stratification inside the glazed central atrium. Acoustically insulated grids designed on-purpose and placed above doors allow for the passage of air between classrooms and the atrium, while glazed clerestories on atrium’s roof facilitate air exhaustion through motorised openings. This system was optimised through CFD simulations of airflows in typical boundary conditions. All CFD simulations were elaborated by Marco Simonetti, an Engineer designer of HVAC systems at that time, and currently tenure-track researcher at the Polytechnic University of Turin.

An energy evaluation was carried out to estimate the energy saving potential of the various technologies, compared to a benchmark using conventional systems current at that time. This work was carried out using the dynamic simulation software TRNSYS, by Luca Raimondo, a brilliant student of mine just graduated in architecture at that time and now a successful professional in the field of building energy evaluation and certification.

After its construction and operation, the school building was interested by an energy and environmental monitoring campaign aimed at assessing operation performance with relevant control optimisation of the installed systems. In particular, a monitoring campaign was carried out on the EAHX system. This system is composed of three distinct fields that count respectively 12-12-8 parallel buried pipes of about 70 m in length. The three fields are located, respectively, 6, 30 and 6 meters from...
the building. Each field is organised in: air catchment head, air inlet chamber, a distribution duct, parallel tubes of rigid polyethylene with a diameter 0.25 m at a 1.1 m distance between each other, a collector duct connected to a condensation drain chamber, a connecting channel (Figs. 2.27 and 2.28). Furthermore, before the AHUs on basement, there is a mixing chamber collecting the pre-treated air coming from the three different fields. The system was dimensioned based on the airflow rate required for classrooms and its thermal performance simulated using the software GAEA (Grosso and Raimondo 2008).

The monitoring campaign was conducted by Giacomo Chiesa, a Ph.D. student under my supervision at that time, during the period May 2011–April 2012 (Chiesa et al. 2014). Results from that field measurements demonstrated the effectiveness of the system (Fig. 2.29). Measurements were also planned to assess the effectiveness of
the night cooling through ventilation of the ceiling slabs (Fig. 2.30), but this campaign could not be implemented due to failure in the management of the School building. A critical review of operational process of the building is reported in a journal paper Chiesa and Grosso (2015).

**MOOM Hotel Complex, Olgiate Olona (VA), Italy**

In 2006, I was contacted by Massimo Riboldi, an entrepreneur in the hospitality sector, who asked me if I could help him to make a project for a construction of a new Hotel/Motel complex in Olgiate Olona (VA), Italy, as much eco-sustainable as possible. The project was commissioned, for the architectural part, to Beppe Riboli,
a designer with office in Crema (CR), who had worked mainly in the field of dance clubs and other leisure facilities. He had already drawn concept schemes and was quite strong in defending his choices with regard to form, layout, structure, and materials, all based on a prevailing criterium of high communication impact targeted to potential users. These were expected to be mainly travellers on the way from the International Malpensa Airport to Milan, being the building located just along the highway connecting these to locations. As I saw those schemes and listened Riboli’s ideas, I soon realised that my collaboration with him would have been not so easy in trying to convince him to accommodate architectural and technological choices to bioclimatic principles. In particular, the main critical aspects were the following.

- The complex has a U-shape layout, with the 3-storey Hotel building as the shorter side, laid down parallel to the highway, oriented to North-East, and the two longer perpendicular sides as two storey terrace-type wings with Motel function (Fig. 2.31). Given that functionally rational form, the orientation was a must, even if not necessarily consistent to a bioclimatic approach.
- The designer proposed as a strong communication feature the installation of an ostensible screen tailored-made of composite metallic material, shaped with sinusoidal curved edges to create a hollowed impressive surface, on both main façades
of the Hotel building and detached from them of about 30 cm (Fig. 2.32), oriented North-East (facing the highway) and South-West (facing the Motels courtyard). In spite of a doubtless commercial meaning, their solar shading function was either
unnecessary (the N-E facing screen) or ineffective (the S-W one), being fixed and hollowed.

- The bearing structure of the Hotel building was conceived as an orthogonal 3-D grid of reinforced concrete elements of the same size, having them the function of pillars or beams. This allows for an intriguing view of the atrium interior, which is full-height open for three storeys (Fig. 2.33). However, it did not allow for applying stack-driven natural ventilation through the atrium for night cooling the hotel rooms by inletting external air, since all walls and doors separating the rooms from the atrium needed to be fireproof compartmented to comply with fire safety requirements. For the same reason, a skylight with an automatically operable opening had to be provided to be shut-off in case of fire inside the atrium.

At the beginning of the consultancy work, various bioclimatic strategies were proposed, including, in addition to the above-mentioned stack-driven ventilation, the installation of solar thermal and PV collectors as well as the installation of an EAHX system (Fig. 2.34). None of them were applied. The only eco-compatible technological choice was the use of a hollowed brick, made of clay with an embedded insulation layer of cellulose material, for the external bearing walls of the Motel wings.

Instead, being energy saving one of the main objective of the property, I proposed the installation of a three-generation system based on gas-fuelled micro-turbines, taking advantage of a fiscal reduction for gas consumption given to Hotels by the National Energy Authority. The micro-turbines generate electricity and heat recovered from exhaust fumes, used for heating water for both sanitary purposes all year, and space heating in winter. In summer, an integrated absorption chiller cools water
by using a fraction of the dissipated heat from the micro-turbines, hence fuelling a fancoil-based space cooling system (Fig. 2.35)

This three-generation system proved to be energy efficient, particularly for cooling: by an energy certification I elaborated after completion of the project, the energy performance resulted of 83.77 kWh/m²-year (Class C) for space heating, and 6.95 kWh/m²-year (Class A) for space cooling; the relevant CO₂-equivalent emissions is of 16.71 kg/m²-year. This value corresponded to a reduction of approximately the 50% of carbon emissions from a comparable Hotel complex of the same dimensions and location of that period, using a conventional compression HVAC system and electricity from the grid.

As a conclusion, that experience was interesting and useful, regardless of the successful outcome in terms of application of bioclimatic principles, because it
allowed me to experience a process of compromising integration between architectural/representation design and technological-environmental applications in a real project context.

**Feasibility study for refurbishment and conversion of ‘Emmanuel Anquetil’ building into an eco-building**

In May 2012, the Ministry of Public Infrastructure of the Republic of Mauritius initiated a public invitation for expression of interest for consultancy services for the feasibility study of the “Refurbishment and Conversion of ‘Emmanuel Anquetil’ Building into an Eco-building”.

Eight Firms were short-listed and invited to submit their offer. The team lead by Design Forum Ltd, with office in St. Louis, Mauritius, was awarded in October 2013 the contract, signed on 22nd January 2014. In addition to the leader and other local consultants, the team comprised of: STEGET srl, directed by arch. Patrizia Giacomelli, ARTECH studio by arch. Giancarlo Pavoni, and me as the eco-building consultant. I had been collaborated previously with both STEGET and ARTECH in several projects, including the design development of the new Mauritius’ Oceanography Institute.

The Emmanuel Anquetil Building (EAB), built in 1979, was outdated and not operating conveniently, hence, needed a thorough refurbishment and had to be put up to standards. The intention of the Client was to go beyond a simple refurbishment and make the project a “mod-el in environment friendly (green) sustainable retrofitting”, by converting the EAB into an eco-building and setting the pace to a responsible set of actions. The decision to refurbish the building rather than to pull down and re-construct it was already a strong statement in favour of the will of the Client to start an ecological development.

Moreover, the EAB had historical values for the newly constituted Mauritian nation, having been built just after Mauritius obtained its independence. It was therefore worthwhile to keep as a historical footprint of achievements of that period (Fig. 2.36).

The main problems were the presence of asbestos panels, the effect of Pigeons’ drops all over, the insufficient places of the vehicle park, high energy consumption due to services conceived when energy conservation was not a priority.

The work carried out included the following main phases:

(a) a thorough survey—conducted using both a direct visual inquiry and questionnaires to users—of the material state and functional performance of the envelope and the bearing structure, the health and comfort conditions, the state of maintenance, the energy consumption, the use of indoor spaces;

(b) proposal of alternative refurbishment solutions, including dynamic energy simulations and a payback time assessment for the energy-related ones;

(c) a proposed time planning for the execution of the refurbishment alternatives

As far as energy and bioclimatic strategies were concerned, the following solutions were proposed.
• Raise current ground floor functions to level 3 including courtyard with a glass covering, redesigning hall and entrance to the building to allow parking on ground level:
• Open up layout of office spaces at each floor eliminating partitions parallel to the longitudinal facades or use ones with height lower than ceiling level, if necessary, to facilitate wind-driven airflow through office rooms:

• Replacement of existing single-glass-pane + no-brake-frame windows with high thermal performance windows including: double-glazing with filled-in argon and low solar factor; low-e films; external operable Venetian blinds; top openings hopper automatically operated at set temperature conditions by sensor-driven motorised devices for natural night cooling.
- Application of lighting dimming control devices connected to daylighting availability.

- Coat insulation layer added to the existing external walls, either externally and protected by a panel cladding or internally and protected by a plasterboard panelling.

- Night cooling by natural ventilation of the high thermal mass of the concrete structure of EAB.

- Integration of photovoltaic panels on shed structures on the terrace roof for renewable power generation:
Dynamic energy simulations on different EAB envelope and HVAC system configurations, corresponding to the proposed refurbishment alternatives, were carried out using the software Design Builder with Energy + solver. The total simulated HVAC + lighting yearly electricity use for the whole EAB existing reference configuration was slightly less than the one measured from August 2012 to July 2013 (1307.15 MWh).

As a benchmark model for the simulations, a configuration was defined where the external glazed walls of office spaces were shifted to the outward edge of the overhanging floor slabs (with an offset of 20 cm for housing the outside shading devices), as a way to increase the net usable floor area, and conventional compression HVAC system applied (Fig. 2.37). Various simulations were then carried out to assess the possible saving potential of the various configurations versus the benchmark model (Fig. 2.38).

The assessment of the payback period of the investments for the energy-related refurbishment options was carried out using both simple and discounted methods.

As a conclusion, that experience was of special importance since it was a unique application of eco-sustainable and bioclimatic principles on a refurbishment project. This had been since then rare in general.

Minimum building energy performance standards and nearly zero energy buildings approach for Turkey
The United Nation Development Programme (UNDP), after a selection of companies invited to submit a proposal for the provision of services for the development of “Minimum Building Energy Performance Standards and nearly Zero Energy Buildings approach for Turkey”, signed the relevant contract with a joint venture between STEGET S.r.l. and IRD Engineering S.r.l., on February 19, 2016. I was appointed as the Team Leader and energy expert of the project.

The work was particularly complex, given the ambitiousness of the objectives, the characteristics of the context, and the scale and geographical extension of its application.
Fig. 2.37  EAB benchmark model in the design builder simulation: view from West

Fig. 2.38  Example of one of the simulated EAB alternative configurations: view from West
The scope of the services was the development of a loose harmonised framework to improve the existing regulations and standards governing building energy performance in Turkey and to carry forward the Turkish building sector and the energy sector to better position among many European and other foremost countries.

Specific objectives of the services were the following:

- improve the existing regulations and standards governing building energy performance;
- promote the use of renewable energy resources in buildings;
- develop Minimum Building Energy Performance Standards (MBEPS);
- upgrade the MBEPS by including nearly-Zero Energy Buildings (nZEB) requirements;
- implement energy efficiency in buildings in a sustainable manner;
- reduce the end-use primary energy consumption and associated GHG emissions;
- outline a programme for future implementations of MBEPS and n-ZEB.

The activities was carried out based on the approach followed by the Directives 2010/31/EU and 2012/27/EU of the European Parliament, characterised by both a cost-optimal approach to the assessment of building energy performance and the nearly-zero energy building target. The definition of nearly-zero energy building had to take into account Turkey’s building cultural heritage, technology, climatic regions and conditions, building materials and construction methods. The aim was to carry out a work not only scientifically sound, but also, and mostly, aimed at an effective and straightforward application of the standards to Turkey’s central and local Government Officials, professionals, developers, and building owners. The target was to achieve a reduction of 35–45% of current levels of energy consumption of the building sector and relevant CO₂ emissions, estimated to amount to the 35.4% of the total final energy consumption in 2012 (equal to 31.8 million TOE).

The applied methodology was characterised by a double-handed approach based on two main procedures: top-down and bottom-up. The top-down procedure was related to a process starting from a statistical analysis of building and energy data and ending to average values on energy consumption for heating and cooling divided by typology and climate zone. The bottom-up procedure was related to a process starting from the calculation of requirements for heating and cooling of building models based on data from the provided examples of projects, or assumptions if needed, and ending with new limits of energy requirements for each building typology and climate zone. In parallel, an analysis of meteorological data (TMYs) for all Turkey’s provinces was carried out by Giacomo Chiesa, through a sub-contract to the Dept. DAD, Polytechnic University of Turin, in order to check the territorial classification foreseen in the software BEP-TR used at that time in Turkey as a reference for building space heating energy performance assessment, and propose a new classification, taking into account both heating and cooling needs.

In the typological analysis, the following main architectural and material construction types were considered: brick masonry; concrete block wall; wooden wall; stone wall. Some examples of traditional building types of Turkey are shown in Fig. 2.39.
The flow-charts of the process followed in the two main phases of the work are shown in Figs. 2.40 and 2.41.

As far as the bioclimatic approach was concerned, an interesting outcome of Chiesa’s climate analysis was an assessment of the potential for various passive/hybrid indoor climate control strategies, evaluated in term of annual comfort-inducing hours for all Turkey’s Province capital cities.

**Fig. 2.39** Examples of typical buildings of Turkey, in wood (left, Istanbul) and stone (right)

**Fig. 2.40** Flow-chart of the process followed for the development of MBEPS
The strategies considered were the following: High Thermal Mass (HTM); High Thermal Mass coupled with Night Ventilation (HTM and NV); Direct Evaporative Cooling (DEC); Controlled Natural Ventilation (CNV); Internal Heat Gains (IHG); Passive Solar Low Mass—Direct Gains (SG LM); Passive Solar High Mass—Direct Gains (SG HM); Dehumidification (DEH). An example of a bar-chart showing the potential comfort-inducing hours in a given location by using the above-listed strategies is shown in Fig. 2.42.

**Collaboration to the ARTECH studio**

My professional collaboration with the ARTECH studio of architect Giancarlo Pavoni, dates back to 2004, although I had known him since the early ‘80s of the XX Century, when he graduated within Matteoli’s group. Giancarlo is an architect particularly skilful in combining technological and architectural design with a
Fig. 2.42 Example of a bar-chart showing the potential comfort-inducing hours (% of the total annual hours) in a given location by using the above-listed passive/hybrid indoor climate control strategies

current attention to the bioclimatic approach. My collaboration have been mostly applied to design competitions, unfortunately rarely won, for which temporary associations of professionals are formed. In them, I have always offered my competence as an environmental, technological, and energy expert and certificate assessor. Amid them, it is worth to mention the participation to the call opened by the Organising Committee of World EXPO Milan 2015 for the design of its services facilities. In addition, I collaborated to the design development of various projects, mostly located in the territory of the Municipality of Grugliasco, at the Western boundaries of Turin, with which Giancarlo has a permanent professional collaboration as an architect: a new City Hall building (never realised), a new Library, and the reconstruction of a High School complex.

But, amid the contribution to the design development of one of the few really constructed works, I would like to cite the Nursery Building “Anna Frank”, located in Nichelino, another city in the outskirts of Turin, at the Southern boundary. It is an example of straightforward and simple application of energy-conservation systems as well as of a harmonious synthesis between them and architectural form (Fig. 2.43). The applied energy-saving systems include mainly active and hybrid systems, the only passive being the sun-space on the Southern façade of the building:

- a controlled mechanical ventilation with heat recovery, assisted by solar air collectors placed on the roof at 55° tilt, to pre-heat air in winter;
- a set of solar water collectors for heating sanitary water, placed on the same plane of the air collectors;
- a radiant underfloor system for peak needs of heating and cooling;
- a mono-bloc water chiller, composed of alternating air-condensers multi-compressors, working continuously at a nominal power of about 9 kW, allowing for a partial de-humidification of air and coolth storage in the floor slab as well as in a 2000 l supplementary inertial tank.
- daylighting-controlled dimming devices applied to the artificial lighting appliances.
The external masonry walls are made of a double layer of hollowed bricks (brick veneer outward and blocks inward), with interposed insulation rigid panels of mineral fibres. The terrace roof has a double layers of insulation on both sides of the air cavity, with rigid panels of mineral glass on the outer surface (below the tar and gravel layer) and boards of expanded poly-styrene on the inner surface. The ground floor is made of multiple layers alternating concrete slabs, air cavities, and rigid panels of mineral fibre, below the outer floor surface and above a thick substrate of gravel, pebbles, and sand-cement. All glazed elements have shading devices: the sun-space is shaded by a portal-shaped concrete structure projected from the building Southern side, with horizontal overhanging slats added to its windows; the windows facing West and East are shaded by external vertical movable louvres.

I also carried out an energo-economic analysis to evaluate the energy reduction, and the related cost savings and payback periods, with respect to the application of conventional systems and standard insulation requirements in force at that time. Results yielded an average payback period of 11.45 years, ranging from: 3.8 year (62.44% of saving) for the increased thermal insulation; 4.17 (19.73%) for heat recovery on the mechanical ventilation system; 7.75 (30.65%) for the solar water collectors (both DHW and space heating); 8.96 (44%) for the cooling system; 19.56 (30%) for the lighting control system; 19.71 (20%) for the sun-space; 19.99 (40%) for the shading devices; 20.51 (19%) for the solar air collectors (heating).

Collaboration to AE.C.I.
The professional collaboration to AE.C.I., a design and construction firm owned by architect Maria Irene Cardillo, started after the end of the PR.I.M.E.3 research project (see above). It has ranged from the participation of several design competitions to the elaboration of pro-posals to be submitted to calls from the European Commission, all dealing with the application of the GREEN-BLOCK system as an outcome of the above-mentioned research project.
The prefabricated GREEN-BLOCK system, still at a TRL 7 phase of prototyping, is composed of a bearing structure made of Aluminium profiles designed on purpose and to be produced according to a process patented by METRA and an envelope also composed of Aluminium panels with an embedded insulation layer made of recycled materials from scraps of textile and tire industries. This modular system, whose basic unit can be carried on a light truck and can be built up to four storeys, is very flexible in its composition options as well as versatile in its potential functions. It has been proposed for various applications, including social housing, luxury residential compound, tourist resorts, emergency facility, and, most recently, as a storage hub for last-mile e-commerce delivery, including transportation of sanitary devices related to the COVID-19 contagion emergency situation (Fig. 2.44).

So far, the proposals presented for calls under the SME Instrument European Programme have been very positively assessed but never funded due to budget restrictions. However, the GREEN BLOCK® system was selected as a EU Ambassador amid the “Best 15 EU Top Technological Innovators” for being presented to the following International fairs: ‘TechInnovation 2017’ at Singapore; ‘CES 2018’ at Las Vegas; ‘CIIF 2018’ at Shanghai. In addition, a Seal of Excellence was assigned to GREEN BLOCK® by the European Commission in 2019 for having “Scored as a high-quality project proposal in a highly competitive evaluation process”. The GREEN BLOCK® system obtained the following certifications: (a) Sustainability certificate—iiSBE 2019; (b) Assessment of the energy performance; (c) LCA—en 15978; (d) CE—control GB certificate for Aluminium profiles; (e) LAPI Certificate and Test for insulation panels.

The most significant project elaborated for design competitions, in collaboration with arch. Maria Irene Cardillo, are described in my book on passive cooling (Grosso 2017, pp. 401–425).
In addition, I contributed to the elaboration of various other projects and proposals, from which I mention here an innovative and original one presented to a Congress-Exhibit Arc13 in Do-ha, Qatar, 2013 (Figs. 2.45 and 2.46). The basic idea was

**Fig. 2.45** Sketch of a 3-D representation of the PUMC Dome for Doha with the main airflows (elaborated by the author)

**Fig. 2.46** Sketch of a section of the PUMC Dome for Doha with the indoor climate and air quality control strategies (elaborated by the author)
to create a large urban space—a passive urban microclimate e-controlled (PUMC) dome—within with various leisure, commercial, and agricultural activities could be exerted. The indoor microclimate is controlled by passive techniques, hence, minimising non-renewable energy consumption and related carbon emissions as well as avoiding exposure to sand-borne winds. The structure is composed of the following elements.

- A geodetic dome-shaped structure is made of Aluminium hexagonal cells enclosing transparent panels made of thermotropic material.
- Transparent hexagonal panels made of thermoplastic materials such as polyolefin, polycarbonate or polymethacrylate, with added thermotropic polymers, autonomously switching from a clear to a scattering state when the temperature rises (see Fraunhofer IAP technology), to reduce high altitude solar radiation transmission causing rising ground surface temperature and, hence, radiative thermal discomfort in urban spaces.
- A multiple controlled natural ventilation system including: (a) rectangular or circular-section air ducts, made of metal foils, crossing the geodetic structure from outside and from under-ground to inside the dome; (b) duct air-inlet southwest-oriented vents placed at various height above ground following the geodetic-shaped structure (from a minimum of 6 m) with embedded dust and sand filtering; (c) duct air-outlet vents placed inside the dome underneath the geodetic-shaped covering at various height (from a minimum of 10 m); (d) dumpers placed at the inlet and outlet vents to automatically control airflow rate depending on microclimate as well as Indoor Air Quality (IAQ) conditions.
- Air solar collectors placed on the top of the leeward Northeast-oriented side of the geodetic structure, with the solar radiation absorbing selective surface and relevant glazing facing Southwest: air-inlet grid are placed at the bottom of collectors towards the inside of the dome and are provided with automatically-controlled dumpers; air-outlet grid are placed on the top of collectors and provided with dumpers as well. Air solar collectors function as air extractors through the stack effect generated by the rising temperature inside the collector air cavities as well as for preheating water to feed absorption chillers.
- A water circulation piping system connecting air solar collectors to absorption chillers—place on technical rooms—which have a function of cooling water flowing in a radiant floor network placed on spots where overheating is more likely, i.e., where the foreseen activity is characterised by people crowding.
- Passive Downdraught Evaporative Cooling (PDEC): water in closed loop is sprinkled or misted through nozzles placed at the under ceiling outlet mouths of the air ducts connecting the outside to the inside space to cool the entering air; the system is automatically switched on when air temperature is above a set-point threshold (generally, between 26 °C and 28 °C) and air humidity below a defined value (usually, 60% of Relative Humidity).
- Earth-to-Air Heat eXchange (EAHX) system, made of horizontal buried ducts made of reinforced polyethylene material, supplying passively-conditioned air in the dome. Air inlet occurs through vertical duct connected to the external vents.
as part of the above described ventilation system; air outlet from the buried pipes goes to Air Treatment Units—placed on technical rooms—which provide for fan-extracting the air as well as controlling air humidity and temperature before the air enter the dome-enclosed space. This automatic control system acts synergistically with the PDEC system in order to guarantee the proper microclimate comfort conditions.

- Vegetation growing by a hydroponic technique on vertical walls confining people assembly places within the dome, thus cooling air by vapour-transpiration and reducing radiant-exchange discomfort by low-emissivity irradiation as well as absorbing air pollution generated by people and equipments.
- Cultivation of plants for both ornamental purposes (flowers) and food production (vegetable and fruits) by a water-saving hydroponic technique in open-air dedicated spaces within the dome. A AEROSEKUR-patented hydroponic water treatment system based on a photo-ozonolysis process was proposed; it destroys metabolites like oxalic acid converting them into CO₂ as well as all other noxious micro-organisms which may grow in the hydroponic water preventing the undesired biofilm build-up.
- In addition to air-filtering at the inlet-vents of the ventilation system and the air outlet of the EAHX ATUs, air treatment for IAQ is provided in spaces where crowd presence is foreseen; for this purpose a AEROSEKUR-patented technology derived from aerospace applications is proposed. It involves the use of a laminar flow through a device composed of plates on which the active sorbent is deposited. The airflow containing the BVOC is completely purified after crossing the laminar flow device with a minimum of energy consumption in comparison to a traditional fixed bed adsorption system. Furthermore, the laminar flow adsorption device can be fully regenerated and the BVOC released with proper flow conditions and vented in the external atmosphere.

As a general comment, my collaboration with Maria Irene Cardillo has been, and still is, of a nature able to emphasise and apply in a synergistic way all best achievements of my academic and professional career, with particular focus on environmental and technological design, including the bioclimatic approach.

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