Chapter 1
Innovations in Ventilative Cooling: An Introduction

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Abstract This chapter introduces the book's contents and its structure. It also includes a short description of why Ventilative Cooling (VC) is increasing in importance in a scenario where building cooling needs are growing. The building sector is responsible for about 40% of primary energy consumption; space heating, cooling and ventilation have proved to be the main consumers. Even though great efforts have been made to reduce energy needs for space heating, much less has been done for space cooling and ventilation. However, this situation is bound to change given that energy consumption for cooling is expected to supersede that for heating between 2050 and 2100. The main features of this growth are analysed in consideration of the international style of buildings, the growth in comfort expectations and changes in comfort culture, the growth in internal heat gains, increasing air temperature and urban heat island, as well as the side effects of the advancement in building envelope optimisation to reduce winter consumption (solar gains, airtightness). In order to face these new developments, which are linked with local increases in air temperature due to the thermal by-product of conditioners and related Green House Gas emissions, natural and hybrid solutions are needed. This book focuses on Ventilative Cooling techniques which aim to be a complete and reliable reference for designers and engineers who are working in the field of environmental design and renewable energy in the building sector. In this book Ventilative Cooling boundaries including all relevant information, background issues, techniques and applications are discussed based on the work of an internationally recognised group of experts. This chapter contains a short description of the contents of each part of the book.

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1.1 Background: Cooling Needs and Overheating Phenomena

Overheating of building spaces is a worldwide rising issue impacting at early-design, advanced-design, and operational stages [1]. This challenge is evident in all climate conditions, from heating-dominated regions to cooling-dominated ones, forcing cooling energy demands and increasing the world population living in uncomfortable indoor conditions due to lack of resources—a number that has grown to more than one billion of people [2]. The growing cooling demand to avoid overheating refers to several causes [3, 4]. In particular, at building level, the international style of buildings has produced a lack in bioregionalism detaching building envelopes from local climate and driving the provision of comfort in internal spaces by mechanical systems. Furthermore, current standards in several regions, such as Europe, are requiring high performances by new and retrofitted buildings focusing on the need to reduce heating demand by implementing high insulation levels and reduced infiltration. This approach, driven by heating dominated climates, needs to be faced carefully in warmer climates due to negative effects on overheating conditions, a challenge now evident even in colder climates during building operations [5, 6]. This effect can be shown by analysing the statistically ranked effects on energy outputs in building dynamic simulations. As an example, results for the Italian climate zones indicate a cooling dominant demand even in colder areas due to the increase in the heating related measures [7]. Additionally, rising in ambient temperatures result to increase overheating risks. This challenge is connected to climate changes and to urban heat island phenomena with a relevant impact on building operation in summer seasons—see Sect. 1.1. This effect has a high impact on building cooling needs, due to the high difference between the local Typical Meteorological Years (TMYs), which are generally used in design phases, and real climate under which buildings operate [8]. In addition, changes in the comfort culture and an improvement of life standards have driven the installation of new cooling units requiring more energy. Finally, a general increase in internal gains—e.g. by electronic devices—is observed during operational phases resulting to an increase in overheating and cooling energy needs. All of these aspects impact on building cooling demand and increase the energy "performance gap" due to an evident deviation between predicted energy demand at design stage and energy use during the operational phases. Several post-occupancy works underline a significant higher energy use in respect to the predicted one and a parallel overheating issue [1]. Studies based on climate models considering climate change scenarios, suggest that in 2100 cooling energy needs will overpass heating ones, even in several locations that at present have a heating-dominated climate [9].

Energy demand for space cooling has quickly growth during recent decades, reaching in 2010 a global consumption for cooling of 1.25 PWh [10, 11], a number which is still growing. This is due to the increase in the number of overheating hours, overheating intensity, and the number of installed cooling units. This trend is not only influencing areas where cooling systems have a high market penetration, such as Japan and U.S., but is also evident in fast-developing countries, such as

China, India, Brazil, and also at European level [2, 12]. In developing countries, air-conditioning industry has shown an evident growth in their market, which, in some cases, has registered a +70% increase in the period 2010–15, from 9 Billion to 16 Billion USD [13]. Additionally, in China the number of installed air-conditioners is growing almost exponentially, and was expected to reach 120 million of installed units in the warm areas in 2017 [14]. It is hence evident, that such an increase at global level requires alternative solutions to mitigate the growth in electricity consumption, to reduce electricity peak costs, prevent blackout risks, and avoid additional $CO_{2\text{-eq}}$ emissions.

Ventilative cooling is a potential solution to these challenges because of its ability to dissipating heat gains using the external air as a thermal sink, especially in climates where ambient temperature and humidity are lower than internal thermal comfort requirements. Referring to IEA EBC Annex 62 [15], Ventilative Cooling (VC) defines "natural or mechanical ventilation strategies to cool indoor spaces" by mixing outside low-temperature air with inside one to decrease energy needs of cooling systems and maintain thermal comfort conditions. Probably, one of the most known ventilative cooling mode is night ventilation (structural ventilation) based on increase ventilation airflows at night time [16], while other modes are for example environmental ventilation (cooling by air exchanges) and personal ventilation (direct airflows flushing on human bodies). VC is a very relevant technology applicable in an extensive range of building typologies to dissipate heat gains by activating the external air natural sink [17]. Main current use of ventilation principally refers to the replacement in a time unit of a given quantity of air in indoor spaces with the same amount of fresh air to guarantee indoor air quality (IAQ), nevertheless its potential for energy space cooling reduction is evident [18], acting on heat gains and air velocity. It is essential to support this solution by acting on standards and regulations, in order to allow to correctly valorise its potential, and supporting the diffusion of appropriate technical solutions [19].

1.1.1 Impact of Climate Change

As mentioned before, local and global climate change result on higher ambient temperatures and consequent overheating issues in building spaces. Climatic conditions have a direct effect on the building cooling loads, and this depends on air temperature, humidity, solar radiation intensity, and wind flows (speed and direction). Among a large number of indicators coupling building cooling energy needs and climate variables, the Degree-Hours index, a cumulative indicator, was adopted by several scientists [18, 20–22]. In addition, ISO 7730 and EN 15251 include the Degree-hours criterion by analysing the occupied hours that indoor operative temperature is above the upper operative temperature comfort limit—for a review of ventilative cooling-connected comfort indices see also [1, 23]. The Cooling Degree Hours (CDH) indicator is defined as follows:

$$CDH = \sum \left\{ \begin{matrix} \vartheta_{amb} - \vartheta_b \Rightarrow \vartheta_{amb} > \vartheta_b \\ 0 \Rightarrow \vartheta_{amb} \leq \vartheta_b \end{matrix} \right\} \quad (1.1)$$

where ϑ_{amb} is the hourly ambient temperature and ϑ_b the base temperature adopted to CDH calculation, defining a balance between ambient temperature and discomfort. This last indicator is generally ranging between 18.3 °C (ASHRAE) and 26 °C [24].

The CDH or the CDD, (which combines the hours to days), were correlated with high R^2 with the local cooling energy demand and the market penetration of air conditioners—see for example [20, 25]. CDH and CDD may also be used to define the impact of climate change on cooling energy demand. At macro-regional level, several researches have shown a global increase in CDD or CDH [11, 26] considering several case studies or focusing on specific regions, such as China [27], Switzerland [28], Africa [29], and the U.S. [22, 30].

A study of the CDD and HDD trends defined at average yearly base for EU-28 countries was carried out by elaborating Eurostat data [31] and is shown in Figs. 1.1 (CDD) and 1.2 (HDD). Figure 1.1 clearly shows how warmer regions have becoming hotter during the past 43 years, while a general increase in CDD is underlined at whole EU-28 level with an R^2 of 0.7039. In contrast, Fig. 1.2 shows a slow decreasing trend during the same period for almost all countries and at EU-28 average, but the R^2 is lower at 0.4.

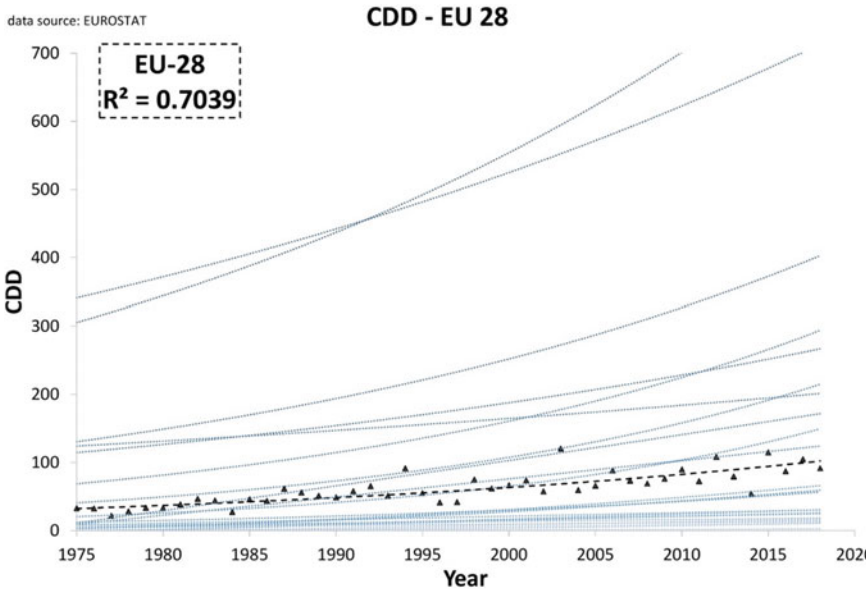

Fig. 1.1 CDD trends for EU-28 countries—average yearly data from 1975 to 2018. Blue dotted lines are regression *polynomial curves calculated for each EU-28 country, while the black dotted line is the regression trend for the average EU-28 data based on yearly value (triangular points). The R^2 value is sufficiently high to define that a general growing trend is evident for CDD in average EU-28 data (elaboration on Eurostat data)*

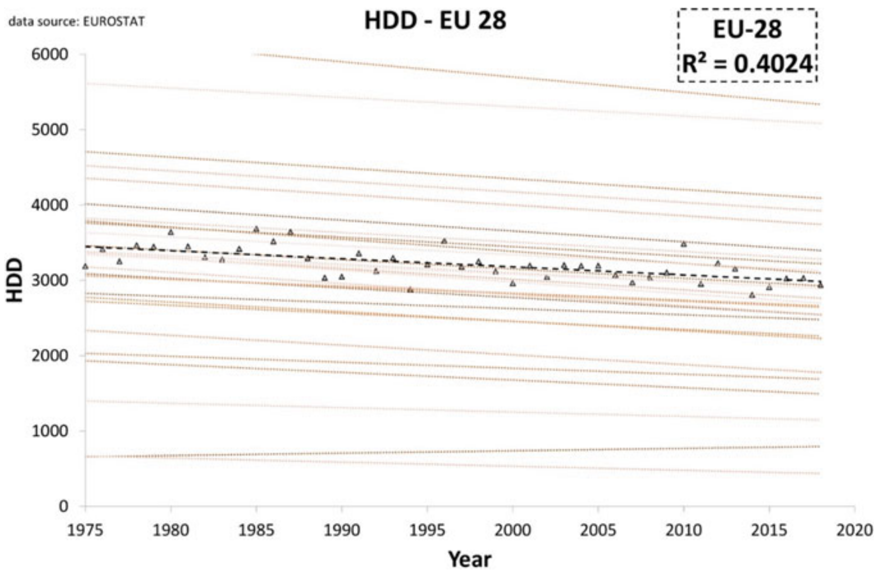

Fig. 1.2 HDD trends for EU-28—average yearly data from 1975 to 2018. Orange dotted lines are regression curves calculated for each EU-28 country, while the black dotted line is the regression trend for the average EU-28 data based on yearly value (triangular points) (elaboration on Eurostat data)

Focusing on three sample countries (Denmark, Belgium, Italy), the 10-year average CDD index was calculated using the same database (Eurostat) to analyse general trends. Furthermore, the percentage variations in respect to the 1975-84 period were generated. Figure 1.3 shows respectively the average values (a) and the percentage variation (b). Figure 1.3 shows more clearly the effect shown in Fig. 1.1, illustrating that in warmer areas the increase in CDD over time is evident, while in colder areas impacts less at average level. A similar result was also presented in [26]

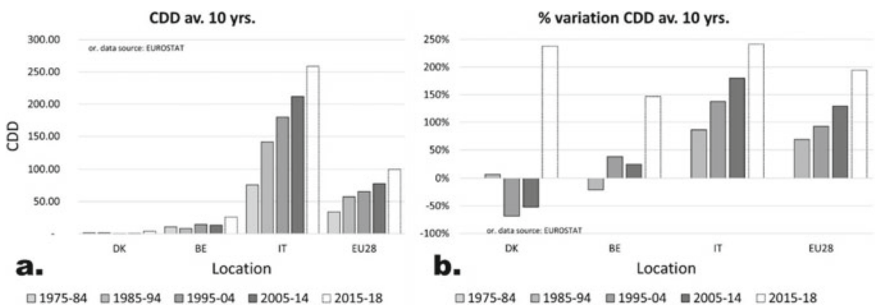

Fig. 1.3 10-year average CDD trends considering **a** CDD values and **b** percentage of the variation in respect to the 1975–1984 reference decade—elaboration on Eurostat data

on the base of 144 case studies. Nevertheless, it was demonstrated, by analysing mortality rates, that people living in heating-dominated locations are less resilient to temperature increasing, i.e. during heat waves, in respect to people living in cooling-dominated areas [32]. In the three example countries and in EU-28, average values show a rapid increase in CDD for the recent period, suggesting that ambient temperature increases will increase cooling loads demanding additional cooling energy in buildings.

The values presented in Figs. 1.2 and 1.3 were mapped in Fig. 1.4. In Fig. 1.4 NUTS (Nomenclature of Territorial Units for Statistics [33]) levels were used which is the European nomenclature of territorial units for statistics. NUTS level 2 (Regional level) was used, for Regions where this is reported, and NUTS level 0 (National level) was adopted for the others. For example, in France, only the Paris NUTS level 2 is accessible through EUROSTAT, while the other parts of the country is represented by the average country level 0 that includes both southern and northern regions. The maps in Fig. 1.4 clearly illustrate the progressive increase in cooling degree-days supporting the consequent linear behaviour of cooling energy demands. This growing trend is principally affecting, as mentioned before, warmer regions, but there is evidently a progressive increase of the warmer zone from South to North areas.

A recent study, based on a simple EnergyPlus residential unit simulated in 9 Mediterranean climates (Cs in Köppen-Geiger classification), shows a preliminary evidence on the fact that regression-based correlations between cooling demand and $CDD_{18.3}$ follow a similar trend for both current and future climates, even if datapoints are translated along the trend to higher values—see for example Fig. 1.5a concerning a naturally ventilated sample building [34]. The graph (a) includes two analyses, the first for a not insulated building (existing flat built in the 50–70s) (round points with larger dashed lines), and the second for an insulated building in line with recent building construction standards (triangular points with dotted regression lines). The same analysis correlates local cooling degree-days with correlated energy needs for cooling showing for both current TMY and future scenario a comparable regression trend with high R^2—see respectively blue and grey lines. For both scenarios, it is evident that a shift, following the same trend, on CDD and energy needs arrives between current and future predicted climate defining an expected increase in the cooling energy needs. It is hence important to verify if low energy cooling solutions, such as ventilative cooling, may cover this growth.

Hence, the priority level for ventilative cooling heat dissipation in Italy was recently analysed suggesting a slightly rise when IPCC A1B mid-scenario is assumed in comparison to current TMYs [35]. Priority levels were defined by combining local cooling demand, based in this specific study on the CDH index, and the potential heat dissipation due to ventilative cooling. Results of this analysis show that the number of locations with a very-low applicability for ventilative cooling is expected to growth in the future, due to a rise in external discomfort hours in several warmer locations when ambient air is too high to perform ventilative cooling—see Fig. 1.5b. Nevertheless, a rise was also expected for the very-high applicability class due to a

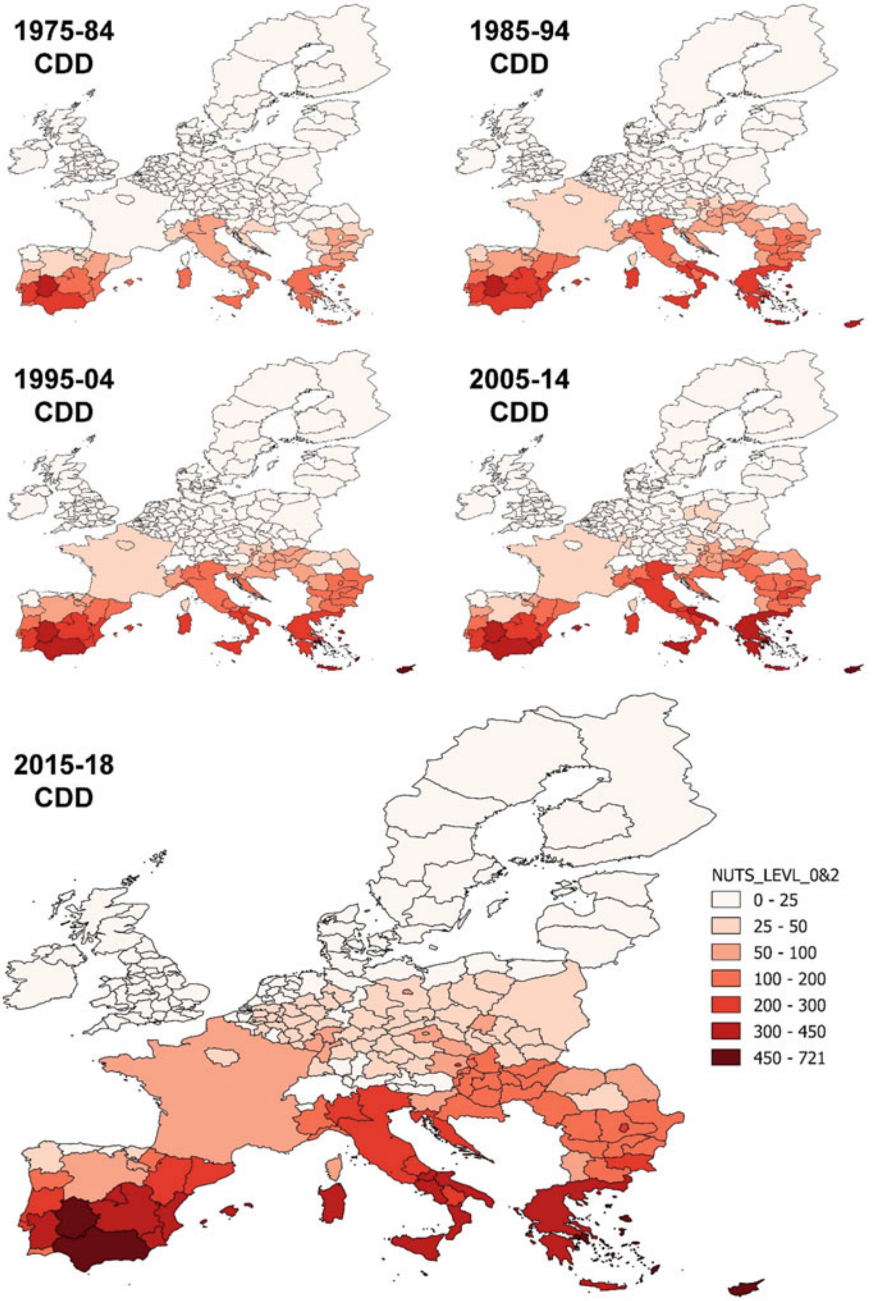

Fig. 1.4 10-year average CDD trends mapped for NUTS level 2 respectively for 1975–84, 1985–94, 1995–2004, 2005–14, and 2015–18 periods. *Note* When data of level 2 are not available NUTS level 0 is adopted—elaboration on Eurostat data

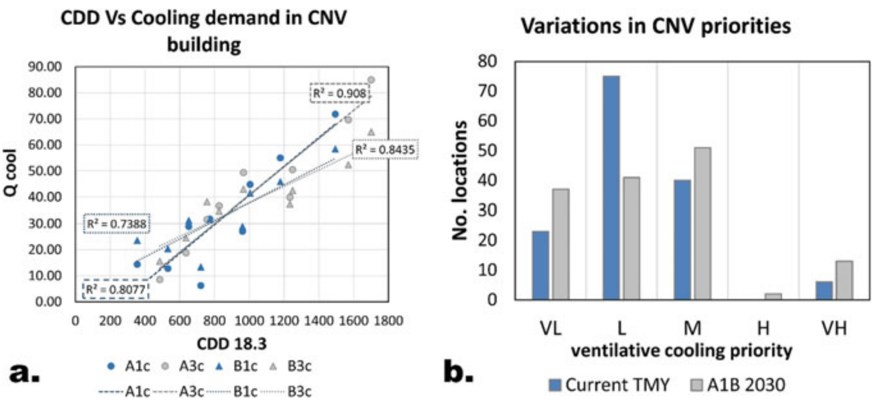

Fig. 1.5 **a** Correlation between $CDH_{18.3}$ and cooling energy needs assuming a reference residential building naturally ventilated in 9 Climate-Mediterranean locations. Case A and B are respectively for uninsulated and insulated buildings, while 1 and 3 are respectively current TMY and future A1B 2050 predicted one. Elaboration from [34]; **b** distribution of ventilative-cooling-priority classes considering current and future-scenario (A1B 2030) TMY for the Italian locations with more than 50 k inhabitants. Elaboration from [35]

higher demand for cooling in temperate locations, where the future predicted environmental air is expected to remain sufficiently low to cool spaces. Furthermore, this preliminary study shows a visible migration from low to medium priority classes—see Fig. 1.5b—thanks to an increase in the number of overheating hours showing a ventilative cooling potential.

Several studies on the topic are currently under development, while a IEA EBC Annex is now working to study "resilient cooling" solutions (Annex 80).

1.2 Innovations in Ventilative Cooling at Building and Urban Scale: Contents and Structure

This book focuses on Ventilative Cooling describing current state of the art of VC strategies and supporting VC diffusion as a valid alternative solution for space cooling and ventilation.

The book is subdivided into 3 parts defined as follows:

- Part I—Boundaries

This part introduces VC boundaries by including: i. general and specific information about VC (main principles, rules of thumb, key performance indicators (KPI), …); ii. background issues, such as comfort models for VC, standards and regulations; iii. new contents related for example to the effect of urban air pollution on VC.

- Part II—Techniques

In Part II the main aspects related to VC techniques and implications are treated in order to define a technical background for the reader and to introduce the latest research issues in the field. Specific aspects of VC are analysed including interaction with passive cooling techniques –e.g. for heat gain prevention, such as shading systems, for heat gain mitigation, such as thermal masses and phase-change materials (PCM)—, and with natural cooling systems—e.g. direct evaporative cooling (DEC), and earth-to-air heat exchangers (EAHX). Furthermore, the positive effect of vertical vegetation, the mixed usage of natural and mechanical VC and control systems are analysed.

- Part III—Applications

This third part describes how VC can be included technically in building design and how the techniques could work from an operational point of view for different building typologies. This part gives practical examples of VC usage, makes suggestions and explains case studies to professionals who are interested in including VC techniques in their projects. It focusses on the importance of controls, applicability to residential buildings (in which night cooling might be difficult to implement), tertiary buildings, and renovation of historic buildings (which have specific requirements but also opportunities because of their construction methods). Furthermore, each chapter covers a particular topic focusing in particular on residential buildings, offices and schools, and on the use of VC in historical building renovation. Additionally, a parametric analysis on ventilative cooling strategies together with climate and microclimate variations is included in the tertiary building chapter to support design actions.

Moreover, each chapter defines a specific VC topic focusing on:

- Ventilative cooling principles, potential and barriers|*Per Heiselberg, Aalborg University, Denmark*;
- Ventilative cooling and comfort models, focusing in particular on the adaptive comfort approach|*Fergus Nicol, London Metropolitan University, UK*;
- Ventilative cooling in standards and regulations, including recent proposals and released standards, and further recommendation for supporting VC applications|*Michal Pomianowski, Aalborg University, Denmark & Christoffer Plesner, Velux, Denmark*;
- Ventilative cooling and air pollution, focusing, in particular, on the minimisation of indoor PM2.5 and considering VC impact on HVAC electricity consumptions|*Guilherme Carrilho da Graça & Nuno R. Martins, Universidade de Lisboa, Portugal*;
- Ventilative cooling and control systems, analysing main control strategies to optimise VC system usage in buildings|*Hilde Breesch & Bart Merema, Ku-Leuven, Belgium*;

- Ventilative cooling in combination with passive cooling, focusing on thermal masses and PCM usage in combination with VC techniques|*Maria Kolokotroni & Thiago Santos, Brunel University, UK*;
- Ventilative cooling in combination with other natural cooling solutions, focusing on direct evaporative cooling technologies, analysing main DEC principles and defining devoted KPI|*Giacomo Chiesa, Politecnico di Torino, Italy & David Pearlmutter, Ben Gurion University, Israel*;
- Ventilative cooling in combination with other natural cooling solutions, focusing on Earth-to-Air heat exchangers, analysing main EAHX principles and technological requirements for building integration and connected KPIs|*Giacomo Chiesa, Politecnico di Torino, Italy*;
- Ventilative cooling and urban vegetation, studying the relation between green envelope technologies, heat gain prevention and positive effect on ventilation systems|*Katia Perini, University of Genova, Italy & Gabriel Perez, University of Lleida, Spain*;
- Ventilative cooling in residential buildings, describing several case studies in which VC is adopted to reach thermal comfort in buildings|*Paul O'Sullivan, Cork Institute of Technology, Ireland*;
- Ventilative cooling in tertiary buildings: description of the VC design experience for a school demo-case and a parametric analysis under Swiss climate conditions considering office, residential and school units|*Flourentzos Flourentzou, Estia SA, EPFL Innovation Parc, Lausanne*;
- Ventilative cooling in historical building renovation, analysing, using the case study of the Houses of Parliament UK, the practical application of VC over a period of 100 years, studying comfort perception|*Henrik Schoenefeldt, University of Kent, UK.*

This book allows to introduce VC issues, define main VC principles and aspects, and open to innovations in the field in order to prepare readers for adopting alternative space cooling solutions able in connecting climate and comfort issues to reduce energy consumptions and face one of the biggest challenges of our time: cooling spaces and providing user comfort in a heating world.

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