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LIVING IN THE AGE OF COMPLEXITY
Indoor air quality between technology, people and nature

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ABSTRACT
Over the last half-century, society has faced the scene of its future self-destruction and the unique condition of being aware of it, witnessing the alarms and warnings for our well-being and lifestyles. The anthropic landscape remains in a state of physical and environmental degradation, with settlements and communities experiencing social distress, pollution and inequality. Physical space, and its formal and social outcomes, are the product of human activity on the environment, adapted and manipulated to build settlements according to unsustainable lifestyles. Before the second industrialisation, human settlements were created by adapting human needs to the characteristics of the natural environment without compromising resources. Today, such ability to respectfully inhabit places is lost. The rate of technological innovation is weakened by consumerist logic, rather than strengthened in the direction of well-being and impact, and the construction industry is not immune to this trend. Health, safety and sustainability are the tracks that should guide development and innovation, both social and technological, the paper aims to rediscover and update these concepts within the construction process, to pursue a new balance between the built and natural environment.

KEYWORDS
living, environment, sustainable architecture, indoor air quality, technology

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The issue of sustainability is unavoidable in the discussion on the development models that contemporary society, on the brink of environmental collapse (Morton, 2019), should aspire to. Under scrutiny, individual habits, political strategies, and industrial productions. Everything contributes to the consolidation of counterproductive development prospects, seemingly innovative on the socio-economic level, but profoundly dangerous on climate and environment. The effect is increasingly evident in extreme climatic phenomena that, with the help of unrestrained anthropisation (Gould and Vrba, 2008), multiply the frequency of environmental disasters worldwide. To build a sustainable consciousness, the media play a central role, increasing community awareness of the risks to which the planet and people are subjected daily.

Pollution and toxic emissions and land consumption on a global scale (Stiglitz, 2006) are the ones for which many measures and strategies have been put forward. In early 2000s, also the world of design was questioning (Manzini 1997; Vezzoli and Manzini, 2007) the challenges of sustainability, which could only be achieved through a progressive dematerialisation of processes, products and services, which required a ‘leapfrog' of all the actors involved. Today, sustainable acceleration on a political, regulatory and design level, pursue environmental performance and risk prevention, recognising the economic, productive, and ecological results. Indeed, contemporary culture, strongly conditioned by capitalist demands for greater technical and economic availability and independence from natural resources, continues to erode and weaken the environment without fully satisfying the needs for urban quality and well-being for its inhabitants (Bragança et alii, 2010). From this complexity, new challenges emerge to ensure adequate well-being and quality of living, technological and social innovation and climate justice.

Sustainability scenario | After the many national and supranational strategies focused on sustainable development, it is necessary to reflect on the progress made and how to shape future measures, taking into account negative trends such as the growing demand for non-renewable resources and energy for industry, buildings and transport. While the objectives of sustainable development to contain the climate crisis are clear, the path to follow at the political level remains vague, while the financial market mobilises with investment initiatives to support the industrial sector to mitigate – sometimes only apparently – its ecological footprint. The paradox brings to the same side of the fence the same actors involved in the worsening climate crisis, who espouse the concept of sustainability for marketing purposes, without implementing or monitoring the impact of erosive production models. CO_2 emissions are increasing (IEA, 2022) and at every international summit, from the Rio Conference (UN, 1992) to the present day, increasingly ambitious goals are announced without having the tools to put them into practice, far from a real turnaround, at least on a global scale (Faloppa, 2016).

Beyond the theoretical and conceptual level, the complexity of sustainability lies in the difficult management of the multiple factors that condition all the productive sec-

Fig. 1 | Indoor Air Quality: 5 Things you need to know (source: Panasonic Corporation of North America).

tors, material and immaterial, of design and services. On the other hand, innovation in design and technology allows us to see, in the field of architecture and construction, concrete prospects for containing the environmental impact and the well-being of individuals in terms of health, comfort and safety of occupants (ECA, 2003). The call for greater scientific rigour is to be welcomed, lest environmentalism evaporates into propaganda, rhetoric or conformism. Already, the report A New Climate for Peace (Rüttinger et alii, 2015) called for the recognition of climate change as one of the threats to the stability of states and society, towards an inevitable and irreparable environmental catastrophe that should be taken into account. The most recent European political strategies (European Commission, 2019) foresight scenarios of environmental, economic, social, and pandemic crises, towards a new sustainable balance that counteracts the wild and predatory use of non-renewable resources.

Based on these assumptions, the contribution presents some research reflections to understand the principles that animate sustainable architecture (Özdamar and Umaroğullari, 2018). That is, whether they are more health, ecology, social justice or economic oriented, implying a cultural transformation and a technical revolution on the social and design spheres and their mutual impact. The implications on production systems, instead, simplified the industrial process while complicating the net of interrelationships between the disciplinary sectors involved. Thus, the concept of 'global technology assessment' (or technology evaluation) of the environmental impact of innovations in sustainable architecture design, according to a multi-criteria and multi-stakeholder approach to monitor and evaluate the obstacles – institutional, financial, legislative – and the solutions to overcome them. The building sector resists the ecological transition of its traditional processes, failing to challenge them problematically more closely related to designers and companies rather than to the market that has already aligned itself to the new requirements. According to Campioli (2005), the issue of pollution produced by the construction industry is a social issue, as it affects the quality of life, people and the environment, with catastrophic effects on the ecosystem and the economy.

The urgency to rethink development processes is a primary goal for national and supranational agendas and for non-academic scholars working on the formulation of degrowth alternatives that are clearly at odds with the paradigms that characterise today's society: capitalism, technicism and globalisation (Latouche, 2013, 2014). The issue that closely concerns the world of architecture and construction is the mutual implications of technique and technology in the growth of the global market and economic wealth at the expense of the environment. The goal of finding compatibility between transformation and environment, artefact and nature, production needs and

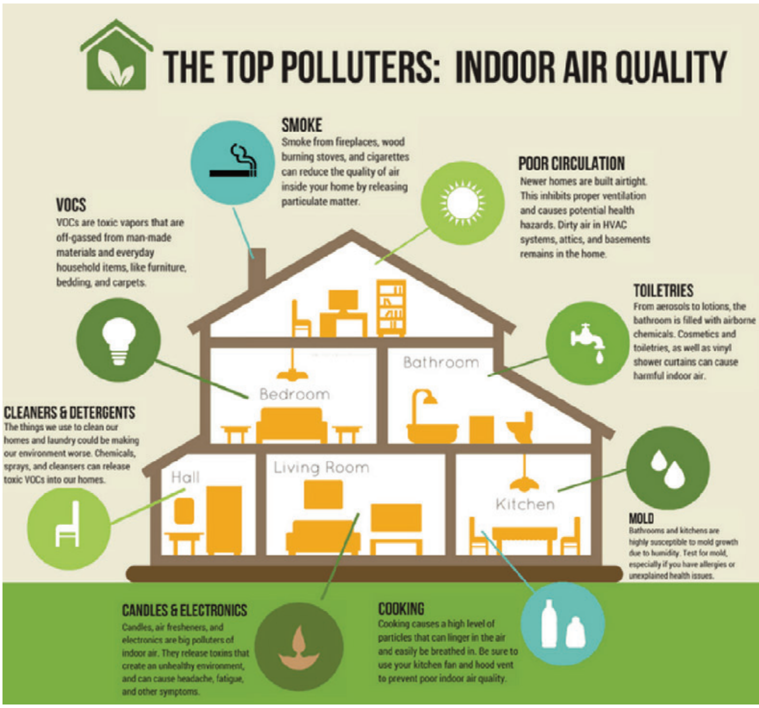


Fig. 2 | Emissions of air pollutants continue to play an important role in a number of air quality issues, states the Environmental Protection Agency (EPA) that, in 2018, about 76 million tons of pollution were emitted into the atmosphere in the United States; these emissions mostly contribute to the formation of ozone and particles, the deposition of acids, and visibility impairment (source: Danrich Environmental Controls Ltd).

Fig. 3 | Plants demonstrate important aspects of natural air purification, humidification and filtration that occur without the use of energy (source: Nedlaw Living Walls Official, nedlawlivingwalls.com).

Fig. 4 | The targeted use of vertical green enclosures to take advantage of possible air quality improvement qualities provides such systems with peculiarities that no other type of building wall can boast (source: Nedlaw Living Walls Official, nedlawlivingwalls.com).

global security requirements, is the real challenge for sustainable and self-sufficient architecture. The contribution discusses the interrelation between the concept of eco-compatibility and healthiness underlying sustainable architecture, with particular reference to Indoor Air Quality (IAQ).

From sustainability to IAQ | The discourse on sustainable development is influenced by different schools of thought (Lanza, 2006) due to heterogeneous boundary conditions, although they agree on the necessary measures to be taken in the construction sector: the formulation of verification criteria for use by the planner to contain the waste of resources, harmful emissions and any activity that threatens the availability of non-renewable resources, the healthiness of the urban and built environment and the wellbeing of individuals (Fig. 1). The most widespread sustainability criteria are global, difficult to scale and therefore difficult to apply in the design process that is also confronted with socio-economic demands oriented towards environmental issues. This gap is bridged by two perspectives: the 'glocal' one on the one hand and the trans-disciplinary one on the other. It is customary to integrate studies from different and very distant disciplinary fields: energy conservation, bioclimatic architecture, indoor air, materials technology, economic compatibility of innovative plants or waste management. These disciplines are united by the objective of conscious design, a synthesis between the needs of production, the needs of contemporary society and the laws of nature, and pursue an experimental approach, no longer exclusively theoretical.

Sustainable materials and technologies are proposed through design expressions appropriate for the recovery of concepts such as healthiness (Fig. 2) and material place of the project, oriented towards traditional construction techniques to counterbalance the negative impact of the use of chemical and synthetic materials for building components, furniture or finishes. In the absence of adequate regulations, controls and product testing, these sometimes proved to be a potential source of indoor air pollution in homes, offices and public places. This phenomenon worsened in the 1970s, with the energy collapse linked to the Middle East crisis and the oil market. Lacking resources to power heating and cooling systems, energy containment was pursued through the hyper-insulation of buildings and the strict enforcement of Italian Law 373/76. The sealing of the rooms and the inevitable lack of adequate air exchange led to a rapid deterioration of IAQ, previously guaranteed by the uncontrolled and inevitable leakage from windows and doors that were not perfectly sealed. Paradoxically, the worsening

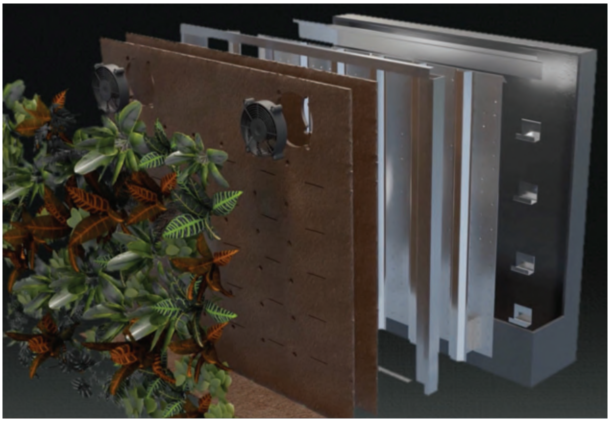


Fig. 5 | The ways in which plants affect air quality involve two factors: the natural humidification of the atmosphere and the biofiltration of pollutants (source: Nedlaw Living Walls Official, nedlawlivingwalls.com).

Fig. 6 | The use of vertical greenery as an air treatment system was adopted by a system called BioWall to emphasize its biofiltration characteristics. A few years later, in 2004, the same was patented in the U.S. under the name NEDLAW Living Wall. It consists of passing the air extracted from a given environment through the felt substrate of a plant wall: the cooperation between the physiological activity of the plants and the actions brought into play by the microorganisms present generates a passive purification of the air that will be ready to be re-injected into the same room. Harnessing the energy provided to them by the sun or by specific electric lamps, plants metabolize and mineralize organic or inorganic molecules in the atmosphere, while the action of bacteria helps eliminate both normal suspended dust and some pollutants such as formaldehyde, benzene, toluene, carbon monoxide, xylene, trichloroethylene, nitrogen oxides (source: Nedlaw Living Walls Official, nedlawlivingwalls.com).

Fig. 7 | The presence of asbestos in buildings (credit: infobuildenergia.it).

of IAQ is followed by an improvement, or perhaps a non-worsening, of air pollution, due to stricter regulations on pollutant emissions and the reduction of vehicle traffic.

The IAQ is not a new chapter of risk conditions linked to particular chemical or biological changes in the air, and it adds to those already known in the history of public hygiene and which have concerned the relationship between environmental conditions, the built environment and the individual: health requirements, risks from air pollution and safety in the workplace. The possibility that it is the home that poses a threat to its occupants is an unpleasant idea, but not a new one, as evidenced by the literature on building hygiene aimed at containing epidemics and diseases in place of overcrowding in confined spaces or the presence of hazardous conditions. Diseases such as rickets, tuberculosis, various forms of rheumatism and lung diseases found ideal conditions for development in cold, damp environments where sunlight rarely entered. The relationship between the built environment and disease gave rise to the concept of public health, which led, centuries later, to modern urban planning and hygiene regulations.

The contribution does not go into detail but recognises the historical evolution of the topic, starting with the Roman-era ordinances on the maximum height of buildings and continuing with Vitruvius' (2008), Alberti's (1966) and Broggi's (1888) proposals on the hygiene, healthiness and decorum of dwellings, up to the rationalist ideology of air, light and greenery. As early as the 18th century, Lavoisier sensed that the by-products of organic tissue combustion expelled through the respiratory tract, consisting mainly of carbon dioxide and reduced oxygen content, were the causes of stale air (Kimball, 1929). This hypothesis was disproved in the middle of the last century by experimental evidence, which showed that under normal room occupancy conditions, the CO_2 level in the confined air never registered values for which it could be harmful ($\approx 5\%$) and that in the case of crowding, the discomfort and discomfort affecting the occupants was felt much earlier than the limiting CO_2 values. It was realised that air pollution depended on the production of volatile organic products (VOCs), which are linked to the presence of humans in the environment. Called 'anthropotoxins' by the hygienists Brown-Sequard and D'Arsonval, they consisted of gases excreted by the lungs, the products of skin perspiration and sweating, and were therefore difficult to measure. With the development of industrial production processes, the attention of hygienists shifted to working environments by assuming high concentrations of pollutants and identifying the exposure risks to which people were subjected, defining the technical and regulatory precautions to be taken (De Capua, 2019).

The IAQ debate focused more on industrial cities, working-class neighbourhoods and production sites, where the main causes of pollution were found (De Capua, 2019) to optimise production by controlling the thermal, humidity and ventilation conditions of the environments. That this then contributed to decreasing the number of infections and illnesses contracted at work is incidental and much more will have to pass before this requirement becomes a right for workers and a regulatory requirement. Another reason for the deepening of IAQ control in industrial settings (Figg. 3-6) is the fact that production processes release high concentrations of pollutants into the environment. In contrast, dwellings have been the subject of study in terms of IAQ for little

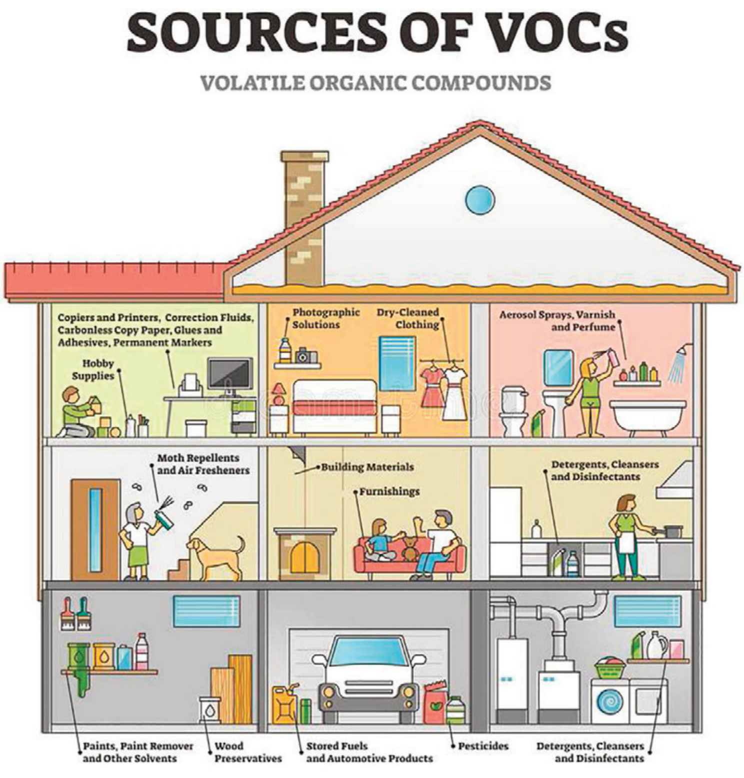


Fig. 8 | Indoor sources of VOCs with dangerous gases origin outline diagram; volatile organic compounds chemical toxic vapour from daily home items (credit: alen.com).

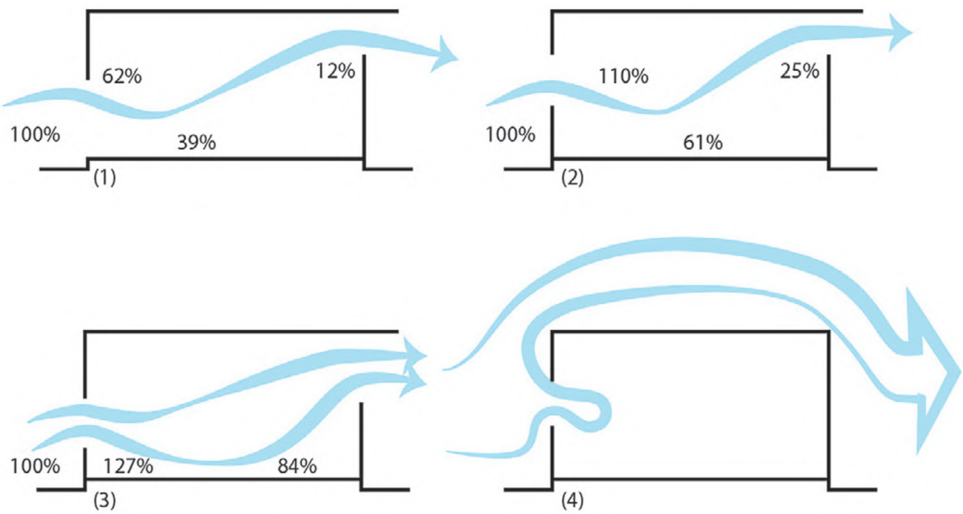


Fig. 9 | Location of inlet and outlet flow openings (credit: A. De Capua and L. Errante).

more than thirty years (De Capua, 2008) and, also to recent health issues, appears to be a field of investigation that has not been fully explored.

IAQ field embraces disciplines and skills required for an analytical approach and trans-scalar intervention strategies. Also, this represents the main obstacle to the implementation of design strategies and regulatory tools, at least in Italy, while in other countries the debate has produced greater results. The regulatory framework is evolving slowly, and although there are decrees and Community Directives concerning IAQ, the Ministries of the Environment and Health have indicated guidelines for research, design and experimental activities to support and promote legislative interventions (De Capua, 2008). Italian regulatory framework is limited to a few specific issues: the ban on smoking in public places to combat passive smoking; decontamination from asbestos (Fig. 7); the use of substances that can produce VOCs (Fig. 8). For other types of pollutants, the government has drawn up recommendations and information documents on health risks (Fig. 9).

The complexity of the topic requires a multi-sectoral approach to capture the variables and translate them into regulatory control indicators on an inter-ministerial, inter-administrative and inter-scalar basis. For example, public administrations and municipalities responsible for building regulations should participate in strategic and regulatory planning to determine the criteria and methods of control. Traditional regulation, fragmented in sectors (building, sanitation, workplace and production) does not have tools to deal with IAQ, environmental design, control or prevention of the healthiness of buildings. This is also due to the attitude of considering the building by

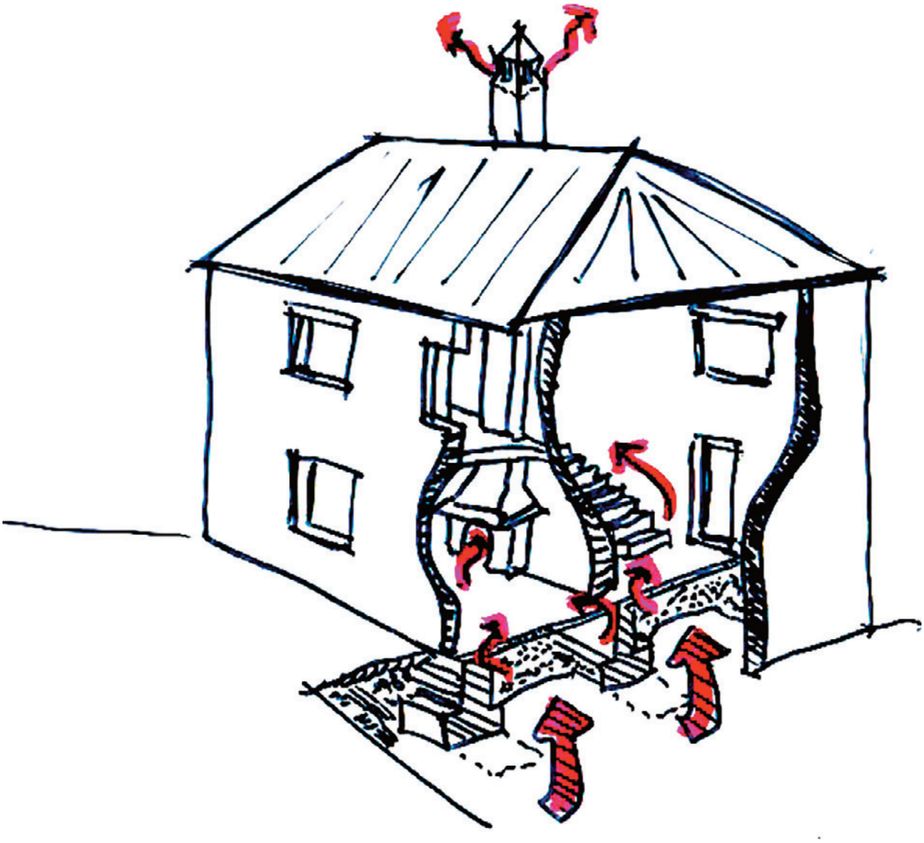
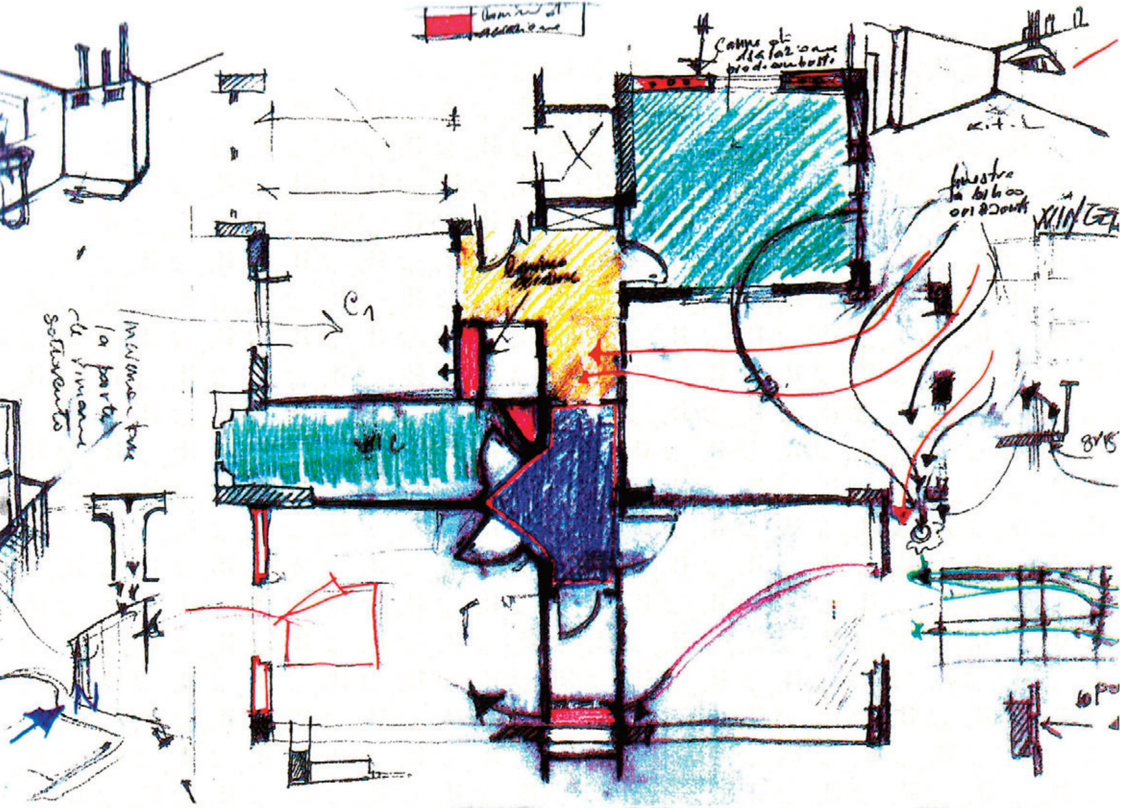


Fig. 10 | Radon infiltration (credit: A. De Capua).

Fig. 11 | Anti-radon membrane, corner kit (credit: brooksonline.ie).



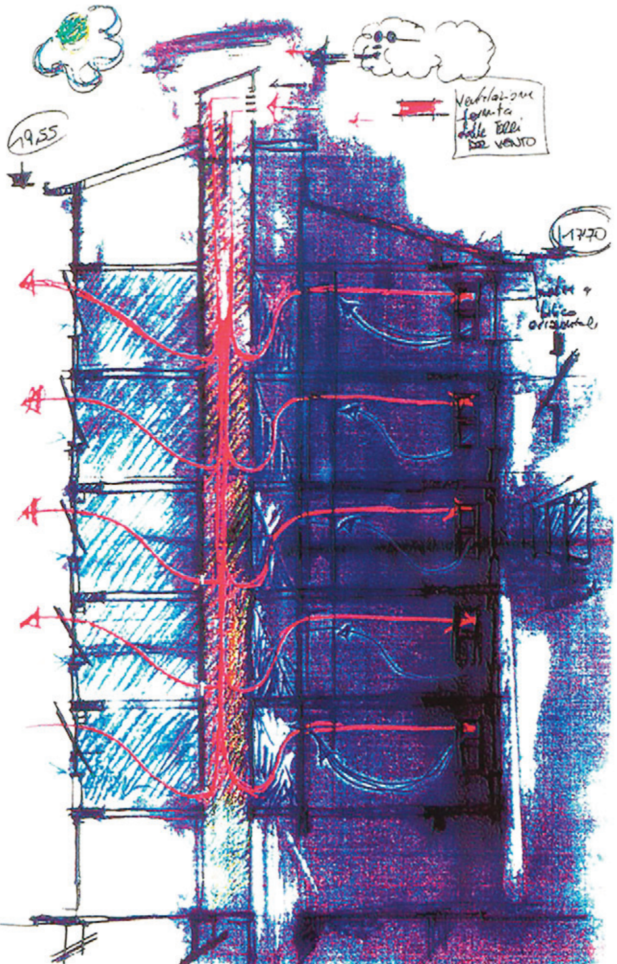


Fig. 12 | Case study, floor plan (credit: A. De Capua).

Fig. 13 | Case study, section (credit: A. De Capua).

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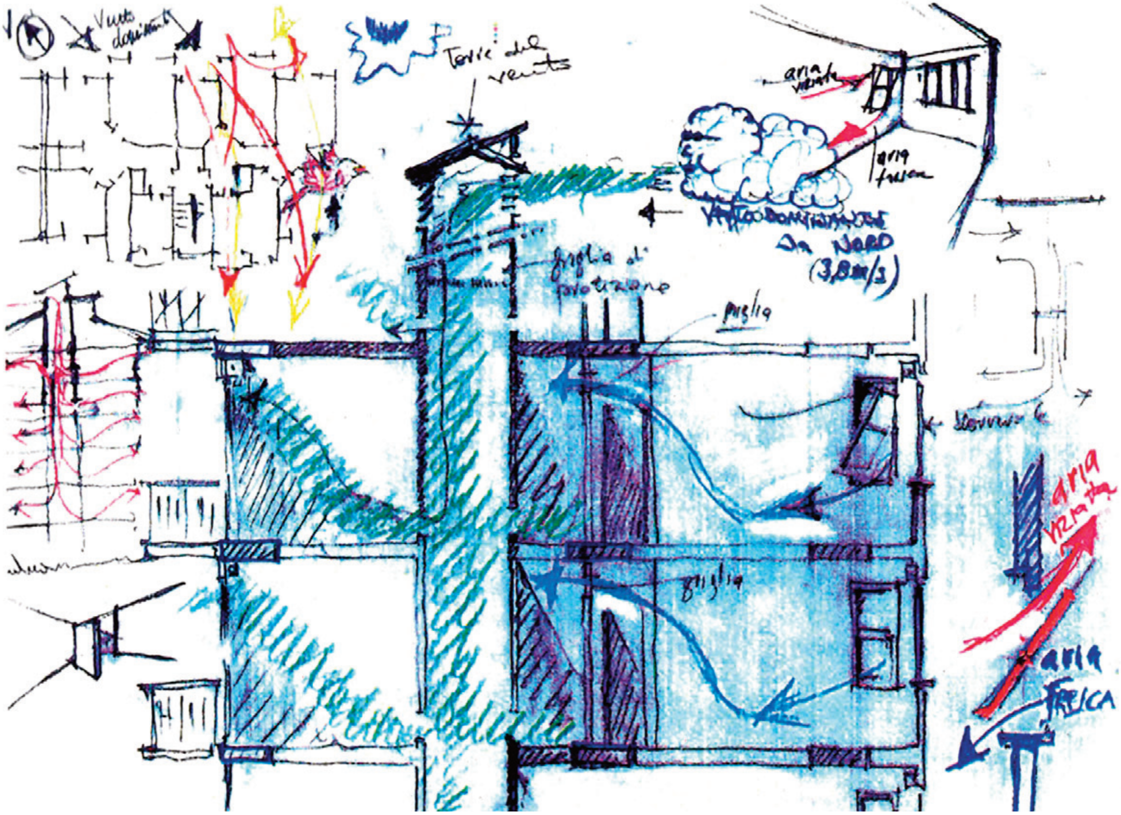
Fig. 14 | Case study, section (credit: A. De Capua).

Fig. 15 | Case study, section (credit: A. De Capua).



aria viziata
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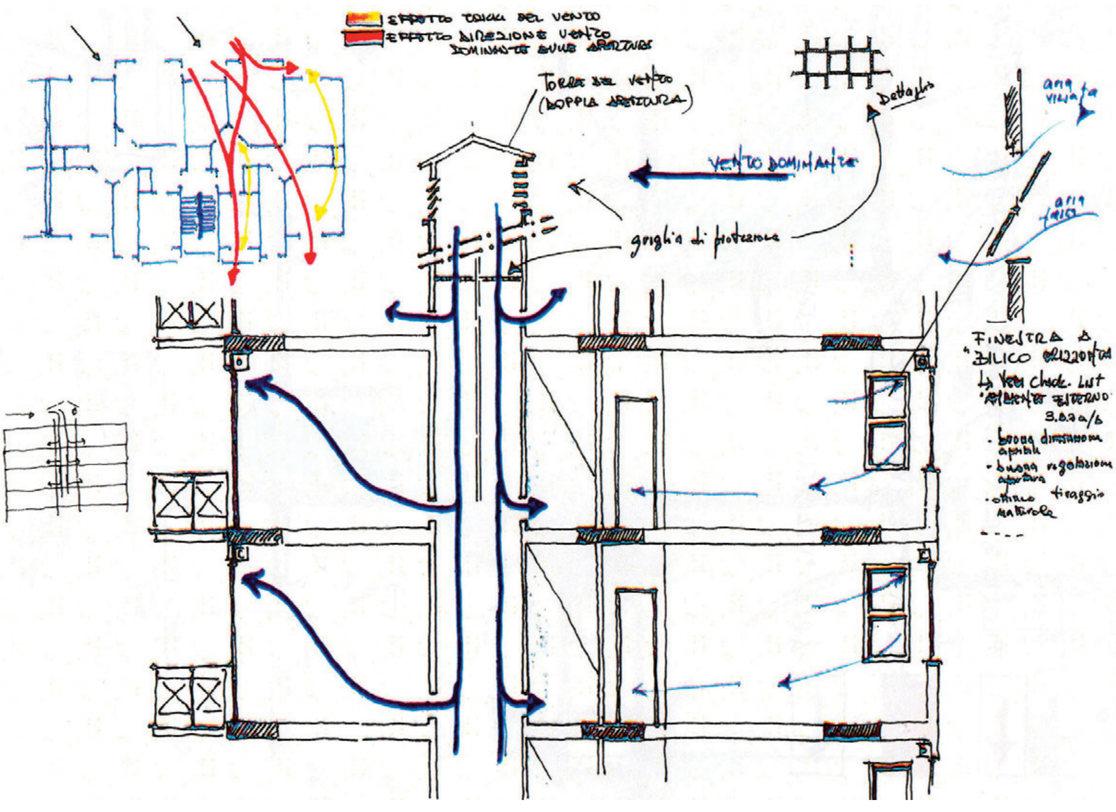
VENTO DOMINANTE
DA NORD
(3,8m/s)
griglia di protezione
griglia
ARIA FRESCA



TORRE DEL VENTO
(DOPPIA APERTURA)
VENTO DOMINANTE
Dettaglio
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aria viziata
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FINESTRA A
"BILICO ORIZZONTALE"

thematic areas and not as an organism (fire protection, sound insulation, moisture insulation, etc.) not considering the correlations between the many subsystems. This limits, if not prevents, an organic view of IAQ by parts and systems, and the involvement of specialists in the various fields (doctors, designers, manufacturers, chemists, etc.). Together with subject-specific standards that have not yet been regulated, it will be useful to revise existing standards in the hygiene and building sector to integrate tools for controlling IAQ.

It is reported that IAQ standards for workplaces are not scalable to other contexts and cannot be used as a reference, due to the peculiarities of the activities carried out and the morphology of the spaces themselves, which are very different from those in the home. The efforts in this field should be directed towards: interpreting current building regulations from the point of view of the effects they have on indoor air quality; documenting and critically reading the measures issued by other countries, which are more advanced in the study of indoor pollution; defining design rules and control methods; drafting or revising building regulations and prevention standards on the health and safety of homes.

Traditional prescriptions for environmental requirements do not guarantee the final quality of buildings and are often conditional on specific technological solutions. The same applies to performance standards, for which it is not yet possible to find indications for IAQ except in outdated regulations. The urgency lies in the fact that, in addition to air pollution and environmental damage on a global scale, the pandemic has brought indoor pollution to the centre of attention, making us rethink the impact on health. Long-term exposure promotes the onset of cardiovascular disease and increases the case of lung cancer. In the short term, the risk is the aggravation of respiratory diseases. In this sense, research should question the health outcomes of over-insulating buildings for energy efficiency reasons.

Controlling IAQ | The issue of IAQ is highly topical since most of the population spends most of their day in confined environments – be it the home, the office or a place of leisure or commerce. This attention is also motivated by increasing health concerns. According to Piardi (1990), the increasing complexity of the production process has also made it complicated to understand the interrelationships between different technical acts. The increasing use of inorganic chemical materials in industrial processes has brought hundreds of new materials into the construction field that should have perfected living and building. Instead, it has happened that the large quantity of new substances and materials has made it difficult to control the quality of the built environment, both concerning the building organism and its response to the needs of users.

Phenomena as speculative building and unrestrained urbanisation for economic growth without environmental or social compromises, and the design of such building complexes do not respond to criteria of internal or external environmental well-being for the inhabitants, neglecting even basic design criteria such as ventilation and natural lighting and their physical and psychological benefits. The rush to build at a lower cost of labour implies to use of materials easier to find but often unexplored. The spread of do-it-yourself has made potentially dangerous products accessible to the common people. These actions, individually and in their combinations, threatened IAQ.

In this sense, inside buildings, public or private, polluting conditions can occur even worse than outside, the causes of which must be identified to contain, reduce or eliminate the source. Technological evolution, which has participated in the progressive worsening of IAQ, can compensate with adequate quality control systems for the built environment and appropriate analysis of the occupants' needs and performance concerning the construction techniques to be adopted, including traditional ones. This perspective is connected to the need to formulate environmental, performance and hygiene requirements that can be integrated into the entire design and construction process, conception, information, technological and regulatory control. According to Nardi (1990), design is decisive both for the causes of discomfort and alternative interventions of prevention and resolution.

Designing a healthy building implies that different actors work together to control the performance according to environmental, normative and social requirements at all stages of the design process. The designer directs the performance of the building by reducing the risks of internal pollution, intervening in the control of factors that worsen IAQ and the reduction (choice of products) and confinement (design of plant location) of sources and dilution of concentrations (design of ventilation) and expulsion (devices for evacuation) of pollutants. The location, orientation, size, shape and envelope of the building, which interact with the air-conditioning systems and energy containment techniques, also need to be verified with their indirect harmfulness as a key factor. It is pivotal to set up a rigorous design procedure with assessment tools to exclude or minimise mistakes in IAQ with different levels of complexity. Checklists, lists of items and operations should be helpful to interrelated design models with design parameters assessed according to contextual conditions. This interdisciplinary process involves actors with specific skills for each control phase (Berglund et alii, 1991) to interpret the data collected and their mutual influence on IAQ.

An IAQ control tool does not limit the designer but empowers him to develop more effective solutions. Theoretical models define the problem from several points of view, noting that the main factors lie in four categories (Molina et alii, 1989): 1) Physical (temperature, relative humidity, ventilation, artificial lighting, noise, ions, fibres and particulate matter are those covered by national and international recommendations and relate to standards that must be met; 2) Chemical (ETS, formaldehyde, VOCs, biocides, CO_2, CO, NO_2, O_3, SO_2) which, too numerous to be considered individually, are usually classified into those emitted indoors and those from outside; 3) Biological (Microorganisms, bacteria, etc.); 4) Psychological.

Conclusions | Updating living quality regulations implies a general awareness of the cultural evolution of the concept of healthiness in renovation, redevelopment and new construction, integrating quality and performance control tools into the process. IAQ is the challenge of the near future, together with the renovation of minor historic centres, two themes that are often parallel when considering the difficulty of adapting older buildings to the norms of Building Regulations and housing or performance standards. Today, in building transformation interventions, technical choices pursue acceptable habitability conditions (Figg. 12-15), and IAQ is the basis of this condition. Recovery, then, is the revitalisation of the existing, restoring the built environment towards well-being, quality of life and liveability.

The perspective adopted in this contribution takes note of the profound transformation that has affected the field of building regulation, design and construction techniques as a whole, towards a renewed approach oriented towards the formulation of analysis or design support tools for controlling and monitoring IAQ. These topics are relatively new professional interests, hoping in the future for a shift from the methodological rigour of academic research to concrete tools for design control. The multi-disciplinary nature of the issue is a slowing factor, ranging from chemistry to physics, architecture to medicine, and climatology to materials science. On the other hand, the domestic sphere as a field of study and data collection makes it difficult to control the behaviour of inhabitants concerning material choices in design or integrated over time, often through a 'do-it-yourself' approach. Moreover, even when research has addressed the issue (see CR1752:1998 – Ventilation for buildings – Design criteria for the indoor environment), there have been no decisive spin-offs to the construction industry.

The authors are currently involved in a working group at the Department of Engineering of the 'Mediterranea' University of Reggio Calabria with a research unit on indoor pollution control, in the iCare project aimed at the realisation of an ICT Platform for home monitoring and techniques to improve the quality of life of patients.

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