buildings

Review

Natural and Mechanical Ventilation Concepts for Indoor Comfort and Well-Being with a Sustainable Design Perspective: A Systematic Review

Luca Zaniboni [1,2,*] and Rossano Albatici [1]

[1] Department of Civil, Environmental and Mechanical Engineering, University of Trento, Via Mesiano 77, 38123 Trento, Italy
[2] Department of Environmental and Resource Engineering, Indoor Environment, Technical University of Denmark, Koppels Allé, 402, 231, 2800 Kongens Lyngby, Denmark
* Correspondence: luczan@dtu.dk

Abstract: Current literature and guidelines on sustainable design often debate on the advantages of natural ventilation (NV) and mechanical ventilation (MV) on indoor environment and energy consumption. The present systematic review explores the existing literature comparing NV and MV on the indoor comfort and well-being points of view. The findings emphasize that thermo-hygrometric comfort is the main driver of occupants' ventilation behavior, while ventilation design is mainly led by indoor air quality targets. Moreover, more recent papers (especially after COVID-19 outbreak) emphasize the necessity of a health-based approach, contrasting airborne pathogens transmission. In this sense, MV is more frequently recommended in public spaces, while hybrid ventilation (HV) is often suggested as a solution to both ensure proper indoor conditions and energy savings. The concept of well-being is currently under-explored, as the present literature only refers to comfort. The same happens with topics such as visual, acoustic, and multi-domain comfort, as well as passive techniques such as night cooling, or analysis of specific environments such as healthcare facilities. Current knowledge would benefit from an expansion of future research in these directions. The choice of the best ventilation solution cannot ignore the context, type, and condition of energy efficient buildings, in order to properly take into account occupants' well-being.

Keywords: building ventilation; indoor comfort; well-being; energy saving; climate-responsive design

Citation: Zaniboni, L.; Albatici, R. Natural and Mechanical Ventilation Concepts for Indoor Comfort and Well-Being with a Sustainable Design Perspective: A Systematic Review. *Buildings* **2022**, *12*, 1983. https://doi.org/10.3390/buildings12111983

Academic Editors: Laura Canale and Biagio Di Pietra

Received: 18 October 2022
Accepted: 10 November 2022
Published: 15 November 2022

1. Introduction

It is well-recognized that the building sector has a key role in the framework of energy savings, being responsible for 40% of energy consumption and 36% of emissions of greenhouse gasses in the European Union [1]. For this reason, design concepts such as net-zero energy buildings (nZEBs), net-positive energy buildings (nPEBs), and climate-responsive architecture are fundamental to reduce the carbon footprint. In fact, in nZEBs the total annual energy balance (produced minus consumed) is equal to zero [2,3], while in nPEBs the balance is even positive [4,5]. On the other hand, climate-responsive design allows the creation of a structure intrinsically connected with building location, using responsive technologies to improve the performance of buildings [6–12]. Furthermore, indoor well-being cannot be neglected in buildings' design. The well-being concept is heterogeneous, and efforts have been made to define it. Nevertheless, the two aspects of environmental comfort and satisfaction, as well as cognitive performance, health, and productivity, emerge in the building context [13]. Therefore, a good definition of well-being regards it as the combination of feeling good and functioning well [14]. For these reasons, good indoor air quality (IAQ), thermal, acoustic, and visual conditions, and their interaction (multi-domain approach) as all part of the indoor environmental quality (IEQ), are fundamental not only for health and comfort, but also for other aspects such as physiological and psychological ones (e.g., working performance) and, since occupants tend to take action to make themselves comfortable, energy consumption [15–22]. Occupants can suffer from illnesses and complaints related with comfort, health, and safety in several indoor spaces [23]. Since the World Health Organization (WHO) Sick Building Syndrome declaration in 1986, IAQ, connected with health and comfort, has been strongly considered in indoor design [24,25]. In fact, several pollutants might be present in internal environments, with an adequate air-supply rate necessary to ensure healthy conditions for occupants [26–28]. In this complex framework, ventilation has a key and fundamental role, since it has high impact on both buildings' energy consumption and IEQ. Depending on the ventilation technique, which can be used in combination with other passive solutions such as the use of thermal inertia for night cooling and shadings to avoid solar heat peaks, the carbon footprint can be consistently lowered [29–35]. Moreover, ventilation choice cannot overlook the well-being of occupants, which needs to be the primary aim of indoor design [25,31].

Generally speaking, ventilation techniques can be divided into three main groups: natural ventilation (NV), mechanical ventilation (MV), and hybrid or mixed mode ventilation (HV or MMV). Each of these categories have different implications on energy consumed and comfort. NV, totally relying on natural forces (wind- or buoyancy-driven), can consistently lower buildings' carbon footprint [36–40]. Moreover, the acceptable range of thermal comfort was noticed to be enlarged when NV is present, with higher acceptance of high indoor temperatures when outdoor temperatures are high too [41,42]. This led to the introduction of the adaptive model for naturally ventilated buildings on ASHRAE Standard 55, which is now used together with Fanger's model in naturally ventilated buildings [41,43–45]. In addition to that, NV might be associated with benefits related with environmental and work satisfaction, productivity, and Sick Building Syndrome, as well as improved feeling of control for occupants and access to the outside environment [30,36,46–55]. The use of NV is suggested by Leadership in Energy and Environmental Design (LEED), in order to decrease both the carbon footprint and heating, ventilation, and air conditioning (HVAC) expenses. In this sense, positive correlations between fulfilled LEED rating and satisfaction perceived was demonstrated [56]. Conversely, the possibility to fully regulate temperature, airflow, and air velocity is a clear advantage of MV, of which performance is perfectly predictable and controllable if compared with NV, with positive implications on the IAQ [25,47,57–59]. The use of heat recovery units can partially overcome the drawback of the larger amount of energy with respect to NV [60–63]. Finally, HV can be a good compromise between the two techniques, guaranteeing energy savings, but exploiting MV when proper IEQ conditions cannot be met with NV only [29,30,55,64–69]. Current literature and standards argue on which of the two techniques should be preferred. Controversial opinions about this topic were also highlighted by the COVID-19 pandemic [70]. In fact, the risk of infection is strongly dependent on relative humidity (RH), temperature (T), and ventilation [71]. In this framework, ASHRAE recommended to use NV only in homes where MV or air-purifiers were not installed, in order to avoid thermal discomfort [72–74]. On the other hand, NV was also associated with the buildings' infection management [75,76]. In fact, CIBSE and REHVA recommended massive use of window openings, even in mechanically ventilated buildings and in winter [77,78]. Moreover, during London's lockdown, windows were noticed to be associated with positive cross influences of indoor mental well-being due to positive perceived soundscapes, vegetation view, and natural sounds [48,49]. In a global warming condition, the adaptive comfort model might cease to be fulfilled in plenty of indoor spaces in the next ten years [79], but a higher use of NV in colder climates might be induced by the shifting of climate conditions [30].

In this framework, it is clear that when dealing with concepts such as nZEBs, nPEBs, and climate-responsive architecture, the choice of ventilation technique is of paramount importance. Moreover, comfort and well-being should be among the main drivers in buildings' design, and therefore a strong literature background on how each type of ventilation influences comfort at different climates and seasonal conditions constitutes an important basis for proper design choices.

The aim of the present review to provide a framework on scientific evidence of papers comparing NV and MV in terms of comfort and well-being, in the perspective of performant and sustainable buildings' design (e.g., nZEBs, nPEBs, and climate-responsive buildings). The main hypothesis is that ventilation is firstly aimed to provide IEQ, with energy savings as a very important additional aim. For this reason, the following research questions were explored:

1. Which differences are present between IEQ conditions guaranteed by NV and MV?
2. Which ventilation techniques are more suitable at different climatic, seasonal, and outdoor pollution conditions according to both IEQ and energy perspectives?
3. Which ventilation techniques are more suitable with different building types and uses?
4. Which are the research gaps in terms of effects of NV and MV on the IEQ, depending on the type of building, the ventilation technique and the comfort domain considered?

If integrated with other studies, the articles here summarized can be exploited by policymakers in order to further expand and update ventilation standards and guidelines taking into account both energy consumption and indoor well-being. The development of such guidelines is fundamental for engineers, architects, and planners in order to help them in conscious and contemplated choices during the design process.

2. Methodology

2.1. Research Methodology

A systematic review [80] was performed using AND/OR Boolean operators [13] in a search on the Web of Science [81] database. The search was aimed at identifying all the studies regarding an NV-MV comparison in terms of comfort and well-being. Figure 1 reports the detailed search string used. The PRISMA flow diagram was used in the systematic review process [82].

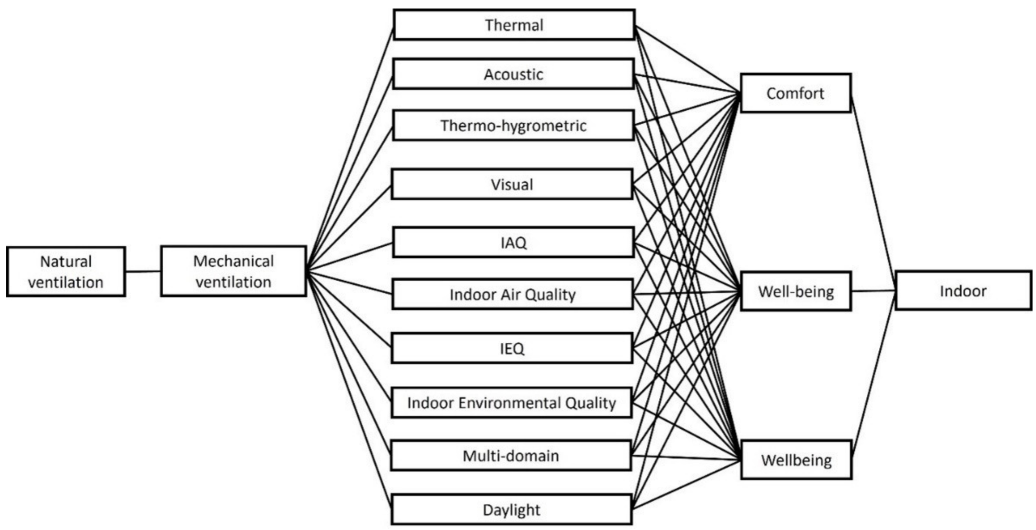

Figure 1. Boolean search string used for the first papers' search query. Keywords on the same column were linked with the "OR" operator, while black lines represent the "AND" operator.

2.2. Inclusion Criteria and Screening Process

All types of articles (journal papers, reviews, and conference proceedings) were included. In order to refine the research, considering only the relevant works, the following inclusion–exclusion process was applied:

1. Limiting of the research to English-written studies within the following research areas: (a) construction building technology; (b) engineering civil; (c) engineering environmental; (d) green sustainable science technology; (e) environmental sciences; (f) public environmental occupational health; (g) environmental studies; (h) architecture;

(i) thermodynamics; (j) engineering mechanical; (k) infectious diseases; (l) regional urban planning; (m) urban studies;
2. Titles and abstracts screening, rejecting all the papers not in compliance with the research questions, thus not comparing NV and MV on a comfort and/or well-being point of view;
3. Rejection of the studies which full text was not available;
4. Full papers' reading.

2.3. Categorization and Data Analysis

Based on the aim of the present research, selected studies were categorized according to different criteria:

1. Type of environment considered (residential, educational, working, healthcare, etc.);
2. Type of paper (journal paper, journal review, and conference proceedings);
3. Comfort domain analyzed by the paper (thermo-hygrometric, visual, IAQ, acoustic, or multi-domain);
4. Type of ventilation recommended, between "NV only", "MV only", "HV (or both HV and NV)", "no clear preference stated".

The geographical area and/or climate the studies were related to were also highlighted when applicable and specified. In the framework of sustainable design such as nZEB, nPEB, and climate-responsive architecture, outcomes in terms of energy consumption and savings were also highlighted. Moreover, when related with NV and when specified, the ventilation aim was also considered, dividing between air change, thermal regulation, and night cooling (as a more specific type of thermal regulation with remarkable passive design applications) [32,33,41,75,83–86]. Keyword co-occurrence analyses were performed by means of the software *VOSviewer 1.6.18*. Further statistics based on the publication year and publication geographic area were also considered.

3. Results

3.1. General Data and Statistics

Details about the number of papers found after each screening phase are reported in Figure 2. A total number of 94 papers was firstly found, with 68 eligible for full paper reading. After this last process, six more papers were rejected, with a final number of 62 papers considered and analyzed in this essay. Further details on the selection process are available in a PRISMA flow diagram in Figure A1 in Appendix A. Most of the included articles (71.0%) are journal papers, followed by reviews (19.4%), and conference papers (9.7%) (Figure 3).

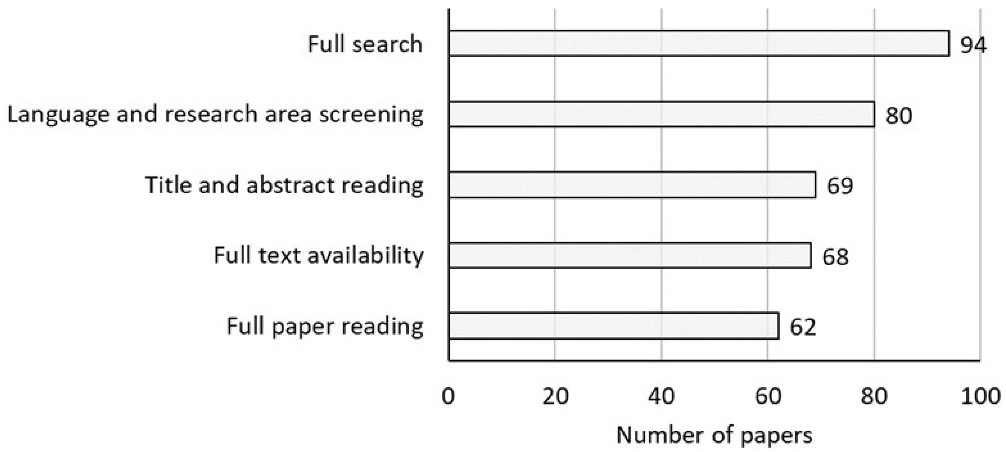

Figure 2. Papers found after each phase of the screening process.

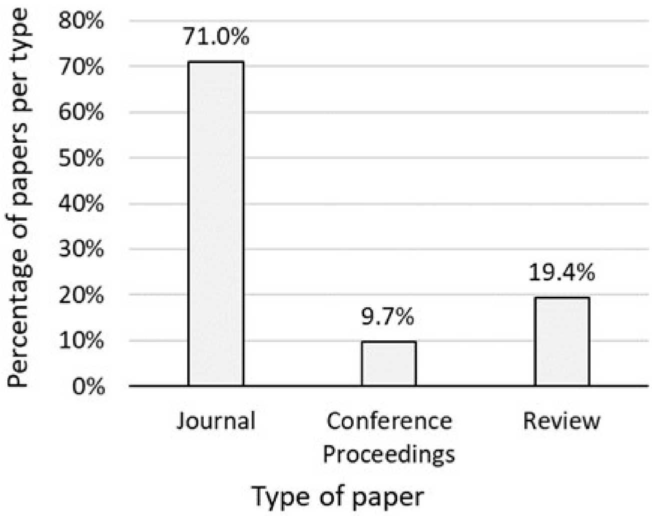

Figure 3. Percentage of papers per type.

Figure A2 shows the number of papers per publication year. It is clear that, starting from 1994, the topic gained a growing interest, with the number of published papers rising year by year (i.e., one in 1994, five in 2021). It is also interesting to notice that year 2020, during the COVID-19 pandemic, showed a peak in the number of papers (9), due to the obvious necessity to deepen the knowledge into ventilation related with infection airborne transmittance. Figure A3 depicts how the majority of the included articles were European (47.0%) and Asian (31.3%). On the other hand, only 4.8% of the papers were African, and none were South American. Details in Figure A4 show that England is the major publisher of included papers (11), followed by China (10), and USA (6).

Eventually, Figure 4 shows the co-occurrence keywords analysis (minimum occurrence number set equal to five for the representation) of the articles included in the present review. With 28 and 27 occurrences respectively, "natural ventilation" and "thermal comfort" were the most frequent keywords. "Indoor air quality" (in the three forms of "Indoor air quality", "Indoor air-quality" and "IAQ") was found 26 times in total. On the other hand, visual and acoustic comfort domains were not frequently explored ("acoustic" and "noise" appeared respectively one and two times, while "daylighting" appeared only once). Furthermore, it is important to highlight that neither the "well-being" nor the "wellbeing" keywords appeared in the articles included.

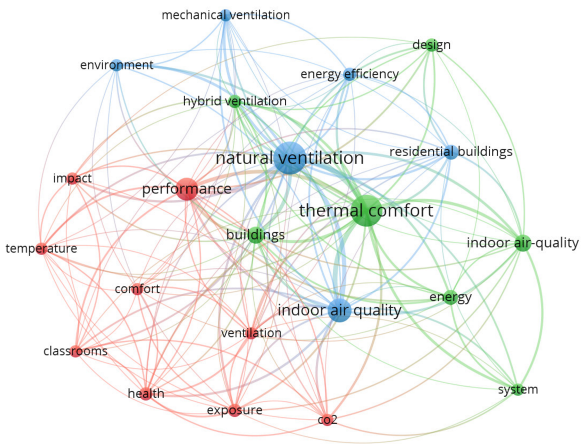

Figure 4. Co-occurrence keywords analysis of the articles included performed with *VOSviewer 1.6.18*, considering the keywords with a minimum number of occurrence equal to 5.

3.2. Papers Related with Residential Environments

In this subsection, results related with papers discussing NV and MV comfort comparison in residential environments are reported. A total number of eighteen articles were found, mainly journal papers (13) and conference papers (4), with only one literature review (1). The highest number of these research (9) were related to case studies located in Europe, followed by Asia (6), Oceania (2), and Africa (1). Ventilation for thermal regulation and ventilation for air change were analyzed, generally with a direct correspondence with thermo-hygrometric comfort and IAQ respectively. Night cooling was also considered in some cases, even though it was mainly listed as a way to better exploit NV. Thermo-hygrometric was the comfort domain most frequently considered by the papers here analyzed (15 articles out of 18), followed by IAQ (10 articles) and acoustics (6 papers). One paper considering visual and multi-domain comfort was found. Contrasting conclusions on which ventilation type is preferrable on the comfort point of view were found, as well as regarding the system providing higher energy savings. Brief summaries of the main findings are reported in this Subsection, in Table 1. The details concerning each paper, key data (type of paper, climate, and ventilation considered and suggested), comfort domains treated and main conclusions are present in Table S1 (available as Supplementary Materials).

Table 1. Key findings related with residential environments.

Thermo-Hygrometric Comfort	
Main findings	**References**
Improvement of thermal comfort or temperature control conditions when using MV or HV, especially when hotter or colder outdoor conditions are present	[87–93]
Good or better performance of NV in terms of thermal comfort	[94,95]
Thermal comfort is one of the main drivers of occupants' behavior associated with NV, with the air change rate and windows opening being dependent on outdoor temperature	[88,96,97]
Necessity of proper design of buildings where NV is planned to be exploited for thermal comfort (architectural elements, windows, openings, orientation, control, etc.)	[98–101]
In a Chinese students' dormitory during winter, temperature and humidity decreased to values under 20 °C and 30% after 4 h of night ventilation with ventilation rates of 0.050 m^3/s and 0.036 m^3/s, respectively	[100]
Too low or too high building tightness is associated with condensation risks	[96]
Too low or too high building tightness is associated with draughts or fluctuating temperature	[101]
In a temperate continental city of China, humidification was seen as an issue with both NV and MV, and occupants perceived drier conditions with MV	[95]
In developing countries, comfort range with NV might be larger (14.6–26.3 °C of comfort range found in an Ethiopian case study), allowing to satisfactorily exploit this ventilation technique	[94]
Thermal comfort, health, and energy savings are the three drivers of ventilation behavior	[97]
Visual comfort	
Main findings	**References**
A higher probability of windows opening was observed in Italy during 2020 winter lockdown, where a vegetation view was present	[102]
IAQ	
Main findings	**References**
Even though their priority is thermal comfort, occupants seem to be more inclined to spend more on energy if healthier environments can be provided	[97]
The use of MV is associated with better air quality or sweeping effect	[87,88,101,103]
MV can mitigate air-tightness issues (lowering the radon concentration from 412 Bq/m^3 to 70 Bq/m^3, and the CO_2 concentration to an average around 760 ppm in a Romanian case study)	[87]

Table 1. *Cont.*

Thermo-Hygrometric Comfort	
Direct link between air change rate (and ventilation behavior) and IAQ conditions	[96,100]
IAQ conditions are strongly dependent on outdoor conditions or air tightness of buildings	[92,95,103]
HV can be a solution when proper IAQ conditions cannot be met with NV alone	[100,104]
Acoustic comfort	
Main findings	**References**
Noise from both outdoors (NV) and systems (MV) can be a discomfort source	[91,92,97,101]
Together with thermal discomfort and stuffy air, noise can be one of the factors reducing the quality of sleep	[88]
During 2020 winter lockdown in Italy and UK, tendency by occupants to keep windows open, at least sometimes, even in urban areas. Necessity to include the concept of pleasant acoustic contexts in standards. Proposal of introduction of an "adaptive acoustic comfort" concept	[102]
Multi-domain	
Main findings	**References**
Study and application of multi-domain concept would be fundamental for the definition of acoustic criteria in naturally ventilated buildings	[102]
Energy consumption and other issues	
Main findings	**References**
MV can allow for reduction in consumption, due to less windows openings	[96]
MV can allow for reduction in consumption, due to the use of heat recovery (86% reduction found with respect to NV)	[87]
NV allows for less demand of energy	[91,93,95]
NV can be exploited with not extreme temperatures or not too high outdoor $PM_{2.5}$ concentration	[95]
Increase in energy consumption up to 20% found with MV in simulative study performed in Mediterranean climate: NV with night cooling suggested for smaller residential buildings, and MV or HV for larger residential or commercial ones	[91]
NV can allow for large energy savings in developing countries (wide comfort range in a field study in Ethiopia). Further research suggested to confirm this conclusion	[94]
Thermal comfort, health, and energy savings are the three drivers of ventilation behavior	[97]
Feasibility, safety, and life cycle costs need to be preliminary analyzed in the design process	[91]
Computational Fluid Dynamics (CFDs) simulations used or encouraged by a significant amount of studies, in order to study air movement and comfort induced by NV or HV	[89,90,98,99]

3.3. Papers Related with Non-Residential Environments

Works related with non-residential environments are here reported. Thirty-one papers were categorized within this group: twenty-five journal papers, two conference papers, and four reviews. Moreover, in this case, most articles were related to case studies located in Europe (12). Five case studies were in Asia and five in North America, while only one case study was in South America, one in Oceania, and one in Africa. One simulative study considered three climate areas, two in Europe and one in Asia. The articles here grouped mainly regard educational (12) and working environments (14). Articles regarding other facilities, such as industrial or healthcare, are also present. Moreover, in the case of non-residential buildings, thermo-hygrometric was the most explored domain (29 papers out of 31), followed by IAQ (21 papers), acoustic (10), and visual (6). Only three articles linkable with the multi-domain concept were found. Present literature is debating whether MV or NV provide better thermo-hygrometric comfort conditions in non-residential buildings. Moreover, similarly to what concerned residential buildings, while papers related with thermo-hygrometric comfort were mainly considering ventilation for thermal regulation, air change was the main focus of studies dealing with IAQ. Visual, acoustic, and multi-domain comfort were only marginally treated. It is finally fundamental to highlight how, after the pandemic, the main focus of the design seems to have changed to the control of pathogens transmission. Key findings are summarized in Table 2, while specific details about each article are reported in Table S2 (Supplementary Materials).

Table 2. Key findings related with non-residential environments.

Thermo-Hygrometric Comfort	
Main findings	**References**
In monitored classrooms in Beijing, both systems provided a too low temperature (below 18 °C) close to the beginning and the end of running heating period	[105]
1.5 ach^{-1} MV suggested in nucleus-type hospitals, in order to provide comfort conditions	[106]
Personalized ventilation suggested in order to have thermal benefits for occupants	[107]
NV alone is not sufficient to ensure thermal comfort in a large semi-transparent ceiling ocean park case study	[108]
NV or HV can be adequate to provide thermal comfort	[30,55,64,67,109–115]
During summer in Dubai, when NV is not sufficient, despite the too high outdoor temperature and too low wind, a reduction of 2–6 °C is possible in office buildings by NV	[109]
Definition of 7 °C outdoor temperature as lower boundary for NV to be ineffective	[115]
Definition of the range of applicability of NV between 10 °C and 25 °C of outdoor temperature	[30]
Preference for NV is often related with the higher degree of control of occupants	[25,30,55,111,116]
The negative effects of NV on productivity are under debate	[111]
A higher productivity by men workers when HV was used instead of MV was found in an office of Tokyo (Japan)	[114]
Dependence of thermo-hygrometric comfort on outdoor temperature and users' behavior	[29,60,67]
Due to global warming, NV use will decrease at warmer climates, simultaneously increasing in colder and mild areas	[30]
HV can be used when non-optimal conditions are achievable with NV only	[67,109,117,118]
Nighttime ventilation and night cooling can be exploited to enhance daily thermal comfort conditions	[30,67]
Specific discomfort conditions (draught, too low temperatures) found with colder outdoor conditions	[117,119,120]
The too low temperatures (around 18 °C) measured in Spanish schools during winter 2021 are admissible only during an emergency situation such as the pandemic	[119]
Importance of particular solutions such as temperature monitoring in schools, local discomfort avoidance (by means of humidifiers, electric heaters of exhaust heat recoveries), building orientation, proper design of the exhaust velocity	[66,112,119,120]
Importance of exhaust velocity optimization (e.g., depending on internal source of heat) in order to maximize thermal comfort and energy efficiency and minimize the short-circuiting risk	[66]
Visual comfort	
Main finding	**References**
Together with IAQ and acoustic, lighting is one of the IEQ aspects which needs deeper studies connected with NV	[111]
Daylight benefits of similar constructive techniques used for NV exploitation, such as operable skylights or high windows. Direct sunlight and large glazed façades can lead to drawbacks on both sides (i.e., overheating and glare)	[30]
Double-skin façades studied for NV have also the capability to provide natural light	[112]
Aspect considered in the study, without direct findings related with NV and MV	[55,106,117]

Table 2. *Cont.*

Thermo-Hygrometric Comfort	
IAQ	
Main findings	**References**
MV can help in providing optimal IAQ	[25,60,107,120–124]
Higher IAQ satisfaction in NV buildings	[113]
Small or no difference in the perception with the two modes	[125]
Difference in the indoor environmental conditions perceived and actually present indoor	[117]
The presence of operable windows can provide a feeling of fresh air perception	[55]
Use of HV recommended, exploiting MV when not sufficient IAQ can be maintained with NV (e.g., too polluted outdoor conditions)	[67,117,118]
NV might not be sufficient in air-tight buildings	[120]
NV will benefit from low polluting mobility solutions such ass electric vehicles	[30]
Most standards focus on perceived IAQ and CO_2 concentration or energy consumption, but several comfort, performance, and health issues are often reported in buildings: necessity to move from a comfort-based to a health-based design. In this sense, benefits can be obtained by the use of personalized ventilation	[107]
Poorly designed or operated ventilation can lead to poor IAQ, which can cause virus airborne transmission due to dry conditions in winter: necessity the adoption of health-based ventilation design	[25]
CO_2 concentration reduction (1000 ppm, with a 1400 ppm decrease) in Spanish schools during the pandemic, due to the most frequent airing	[119]
Importance of having long and frequent airing periods with NV	[67,118,121,126]
Suggestion of automated windows and/or CO_2 and pollutants monitoring devices	[117–119,122]
Acoustic comfort	
Main findings	**References**
Loud noise reported as one factor preventing the use of MV in Spanish schools	[119]
Importance of noise evaluation when designing the ventilation solution	[67,105,118]
Evaluation of noise with measurements or surveys in studies related with NV and MV	[55,117,122,123]
In university classrooms, the intermittent noise of intermittent windows was better tolerated than the continuous one of MV	[117]
Benefits from less noisy mobility will be provided to NV	[30]
Acoustics related with NV will need further studies in the future	[111]
Multi-domain	
Main findings	**References**
IAQ has the potential to influence the other comfort domains (e.g., higher noise with higher IAQ due to higher machines regimes, sunlight causing surfaces' emissions of pollutants). These aspects should be evaluated and studied altogether to assure comfort and health of occupants	[107]
Importance of deepening the studies of all the comfort aspects which are related to NV	[111]
Direct association of noise level and IAQ with MV	[123]
Energy consumption and other issues	
Main findings	**References**
NV or HV allow to save energy	[29,30,67,105,110,111,114, 117–119,125,126]
Energy savings of ranging from 3.1 to 85% (coupling it with PV- system) reported with the use of NV or HV	[114]

Table 2. *Cont.*

Thermo-Hygrometric Comfort	
Not using adaptive model encouraging NV in green certification systems, might obstruct designers' and occupants' change in decision	[111]
NV is widely used in schools of developing countries, in order to save energy	[127]
If properly designed and with the use of proper techniques (energy storage or heat recovery), reduction in energy consumption can be achieved with MV	[121,124]
Automatic windows coupled with heat recovery counter-flow system through outside wall slots can reduce the energy consumed in classrooms	[122]
Careful design of ventilation (architecture, presence of heat recovery, technological solutions such as occupancy sensors, temperature or CO_2 monitoring, night cooling coupled with massive elements) encouraged in order to reduce the carbon footprint	[29,66,67,106,109,118–120,123,124,126,127].
The use of local climate conditions instead of international standards, with a consequent expansion of upper and lower comfort limits, can lead to higher energy savings	[110]

3.4. Papers Not Linked to a Specific Environment Type (Various, Unspecified, . . .)

This subsection comprises the articles which do not refer to a specific type of environment. This is due to two main reasons: 1. articles (mainly reviews) referred to all the types of environments in general; 2. studies referred to general mock-ups or models. Consequently, seven papers among the ones in this subsection are literature reviews, constituting the majority of all the reviews considered in the present work. The rest of the articles here explored are journal papers (6). No conference papers are present in this subsection. Similarly, several studies (7) were not linkable to a specific continent, country, or climate. Among the others, four studies were related with Asia, one with Europe, and one was referred to tropical climate in general. Twelve articles out of thirteen considered the thermo-hygrometric domain. The domain was again followed by IAQ (9), acoustic and visual (5 each), and multi-domain (2). Moreover, also in this case, the thermo-hygrometric domain was mostly linked with ventilation for thermal regulation and IAQ was mostly linked with air change. Similarly to residential and non-residential sections, night cooling, when considered, was mainly named or implied (e.g., as ventilation performed at night). Brief summaries of the main results are reported in Table 3, while Table S3 (Supplementary Materials) contains further and specific details about the articles considered in this subsection.

Table 3. Key findings related with various or unspecified environments.

Thermo-Hygrometric Comfort	
Main Findings	**References**
NV can sometimes be inapplicable due to extreme conditions (temperature or running air)	[128]
In hot and humid climates (such as Malaysian) MV can be advantageous on the thermal comfort point of view	[129]
Well-designed NV is often adequate to maintain acceptable indoor thermo-hygrometric conditions	[130–134]
Wider ranges of thermal comfort are present in hot, humid climates, than what is generally indicated in international standard	[131]
Cooling from MV should be used only when adequate thermal comfort conditions cannot be guaranteed	[65]
Ventilation energy can be reduced only if comfort of occupants can be guaranteed	[31]
Importance of well-designed ventilation to guarantee occupants' comfort	[130,135]
Numerical models can be useful for control strategies	[133]
Visual comfort	

Table 3. *Cont.*

Thermo-Hygrometric Comfort	
Main findings	**References**
Similar constructive techniques such as atriums, double skin façades, and apertures can be exploited for both NV and daylight	[31,132]
Used together with the other comfort domains to categorize the studies considered in the review	[136]
IAQ	
Main findings	**References**
Even though NV is the cheapest and most often used environmental disinfection method against airborne transmittable diseases, proper disinfection is provided by MV	[128]
Higher morbidity cases (13–38% increase) and mortality (28% increase) related with NV adoption in residential buildings of Singapore; adoption of technologies such as MV and filtration from current NV in schools would diminish the number of asthma cases; mortality would also be decreased by the use of filtration in workplaces	[137]
Importance of taking into account occupants' behavior and pollutions' sources in ventilation design	[31,130,138]
Acoustic comfort	
Main findings	**References**
Noise is one of the parameters affecting occupants' behavior. Atriums and double-skin façades can be used to exploit NV, while protecting from noise	[31]
Importance of considering outdoor noise when designing ventilation	[130,133]
Used for categorization or marginally considered	[136,138]
Multi-domain	
Main findings	**References**
Elements such as daylight availability (heat-load related), thermal mass, and night ventilation (cooling load related) are essential for thermal comfort	[138]
Thermal perception is also influenced by healthy IAQ	[131]
Energy consumption and other issues	
Main findings	**References**
Energy savings are associated with passive cooling and NV	[65,128,130,132]
Necessity of coupling ventilation techniques with other passive strategies, with the aim of decreasing the carbon footprint of buildings	[131]
Climatic design for passive cooling, use of orientation and materials (e.g., for night cooling) and proper MV operations are fundamental for ventilation design	[130]
Necessity of studies on vernacular apertures and elements, as well as louvered windows to exploit night cooling, in order to maximize NV efficiency in tropical climate	[132]
Importance of more studies in the field of balconies' design, as well as post-occupancy evaluations, for NV optimization	[136]
Remarkable energy savings can be obtained by means of HV: more studies on smart window based HV should be made	[31]
Ventilation of unoccupied or low-occupied spaces leads to a significant amount of wasted energy	[31]
A combination of mechanical and passive cooling and different control strategies can lead to a reduction of more than the 60% of the system size and associated energy used	[65]
Use of models and simulations applied and encouraged in design and evaluation	[129,130,133,134]

3.5. Final Statistics

Table 4, on the left, reports the number of papers suggesting specific ventilation types. Nineteen papers do not express a clear suggestion between MV, NV, and HV. Among the rest of the papers, a relative similar share suggest NV (13) and MV (9), while most studies (21) recommend the use of HV in order to guarantee energy savings with backup mechanical systems when IEQ conditions cannot be maintained by passive techniques only. It is fundamental to stress that papers recommending HV normally suggest it when satisfactory indoor conditions cannot be reached with NV alone. For this reason, it was decided to group together papers recommending HV and both HV and NV, as "HV (and NV)". In the same table, on the right, the number of papers treating each comfort domain is reported. As previously implied, thermo-hygrometric is the mostly explored domain (56 papers), followed by IAQ (40), acoustic (21), and visual (12). Only six papers consider or name the importance of a multi-domain approach.

Table 4. Number of studies suggesting each ventilation type and number of studies treating each comfort domain. NV: natural ventilation; MV: mechanical ventilation; HV: hybrid ventilation; NP: no preference. T.H.: thermo-hygrometric; Vis.: =visual; IAQ: indoor air quality; Ac.: acoustic; M.Do.: multi-domain.

	Ventilation Type Suggested				Comfort Domain Treated				
	NV	**MV**	**HV (and NV)**	**NP**	**T.H.**	**Vis.**	**IAQ**	**Ac.**	**M.Do.**
N. of papers	13	9	21	19	56	12	40	21	6

Figure 5 allows to explore the association between the publication year and the type of ventilation recommended. It is interesting to notice how the share of papers recommending NV or HV (and NV) seem to slightly increase in time, probably in relation with energy efficiency issues. This trend seems to interrupt in 2021, most likely due to the pandemic, causing more research to suggest the use of MV for health reasons and contrast of virus transmission.

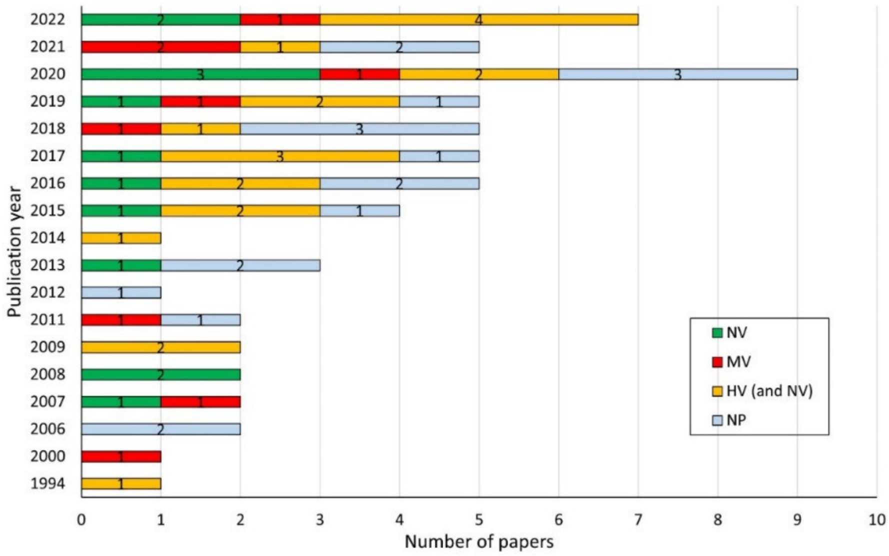

Figure 5. Association between ventilation type suggested and publication year. Numbers indicate the number of papers recommending each ventilation type. NV: natural ventilation; MV: mechanical ventilation; HV: hybrid ventilation; NP: no preference.

Similarly, Figure 6 shows association of comfort domain treated and year of publication. The share of domains considered does not seem to be correlated with the publication year. Nevertheless, as previous subparagraphs underline, visual and acoustic domain are mainly treated marginally, especially in older publications. New publications, instead, more often link these two domains with the multi-domain approach, which is actually more frequent in recent years. Nevertheless, the approach is mainly suggested without performing complete studies about it.

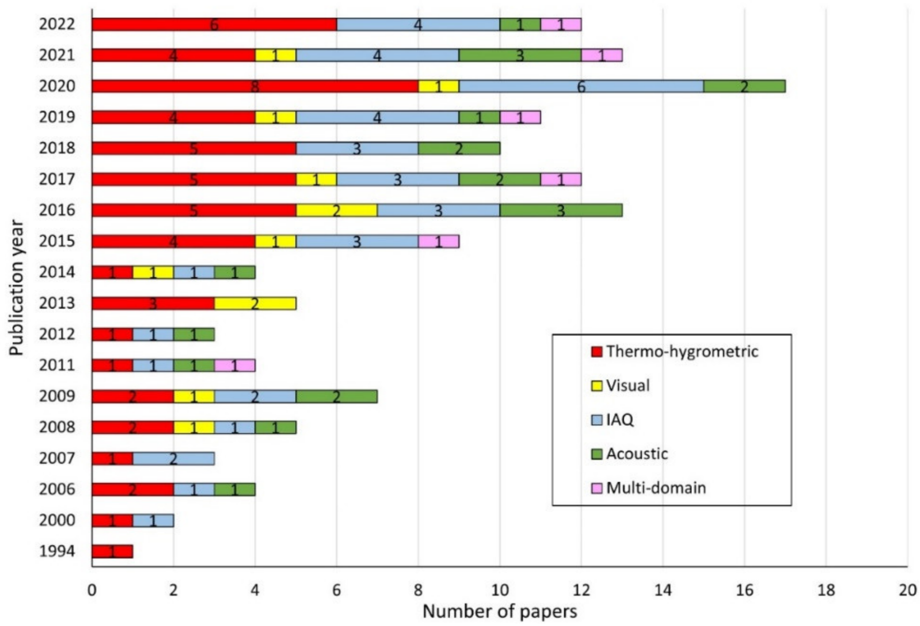

Figure 6. Association between comfort domain treated and publication year. Numbers indicate the number of papers considering each comfort domain.

The number of papers for each building category is reported in Table 5. Eighteen papers refer to residential environments. On the other hand, thirteen studies are not linked with any specific environment (e.g., laboratory studies) or are referred to various types of buildings (typically reviews). The majority of papers (31) regard non-residential environments. The highest share of these refer to educational (schools or universities) facilities (12) or working (office) facilities (14). The rest regard industrial (1), amusement (1) or non-residential buildings in general (2). Only one paper related with healthcare facilities was found. The details about the type of ventilation recommended depending on the building type are reported in Figure 7. It is clear that the share of articles suggesting MV or HV is higher in non-residential buildings.

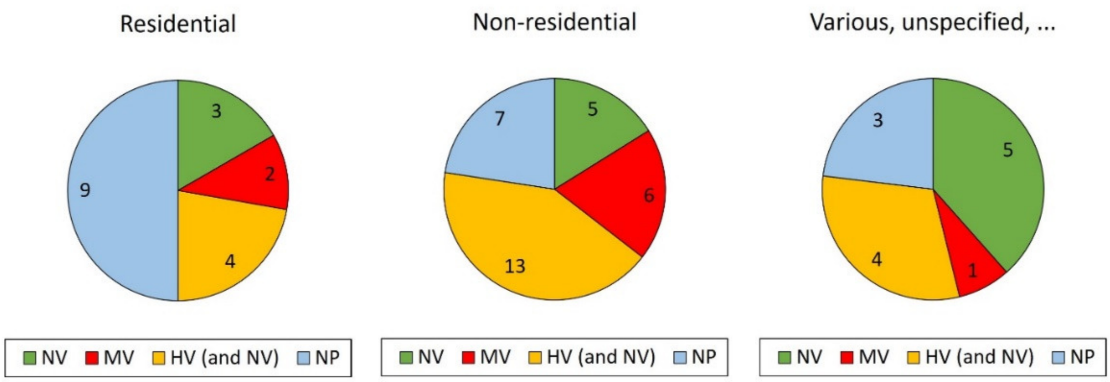

Figure 7. Type of ventilation suggested depending on building type. Numbers indicate the number of papers recommending each ventilation type. NV: natural ventilation; MV: mechanical ventilation; HV: hybrid ventilation; NP: no preference.

Table 5. Number of studies per building type. Res.: residential; Non-res.: non-residential; Var.: Various/Inapplicable; Edu.: educational; Hea.: healthcare; Wor.: working; Ind.: industrial; Amu.: amusement; Gen.: non-residential in general.

	Res.	Non-Res.							Var.
		TOT	Edu.	Hea.	Wor.	Ind.	Amu.	Gen.	
N. of papers	18	31	12	1	14	1	1	2	13

4. Discussions

The present literature review focuses on the comparison of IEQ conditions provided by natural ventilation (NV) and mechanical ventilation (MV), with the aim of collecting and offering a framework of scientific evidence to be exploited for sustainable design (e.g., nZEB, nPEB, and climate-responsive architecture). For this reason, the comparison of energy consumption by the two ventilation types was also highlighted, when present in the literature analyzed. When present in the analyzed articles, benefits of HV were also stressed.

The study permitted to highlight the following main considerations:

1. The articles comparing NV and MV in terms of indoor comfort and well-being found in literature are not very numerous. Moreover, even though current research is moving to the concept of well-being, this aspect is not explored in the studies included in the present review, as related keywords never appear in the articles analyzed. Most of the papers found regard non-residential facilities, in particular educational and working environments, underlining the key role of ventilation for obtaining healthy and comfortable conditions in highly occupied premises. Surprisingly, only one paper related to healthcare facilities was found. Several papers highlighting the performance of either MV or NV in healthcare facilities are present in the literature, but the comparison between comfort and well-being provided by NV and MV in this type of building is mainly under-explored. This is probably due to the specific field the present review is related with: studies about ventilation in hospitals that mainly deal with sanitation reasons; therefore, the comparison between the ventilation techniques mainly regards that topic instead of indoor comfort. The association between the number of studies and the publication year has been growing in time, with a sudden increase during 2020, due to the COVID-19 pandemic. The highest amount of papers was related to case studies located in Europe and Asia, highlighting a need for more research in other areas of the world. Most papers explored thermo-hygrometric and IAQ domains. When present, other domains were mainly considered only marginally, for instance stating that a relation between them and ventilation (e.g., noise) is present, and that further research in the field is necessary. During the most recent years, some articles highlighting the importance of multi-domain research appeared. Nevertheless, the topic has not been deeply explored yet.
2. Thermal comfort was the most frequently explored domain in all the types of environments. In all cases, contrasting conclusions on whether MV or NV is preferrable were drawn. Confirming what previously found in the literature, the main advantage of MV was recognized to be the ability to precisely set the indoor conditions. Nevertheless, this is not frequently perceived by occupants, who often prefer NV due to a higher degree of control over the environment they occupy and a major air movement, underlining the influence of the sensation of accessing to the outside. In this sense, the thermal environment was observed to be the main driver of occupants' NV behavior, with outdoor temperature (due to climate or season) being the main parameter affecting windows opening. Moreover, a shift in the usage of NV might be observed due to climate change, with the hours of windows opening potentially decreasing at warmer climates, but increasing at mild or colder ones. Furthermore, some articles highlight the presence of wider comfort ranges in warmer and/or developing

countries. This is probably due to reasons dealing with adaptation. The necessity of proper ventilation design to ensure the right indoor thermo-hygrometric conditions without creating local discomfort (such as draught) was stressed by several papers. In this sense, a more local focus, instead of the reference to international standards and the integration of other passive or active technologies such as night cooling or heat recovery, was promoted. No remarkable differences in findings were found among the different environment types.

3. After thermo-hygrometric, IAQ was the second most explored domain by the papers considered. Especially in residential environments, air tightness of refurbished buildings was seen as an issue for IAQ conditions and proper ventilation design. Particularly in non-residential buildings, MV was often associated with better air quality and less CO_2 and particles concentration. Type of ventilation must be carefully chosen depending on several conditions comprising outdoor pollution. In non-residential facilities in particular, a sudden change in perspective was observed after 2020, with a more health-driven vision of ventilation, strongly focused on the stop of airborne transmission of pathogens.
4. Visual and acoustic comfort were mainly explored marginally, as well as multi-domain approach. For instance, some recent works named visual and acoustic domains highlighting that their connection with ventilation, thermo-hygrometric, and IAQ conditions are important for future research, with a multi-domain point of view. Some papers highlighted how daylight and NV often benefit of the same constructive and architectural characteristics, such as high windows or operable skylights. Acoustic comfort was often explored in terms of noise, seen as an issue for the application of NV (when noise from the outside is present) or MV (poorly designed plants). Nevertheless, the effect of outside pleasant sounds or the so called "adaptive acoustic comfort" needs to be further studied and explored.
5. A high number of papers highlighted how energy consumption is the main disadvantage in the use of MV. On the other hand, NV might be too dependent on occupants' behavior and might lead to a loss of energy at colder or warmer conditions. Most papers, especially when dealing with extreme climates or larger and commercial buildings, proposed HV as a solution. This technique allows to lower the carbon footprint of buildings, while ensuring sufficient air change when proper indoor conditions cannot be met with passive solutions. The higher share of papers suggesting MV or HV in non-residential buildings is due to the fact that these facilities are constituted by environments which are normally studied for a higher number of occupants (i.e., schools, offices). For this reason, automated or semi-automated systems seem to be more adequate to guarantee the right amount of fresh air in these facilities. In order to improve the ventilation efficiency and the energy savings, the use of advanced technologies (e.g., heat recovery or energy storage) and proper and careful ventilation design were often promoted. For instance, focus should be placed on the optimal velocity of the exhaust in order to obtain the maximization of energy and ventilation efficiency without creating supply exhaust short-circuiting. In this sense, the use of CFD simulations was encouraged, helping with architectural characteristics improving NV, such as building orientation and position, façades, size, and location of inlets and outlets. Finally, a change in standards and guidelines was suggested by some authors in order to improve energy consumption and energy savings, for instance encouraging NV when possible.

5. Conclusions

Even though ventilation design is often aimed at ensuring adequate IAQ, thermo-hygrometric comfort seems to be the main ventilation behavior driver for occupants. Especially in non-residential buildings and after the COVID-19 pandemic, the approach in ventilation studies has slightly changed to a health-based driven, rather than a comfort- or energy-based one. In general, present research strongly highlights that hybrid ventilation is the most recommended solution in order to guarantee both energy savings and proper IEQ conditions when not achievable with natural ventilation alone. This is particularly true in extreme or polluted climates, where window openings alone can lead to poor indoor conditions, and/or highly occupied or healthcare environments, where NV alone might not be sufficient to maintain an adequate level of IAQ and healthy conditions. The literature analyzed also suggests that, when possible (e.g., residential environments and smaller offices) the hybrid solutions should also consider the necessity of control by occupants, allowing to switch to a total manual system if required. Proper design of ventilation is encouraged, promoting the use of numerical modelling such as CFD analyses, in order to ensure IEQ and avoid issues such as short-circuiting of supply and exhaust air and draught sensation by occupants. From present literature, it was highlighted how some topics remain under-explored. The current tendency in indoor climate studies is to move from the concept of comfort to a more holistic well-being one, considering aspects related with comfort, satisfaction, health, and well-functioning. Nevertheless, the concept of well-being was not explored in the literature here analyzed. Moreover, only marginal attention was provided to visual, acoustic, and multi-domain comfort. Other under-explored topics regard passive technologies such as night cooling, as well as some types of environments such as healthcare facilities.

6. Future Developments

Ventilation is a key factor in the field of sustainable design, specifically regarding nZEB, nPEB, and climate-responsive design, as energy savings strongly depend on ventilation techniques. In this framework, the choice of proper ventilation type (to be energy-driven or IEQ-driven) cannot be made regardless of indoor comfort and well-being. The use of either NV, MV, or HV is highly dependent on the climate, the outside pollution, the building type, and the season. In this sense, the ventilation system should be coupled with sensors and smart home solutions, being able to switch from one typology to another whenever the indoor and outdoor conditions allow or require it. Moreover, warning sensors might be useful to advise occupants on the indoor pollutants and CO_2 concentration when NV is used.

Studies addressing the topic of well-being related with the comparison of NV and MV are beneficial for human-centered indoor building design. Moreover, the literature, standards, and guidelines would benefit from studies on ventilation exploring comfort with a multi-domain perspective. Ventilation is clearly and directly connected with thermo-hygrometric environment and IAQ, but recent studies agree on how all the comfort aspects interact (e.g., noise-IAQ, emissions of pollutants with higher sunlight, phycological aspects). For this reason, comfort studies coupling subjective surveys with objective measurements, and correlating the comfort perception in terms of the four domains with each other would be necessary. Moreover, some environments such as healthcare facilities need further research in terms of comfort related with comparison of different ventilation techniques. Ventilation studies might be mostly health-driven in these environments, but a significant amount of previous literature underline the relationship between healing processes and indoor well-being [52,139–141]: therefore, this aspect cannot be neglected.

The exploitation of night cooling allows to further exploit natural ventilation during nighttime, when lower temperatures are present, using the delay in the heating process of massive elements. Therefore, comparative comfort studies with and without this technique would allow to assess the comfort benefits during morning hours, further encouraging designers and stakeholders to exploit this technique. Other innovative passive solutions have been proposed in the last years, including the use of internal cladding for improving the thermal inertia, the coupling of massive elements with the smart use of shadings, use of compact form to reduce the heat loss through the envelope area, organization of spaces (e.g., non-habitable areas on eastern and western sides to act as additional thermal buffers, living rooms towards south to better exploit solar gains, etc.), air quality control through proper selection of materials in air-tight buildings, etc. [34,35,97,142–153]. The use of these techniques should be explored in terms of indoor well-being when coupled with MV and NV systems.

7. Limitations

The present paper aims at providing an overview on the comparison of IEQ conditions provided by different ventilation types. For this reason, it was chosen to include only papers comprising and treating both the types of ventilation, in order to highlight the points in common and differences in the indoor conditions and energy savings provided by each ventilation technique. For this reason, the research can be expanded considering the two ventilation types separately. Moreover, as it is common in review processes, the final papers analyzed depend on the search query, the inclusion criteria, and the database considered.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings12111983/s1. Table S1. Studies related with residential environments: summary of key data, comfort domain treated, approach, main conclusions and type of ventilation recommended. JP = journal paper; R = review; CP = conference paper. A.Ch. = air-change; T.R. = thermal regulation; N.C. = night cooling. "T.H." = thermo-hygrometric; "Vis." = visual; "IAQ" = indoor air quality; "Ac." = acoustic; "M.Do." = multi-domain. NV = natural ventilation; MV = mechanical ventilation; HV = hybrid ventilation; NP = no preference. "Env." = environment; "Vent. Rec." = ventilation recommended; "Res." = residential. T = temperature; RH = Relative Humidity; ACR=air-change rate. Table S2. Studies related with non-residential environments: summary of key data, comfort domain treated, approach, main conclusions and type of ventilation recommended. JP = journal paper; R = review; CP = conference paper. A.Ch. = air-change; T.R. = thermal regulation; N.C. = night cooling. "T.H." = thermo-hygrometric; "Vis." =visual; "IAQ" = indoor air quality; "Ac." = acoustic; "M.Do." = multi-domain. NV = natural ventilation; MV = mechanical ventilation; HV = hybrid ventilation; NP = no preference. "Env." = environment; "Vent. Rec." = ventilation recommended; "Edu." = educational; "Hea." = healthcare; "Wor." = working; "Ind." = industrial; "Amu." = amusement; "Gen." = non-residential in general. T = temperature; RH = Relative Humidity; ACR=air-change rate. Table S3. Studies not related with a specific type of environment: summary of key data, comfort domain treated, approach, main conclusions and type of ventilation recommended. JP = journal paper; R = review; CP = conference paper. A.Ch. = air-change; T.R. = thermal regulation; N.C. = night cooling. "T.H." = thermo-hygrometric; "Vis." =visual; "IAQ" = indoor air quality; "Ac." = acoustic; "M.Do." = multi-domain. NV = natural ventilation; MV = mechanical ventilation; HV = hybrid ventilation; NP = no preference. "Env." = environment; "Vent. Rec." = ventilation recommended; "Var." = Various/Inapplicable. T = temperature; RH = Relative Humidity; ACR = air-change rate.

Author Contributions: Conceptualization, L.Z. and R.A.; Methodology: L.Z. and R.A.; Formal Analysis: L.Z.; Investigation: L.Z.; Resources: R.A.; Data curation and data interpretation: L.Z.; Writing—Original Draft Preparation: L.Z.; Writing—Review and Editing: L.Z. and R.A.; Visualization: L.Z.; Supervision: R.A.; Project Administration: R.A.; Funding Acquisition: R.A. All authors have read and agreed to the published version of the manuscript.

Funding: The research received support from the project "Climate Positive Circular Communities"—"ARV" funded within the European Union's Horizon 2020 Research and Innovation Programme, agreement No. 101036723.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A

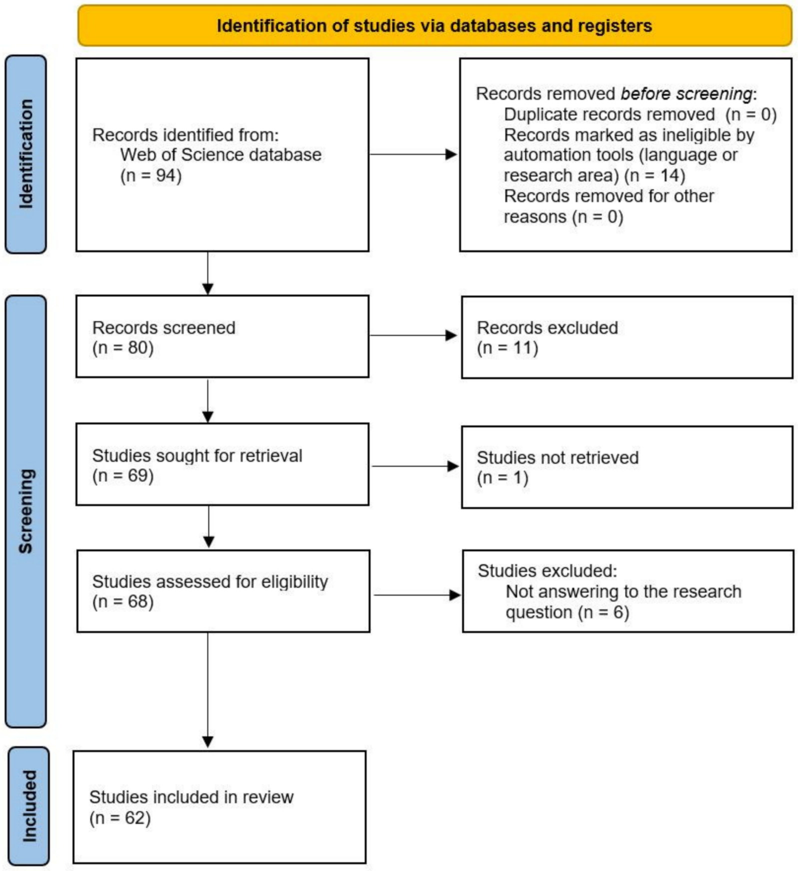

Figure A1. PRISMA flowchart depicting the inclusion/exclusion and screening process. Adapted with permission from PRISMA Website [82].

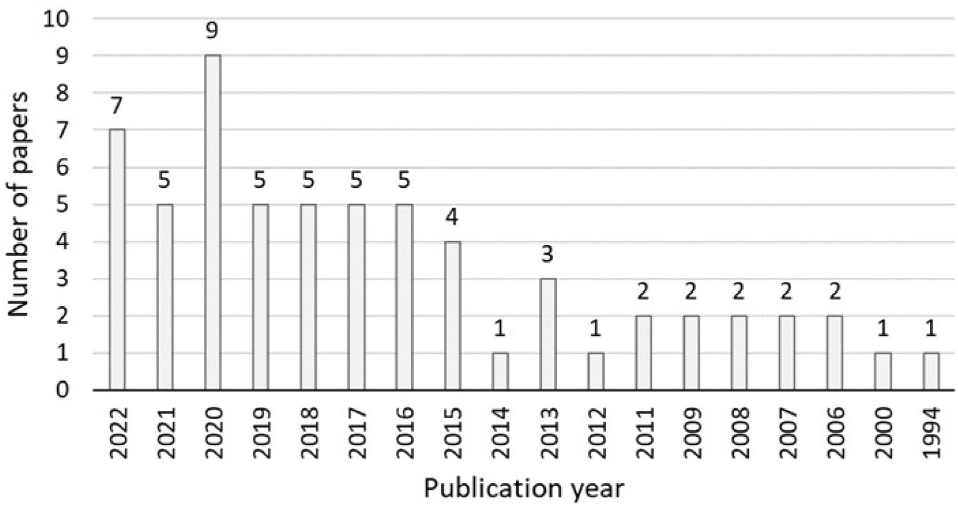

Figure A2. Papers found for each publication year.

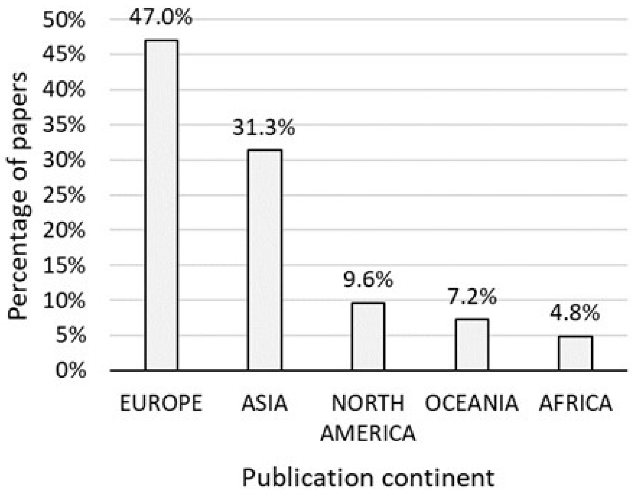

Figure A3. Percentage of papers produced in each continent.

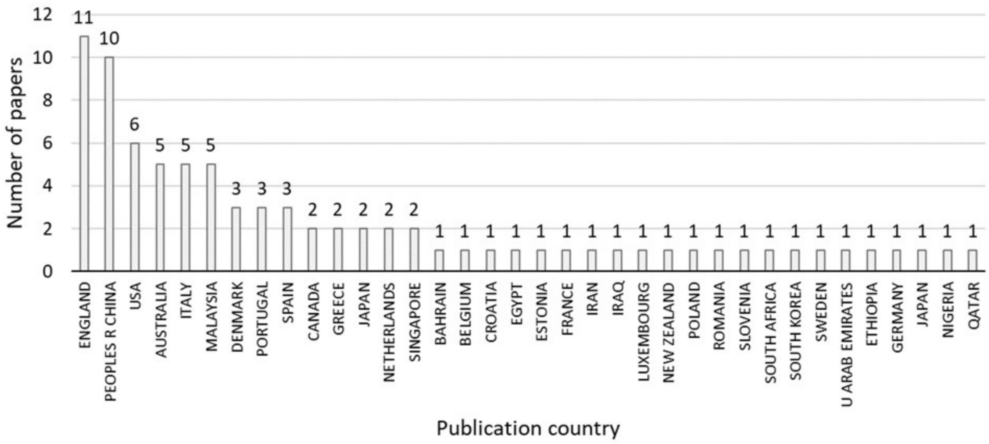

Figure A4. Papers found for each country/region.

References

1. In Focus: Energy Efficiency in Buildings. Available online: https://ec.europa.eu/info/news/focus-energy-efficiency-buildings-2020-lut-17_en (accessed on 14 June 2022).
2. Torcellini, P.; Pless, S.; Deru, M.; Crawley, D. *Zero Energy Buildings: A Critical Look at the Definition*; National Renewable Energy Lab.: Golden, CO, USA, 2006; p. 13.
3. U.S. Department of Energy. *A Common Definition for Zero Energy Buildings*; U.S. Department of Energy: Washington, DC, USA, 2015. Available online: https://www.energy.gov/sites/prod/files/2015/09/f26/A%20Common%20Definition%20for%20Zero%20Energy%20Buildings.pdf (accessed on 3 June 2022).
4. Magrini, A.; Lentini, G.; Cuman, S.; Bodrato, A.; Marenco, L. From nearly zero energy buildings (NZEB) to positive energy buildings (PEB): The next challenge—The most recent European trends with some notes on the energy analysis of a forerunner PEB example. *Dev. Built Environ.* **2020**, *3*, 100019. [CrossRef]
5. Hu, M. Net-positive building and alternative energy in an institutional environment. In *ACEEE Summer Study on Energy Efficiency in Buildings*; American Council for an Energy-Efficient Economy: Washington, DC, USA, 2016; pp. 10–12. Available online: https://www.aceee.org/files/proceedings/2016/data/papers/10_80.pdf (accessed on 3 June 2022).
6. Sterk, T. Thoughts for Gen X—Speculating about the rise of continuous measurement in architecture' in Sterk, Loveridge, Pancoast "Building A Better Tomorrow". In *Building A Better Tomorrow, Proceedings of the 29th Annual Conference of the Association of Computer Aided Design in Architecture, Chicago, IL, USA, 22–25 October 2009*; Loveridge, S., Pancoast, D., Eds.; The Art Institute of Chicago: Chicago, IL, USA, 2009.
7. Negroponte, N. *Soft Architecture Machines*; MIT Press: Cambridge, MA, USA, 1975.
8. Bullivant, L. *Responsive Environments: Architecture, Art and Design (V&A Contemporary)*; Victoria and Albert Museum: London, UK, 2006.
9. Bullivant, L. *4dspace: Interactive Architecture*; AD/John Wiley & Sons: London, UK, 2005.
10. Bullivant, L. *4dsocial: Interactive Design Environments*; AD/John Wiley & Sons: London, UK, 2007.

11. Beesley, P.; Hirosue, S.; Ruxton, J.; Trankle, M.; Turner, C. *Responsive Architectures: Subtle Technologies*; Riverside Architectural Press: Cambridge, ON, USA, 2006.
12. Designing for Typologies: 15 Examples of Climate Responsive Buildings around the World. Available online: https://www.re-thinkingthefuture.com/designing-for-typologies/ (accessed on 19 May 2022).
13. Hanc, M.; McAndrew, C.; Ucci, M. Conceptual approaches to wellbeing in buildings: A scoping review. *Build. Res. Inf.* **2019**, *47*, 767–783. [CrossRef]
14. Ruggeri, K.; Garcia-Garzon, E.; Maguire, Á.; Matz, S.; Huppert, F.A. Well-being is more than happiness and life satisfaction: A multidimensional analysis of 21 countries. *Health Qual. Life Outcomes* **2020**, *18*, 192. [CrossRef] [PubMed]
15. *UNI EN 15251:2007*; Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics. Comite'Europe'en de Normalisation: Brussels, Belgium, 2007.
16. *UNI EN ISO 16798-1:2019*; Energy Performance of Buildings—Part 1: Indoor Environmental Input Parameters For Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics. Comite'Europe'en de Normalisation: Brussels, Belgium, 2019.
17. Toftum, J. Human response to combined indoor environment exposures. *Energy Build.* **2002**, *34*, 601–606. [CrossRef]
18. Torresin, S.; Pernigotto, G.; Cappelletti, F.; Gasparella, A. Combined effects of environmental factors on human perception and objective performance: A review of experimental laboratory works. *Indoor Air* **2018**, *28*, 525–538. [CrossRef]
19. Schweiker, M.; Ampatzi, E.; Andargie, M.S.; Andersen, R.K.; Azar, E.; Barthelmes, V.M.; Berger, C.; Bourikas, L.; Carlucci, S.; Chinazzo, G.; et al. Review of multi-domain approaches to indoor environmental perception and behaviour. *Build. Environ.* **2020**, *176*, 106804. [CrossRef]
20. Aries, M.B.C.; Veitch, J.A.; Newsham, G.R. Windows, view, and office characteristics predict physical and psychological discomfort. *J. Environ. Psychol.* **2010**, *30*, 533–541. [CrossRef]
21. Kubba, S. *Handbook of Green Building Design and Construction: LEED, BREEAM, and Green Globes*; Butterworth-Heinemann: Oxford, UK, 2012.
22. Azar, E.; O'Brien, W.; Carlucci, S.; Hong, T.; Sonta, A.; Kim, J.; Andargie, M.S.; Abuimara, T.; El Asmar, M.; Jain, R.K.; et al. Simulation-aided occupant-centric building design: A critical review of tools, methods, and applications. *Energy Build.* **2020**, *224*, 110292. [CrossRef]
23. Olesen, B.W.; Bluyssen, P.; Roulet, C.-A. Ventilation and Indoor Environmental Quality. In *Ventilation Systems—Design and Performance*; Awbi, H.B., Ed.; Taylor & Francis: London, UK, 2008.
24. WHO. *Indoor Air Quality Research*; World Health Organization: Copenhagen, Denmark, 1986.
25. Wolkoff, P.; Azuma, K.; Carrer, P. Health, work performance, and risk of infection in office-like environments: The role of indoor temperature, air humidity, and ventilation. *Int. J. Hyg. Environ. Health* **2021**, *233*, 113709. [CrossRef]
26. Bekö, G.; Weschler, C.J.; Langer, S.; Callesen, M.; Toftum, J.; Clausen, G. Children's Phthalate Intakes and Resultant Cumulative Exposures Estimated from Urine Compared with Estimates from Dust Ingestion, Inhalation and Dermal Absorption in Their Homes and Daycare Centers. *PLoS ONE* **2013**, *8*, e62442. [CrossRef]
27. Wargocki, P.; Wyon, D.P.; Baik, Y.K.; Clausen, G.; Fanger, P.O. Perceived Air Quality, Sick Building Syndrome (SBS) Symptoms and Productivity in an Office with Two Different Pollution Loads. *Indoor Air* **1999**, *9*, 165–179. [CrossRef] [PubMed]
28. Wargocki, P.; Wyon, D.P.; Sundell, J.; Clausen, G.; Fanger, P.O. The Effects of Outdoor Air Supply Rate in an Office on Perceived Air Quality, Sick Building Syndrome (SBS) Symptoms and Productivity: Effects of Outdoor Air Supply Rate. *Indoor Air* **2000**, *10*, 222–236. [CrossRef] [PubMed]
29. Salcido, J.C.; Raheem, A.A.; Issa, R.R.A. From simulation to monitoring: Evaluating the potential of mixed-mode ventilation (MMV) systems for integrating natural ventilation in office buildings through a comprehensive literature review. *Energy Build.* **2016**, *127*, 1008–1018. [CrossRef]
30. Carrilho da Graça, G.; Linden, P. Ten questions about natural ventilation of non-domestic buildings. *Build. Environ.* **2016**, *107*, 263–273. [CrossRef]
31. Chenari, B.; Dias Carrilho, J.; Gameiro da Silva, M. Towards sustainable, energy-efficient and healthy ventilation strategies in buildings: A review. *Renew. Sustain. Energy Rev.* **2016**, *59*, 1426–1447. [CrossRef]
32. Givoni, B. Effectiveness of mass and night ventilation in lowering the indoor daytime temperatures. Part I: 1993 experimental periods. *Energy Build.* **1998**, *28*, 25–32. [CrossRef]
33. Shaviv, E.; Yezioro, A.; Capeluto, I.G. Thermal mass and night ventilation as passive cooling design strategy. *Renew. Energy* **2001**, *24*, 445–452. [CrossRef]
34. Nikoofard, S.; Ugursal, V.I.; Beausoleil-Morrison, I. Effect of external shading on household energy requirement for heating and cooling in Canada. *Energy Build.* **2011**, *43*, 1627–1635. [CrossRef]
35. Zaniboni, L.; Pernigotto, G.; Gasparella, A. Analysis of two shading systems in a glazed-wall physiotherapy center in Bolzano, Italy. In Proceedings of the BSA Conference 2019: Fourth Conference of IBPSA-Italy, Rome, Italy, 2–4 September 2019; pp. 77–84.
36. Krarti, M. Integrated design and retrofit of buildings. In *Optimal Design and Retrofit of Energy Efficient Buildings, Communities, and Urban Centers*; Elsevier: Amsterdam, The Netherlands, 2018; pp. 313–384. [CrossRef]
37. Passe, U.; Battaglia, F. *Designing Spaces for Natural Ventilation—An Architect's Guide*; Routledge: London, UK, 2015.

38. CIBSE. *TM40: Health and Wellbeing in Building Services*; Chartered Institution of Building Services Engineers (CIBSE): London, UK, 2019. Available online: https://www.cibse.org/Knowledge/CIBSETM/TM40-2019-Health-Issues-and-Wellbeing-in-Building-Services#Exec%20summary (accessed on 4 April 2022).
39. Alvarez, S.; Dascalaki, E.; Guarracino, G.; Maldonado, E.; Sciuto, S.; Vandaele, L. *Natural Ventilation in Buildings. A Design Handbook*; James & James: Northampton, UK, 1998.
40. Etheridge, D. *Natural Ventilation of Buildings: Theory, Measurement and Design*; John Wiley & Sons: Hoboken, NJ, USA, 2011.
41. De Dear, R.J.; Brager, G.S. Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE Standard 55. *Energy Build.* **2002**, *34*, 549–561. [CrossRef]
42. De Dear, R.; Schiller Brager, G. The adaptive model of thermal comfort and energy conservation in the built environment. *Int. J. Biometeorol.* **2001**, *45*, 100–108. [CrossRef]
43. De Dear, R.; Brager, G. *Developing an Adaptive Model of Thermal Comfort and Preference*; Center for the Built Environment: Berkeley, CA, USA, 1998. Available online: https://www.semanticscholar.org/paper/Developing-an-adaptive-model-of-thermal-comfort-and-Dear-Brager/aba60223bb4216c3d145886f385a3a019d1c86c4 (accessed on 6 June 2022).
44. *ANSI/ASHRAE Standard 55: 2017*; Thermal Environmental Conditions for Human Occupancy. ASHRAE: Atlanta, GA, USA, 2017.
45. Fanger, P.O. *Thermal Comfort. Analysis and Applications in Environmental Enigeering*; Danish Technical Press: Copenhagen, Denmark, 1970.
46. Seppänen, O.; Fisk, W.J. Association of ventilation system type with SBS symptoms in office workers: SBS symptoms in office workers. *Indoor Air* **2002**, *12*, 98–112. [CrossRef] [PubMed]
47. Ronold, A. Chapter 17—Ventilation. In *Computational Wind Engineering 1*; Elsevier: Amsterdam, The Netherlands, 1993.
48. Torresin, S.; Albatici, R.; Aletta, F.; Babich, F.; Oberman, T.; Stawinoga, A.E.; Kang, J. Indoor soundscapes at home during the COVID-19 lockdown in London—Part I: Associations between the perception of the acoustic environment, occupantś activity and well-being. *Appl. Acoust.* **2021**, *183*, 108305. [CrossRef]
49. Torresin, S.; Albatici, R.; Aletta, F.; Babich, F.; Oberman, T.; Stawinoga, A.E.; Kang, J. Indoor soundscapes at home during the COVID-19 lockdown in London—Part II: A structural equation model for comfort, content, and well-being. *Appl. Acoust.* **2022**, *185*, 108379. [CrossRef]
50. Olgyay, V. *Design with Climate: Bioclimatic Approach to Architectural Regionalism*; Princeton University Press: Princeton, NJ, USA, 1963.
51. Ryan, C.O.; Browning, W.D.; Clancy, J.O.; Andrews, S.L.; Kallianpurkar, N.B. BIOPHILIC DESIGN PATTERNS: Emerging Nature-Based Parameters for Health and Well-Being in the Built Environment. *Int. J. Archit. Res. ArchNet-IJAR* **2014**, *8*, 62. [CrossRef]
52. Ulrich, R.S. View Through a Window May Influence Recovery from Surgery. *Science* **1984**, *224*, 420–421. [CrossRef] [PubMed]
53. Hähn, N.; Essah, E.; Blanusa, T. Biophilic design and office planting: A case study of effects on perceived health, well-being and performance metrics in the workplace. *Intell. Build. Int.* **2021**, *13*, 241–260. [CrossRef]
54. Altomonte, S.; Allen, J.; Bluyssen, P.; Brager, G.; Heschong, L.; Loder, A.; Schiavon, S.; Veitch, J.; Wang, L.; Wargocki, P. Ten questions concerning well-being in the built environment. *Build. Environ.* **2020**, *180*, 106949. [CrossRef]
55. Brager, G.; Baker, L. Occupant satisfaction in mixed-mode buildings. *Build. Res. Inf.* **2009**, *37*, 369–380. [CrossRef]
56. Lee, Y.S. Comparisons of Indoor Air Quality and Thermal Comfort Quality between Certification Levels of LEED-Certified Buildings in USA. *Indoor Built Environ.* **2011**, *20*, 564–576. [CrossRef]
57. *UNI 10339*; Air-Conditioning Systems for Thermal Comfort in Buildings—General, Classification and Requirements—Offer, Order and Supply Specifications. Ente Italiano di Normazione: Milan, Italy, 1995.
58. ASHRAE. *ASHRAE Handbook—Fundamentals*; American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 2021. Available online: https://www.hrai.ca/technical-manual/residential-mechanical-ventilation---national--sar-r4- (accessed on 6 June 2022).
59. *HRAI Residential Mechanical Ventilation—National (SAR-R4)*; The Heating, Refrigeration and Air Conditioning Institute of Canada (HRAI): Mississauga, ON, Canada, 2010.
60. Abdul Hamid, A.; Johansson, D.; Bagge, H. Ventilation measures for heritage office buildings in temperate climate for improvement of energy performance and IEQ. *Energy Build.* **2020**, *211*, 109822. [CrossRef]
61. Diaz de Garayo, S.; Martínez, A.; Astrain, D. Optimal combination of an air-to-air thermoelectric heat pump with a heat recovery system to HVAC a passive house dwelling. *Appl. Energy* **2022**, *309*, 118443. [CrossRef]
62. Lazzarin, R.M.; Gasparella, A. Technical and economical analysis of heat recovery in building ventilation systems. *Appl. Therm. Eng.* **1998**, *18*, 47–67. [CrossRef]
63. Mardiana-Idayu, A.; Riffat, S.B. Review on heat recovery technologies for building applications. *Renew. Sustain. Energy Rev.* **2012**, *16*, 1241–1255. [CrossRef]
64. Chen, J.; Augenbroe, G.; Song, X. Model predictive control strategy for hybrid ventilation building operation. In Proceedings of the Construction Research Congress 2018, New Orleans, LA, USA, 2–4 April 2018; American Society of Civil Engineers: New Orleans, LA, USA; 2018; pp. 390–399.
65. Mathews, E.H.; Shuttleworth, A.G.; Rousseau, P.G. Validation and further development of a novel thermal analysis method. *Build. Environ.* **1994**, *29*, 207–215. [CrossRef]

66. Meng, X.; Wang, Y.; Xing, X.; Xu, Y. Experimental study on the performance of hybrid buoyancy-driven natural ventilation with a mechanical exhaust system in an industrial building. *Energy Build.* **2020**, *208*, 109674. [CrossRef]
67. Raji, B.; Tenpierik, M.J.; Bokel, R.; van den Dobbelsteen, A. Natural summer ventilation strategies for energy-saving in high-rise buildings: A case study in the Netherlands. *Int. J. Vent.* **2020**, *19*, 25–48. [CrossRef]
68. Heiselberg, P. *Principles of Hybrid Ventilation*; Aalborg University: Hybrid Ventilation Centre: Aalborg, Denmark, 2002. Available online: https://iea-ebc.org/Data/publications/EBC_Annex_35_Principles_of_H_V.pdf (accessed on 13 May 2022).
69. Rysanek, A. Annex 35—Hybrid Ventilation in New and Retrofitted Office Buildings; Hybrid Ventilation in New and Retrofitted Office Buildings; Faber Maunsell Ltd.: Hertfordshire, UK. Available online: https://www.iea-ebc.org/Data/publications/EBC_Annex_35_tsr.pdf (accessed on 13 May 2022).
70. Rethinking IEQ Standards for a Warming Post-COVID World—Are Standards Promoting Air Conditioning and Marginalising Natural Ventilation? Available online: https://www.buildingsandcities.org/insights/commentaries/rethinking-ieq-standards.html (accessed on 19 May 2022).
71. Azuma, K.; Yanagi, U.; Kagi, N.; Kim, H.; Ogata, M.; Hayashi, M. Environmental factors involved in SARS-CoV-2 transmission: Effect and role of indoor environmental quality in the strategy for COVID-19 infection control. *Environ. Health Prev. Med.* **2020**, *25*, 66. [CrossRef]
72. ASHRAE. *COVID-19 Guidance for Multifamily Building Owners/Managers*; American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 2020. Available online: https://www.ashrae.org/file%20library/technical%20resources/covid-19/covid-19-guidance-for-multifamily-building-owners_managers.pdf (accessed on 4 April 2022).
73. ASHRAE. *Residential COVID-19 Guidance*; American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 2021.
74. ASHRAE. *Residences FAQ*; American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 2021. Available online: https://www.ashrae.org/technical-resources/residences-faq (accessed on 4 April 2022).
75. Atkinson, J.; Chartier, Y.; Pessoa-Silva, C.L.; Li, Y.; Seto, W.-H. *Natural Ventilation for Infection Control in Health-Care Settings*; World Health Organization: Geneva, Switzerland, 2009.
76. Short, C.A.; Yao, R.; Luo, G.; Li, B. Exploiting a Hybrid Environmental Design Strategy in the Continental Climate of Beijing. *Int. J. Vent.* **2012**, *11*, 105–130. [CrossRef]
77. CIBSE. *COVID-19: Ventilation. Version 5*; Chartered Institution of Building Services Engineers (CIBSE): London, UK, 2021. Available online: https://www.cibse.org/emerging-from-lockdown#1 (accessed on 4 April 2022).
78. REHVA. *COVID-19 Guidance. Version 4.1*; Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA): Lausanne, Switzerland, 2021. Available online: https://www.rehva.eu/activities/covid-19-guidance/rehva-covid-19-guidance (accessed on 4 April 2022).
79. Rysanek, A.; Nuttall, R.; McCarty, J. Forecasting the impact of climate change on thermal comfort using a weighted ensemble of supervised learning models. *Build. Environ.* **2021**, *190*, 107522. [CrossRef]
80. Systematic Reviews & Other Review Types. Available online: https://guides.temple.edu/c.php?g=78618&p=4178713#:~{}:text=A%20systematic%20review%20is%20defined,The%20methods%20used%20must%20be (accessed on 4 April 2022).
81. Web of Science. Clarivate. Available online: https://clarivate.com/webofsciencegroup/solutions/web-of-science/ (accessed on 27 April 2022).
82. Transparent Reporting of Systematic Reviews and Meta-Analyses. PRISMA. Available online: https://prisma-statement.org/ (accessed on 16 April 2022).
83. Orosa, J.A.; Oliveira, A.C. *Passive Methods as a Solution for Improving Indoor Environments*; Springer: Berlin/Heidelberg, Germany, 2012.
84. De Dear, R. The Theory of Thermal Comfort in Naturally Ventilated Indoor Environments—"The Pleasure Principle". *Int. J. Vent.* **2009**, *8*, 243–250. [CrossRef]
85. Blondeau, P.; Spérandio, M.; Allard, F. Night ventilation for building cooling in summer. *Sol. Energy* **1997**, *61*, 327–335. [CrossRef]
86. Erba, S.; Sangalli, A.; Pagliano, L. Present and future potential of natural night ventilation in nZEBs. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *296*, 012041. [CrossRef]
87. Mareș, I.-C.; Catalina, T.; Istrate, M.-A.; Cucoș, A.; Dicu, T.; Burghele, B.D.; Hening, K.; Popescu, L.L.; Popescu, R.S. Research on Best Solution for Improving Indoor Air Quality and Reducing Energy Consumption in a High-Risk Radon Dwelling from Romania. *Int. J. Environ. Res. Public. Health* **2021**, *18*, 12482. [CrossRef] [PubMed]
88. Liao, C.; Akimoto, M.; Bivolarova, M.P.; Sekhar, C.; Laverge, J.; Fan, X.; Lan, L.; Wargocki, P. A survey of bedroom ventilation types and the subjective sleep quality associated with them in Danish housing. *Sci. Total Environ.* **2021**, *798*, 149209. [CrossRef] [PubMed]
89. Usman, F.; Bakar, A.R.A. Thermal comfort study using CFD analysis in residential house with mechanical ventilation system. In Proceedings of the AWAM International Conference on Civil Engineering, Penang, Malaysia, 21–22 August 2019; Springer: Cham, Switzerland, 2019; pp. 1613–1628.
90. Barbolini, F.; Cappellacci, P.; Guardigli, L. A Design Strategy to Reach nZEB Standards Integrating Energy Efficiency Measures and Passive Energy Use. *Energy Procedia* **2017**, *111*, 205–214. [CrossRef]
91. Grigoropoulos, E.; Anastaselos, D.; Nižetić, S.; Papadopoulos, A.M. Effective ventilation strategies for net zero-energy buildings in Mediterranean climates. *Int. J. Vent.* **2016**, *16*, 291–307. [CrossRef]

92. Yu, C.W.F.; Kim, J.T. Low-Carbon Housings and Indoor Air Quality. *Indoor Built Environ.* **2012**, *21*, 5–15. [CrossRef]
93. Razman, R.; Abd, H.; Bin, A.; Abdul, A. *Study on Thermal Comfort in University Hostel Building Case Study at Universiti Tun Hussein Onn Malaysia (UTHM), Batu Pahat*; IACSIT Press: Singapore, 2011; Volume 8. Available online: https://www.researchgate.net/profile/Abd-Halid-Abdullah/publication/267790423_Study_On_Thermal_Comfort_In_University_Hostel_Building_Case_Study_At_Universiti_Tun_Hussein_Onn_Malaysia_UTHM_Batu_Pahat/links/54c3401f0cf256ed5a90e291/Study-On-Thermal-Comfort-In-University-Hostel-Building-Case-Study-At-Universiti-Tun-Hussein-Onn-Malaysia-UTHM-Batu-Pahat.pdf (accessed on 4 April 2022).
94. Yadeta, C.; Indraganti, M.; Alemayehu, E.; Tucho, G.T. An investigation of human thermal comfort and adaptation in naturally ventilated residential buildings and its implication for energy use in tropical climates of Ethiopia. *Sci. Technol. Built Environ.* **2022**, *28*, 896–915. [CrossRef]
95. Zhao, Y.; Sun, H.; Tu, D. Effect of mechanical ventilation and natural ventilation on indoor climates in Urumqi residential buildings. *Build. Environ.* **2018**, *144*, 108–118. [CrossRef]
96. Fernández-Agüera, J.; Domínguez-Amarillo, S.; Alonso, C.; Martín-Consuegra, F. Thermal comfort and indoor air quality in low-income housing in Spain: The influence of airtightness and occupant behaviour. *Energy Build.* **2019**, *199*, 102–114. [CrossRef]
97. Lai, D.; Qi, Y.; Liu, J.; Dai, X.; Zhao, L.; Wei, S. Ventilation behavior in residential buildings with mechanical ventilation systems across different climate zones in China. *Build. Environ.* **2018**, *143*, 679–690. [CrossRef]
98. Izadyar, N.; Miller, W.; Rismanchi, B.; Garcia-Hansen, V. Numerical simulation of single-sided natural ventilation: Impacts of balconies opening and depth scale on indoor environment. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *463*, 012037. [CrossRef]
99. Izadyar, N.; Miller, W.; Rismanchi, B.; Garcia-Hansen, V. A numerical investigation of balcony geometry impact on single-sided natural ventilation and thermal comfort. *Build. Environ.* **2020**, *177*, 106847. [CrossRef]
100. Lei, Z.; Liu, C.; Wang, L.; Li, N. Effect of natural ventilation on indoor air quality and thermal comfort in dormitory during winter. *Build. Environ.* **2017**, *125*, 240–247. [CrossRef]
101. Kalamees, T. Indoor Climate Conditions and Ventilation Performance in Estonian Lightweight Detached Houses. *Indoor Built Environ.* **2006**, *15*, 555–569. [CrossRef]
102. Torresin, S.; Albatici, R.; Aletta, F.; Babich, F.; Oberman, T.; Kang, J. Associations between indoor soundscapes, building services and window opening behaviour during the COVID-19 lockdown. *Build. Serv. Eng. Res. Technol.* **2021**, *43*, 225–240. [CrossRef]
103. Cardoso, V.E.M.; Pereira, P.F.; Ramos, N.M.M.; Almeida, R.M.S.F. The Impacts of Air Leakage Paths and Airtightness Levels on Air Change Rates. *Buildings* **2020**, *10*, 55. [CrossRef]
104. Yin, H.; Zhai, X.; Ning, Y.; Li, Z.; Ma, Z.; Wang, X.; Li, A. Online monitoring of PM2.5 and CO_2 in residential buildings under different ventilation modes in Xi'an city. *Build. Environ.* **2022**, *207*, 108453. [CrossRef]
105. Cai, C.; Sun, Z.; Weschler, L.B.; Li, T.; Xu, W.; Zhang, Y. Indoor air quality in schools in Beijing: Field tests, problems and recommendations. *Build. Environ.* **2021**, *205*, 108179. [CrossRef]
106. Giridharan, R.; Lomas, K.J.; Short, C.A.; Fair, A.J. Performance of hospital spaces in summer: A case study of a 'Nucleus'-type hospital in the UK Midlands. *Energy Build.* **2013**, *66*, 315–328. [CrossRef]
107. Ding, E.; Zhang, D.; Bluyssen, P.M. Ventilation regimes of school classrooms against airborne transmission of infectious respiratory droplets: A review. *Build. Environ.* **2022**, *207*, 108484. [CrossRef]
108. Guo, P.; Wang, S.; Xu, B.; Meng, Q.; Wang, Y. Reduced-scale experimental model and numerical investigations to buoyance-driven natural ventilation in a large space building. *Build. Environ.* **2018**, *145*, 24–32. [CrossRef]
109. Aldawoud, A. Windows design for maximum cross-ventilation in buildings. *Adv. Build. Energy Res.* **2017**, *11*, 67–86. [CrossRef]
110. Elnabawi, M.H.; Saber, E. Reducing carbon footprint and cooling demand in arid climates using an integrated hybrid ventilation and photovoltaic approach. *Environ. Dev. Sustain.* **2022**, *24*, 3396–3418. [CrossRef]
111. Rasheed, E.; Byrd, H.; Money, B.; Mbachu, J.; Egbelakin, T. Why Are Naturally Ventilated Office Spaces Not Popular in New Zealand? *Sustainability* **2017**, *9*, 902. [CrossRef]
112. Azarbayjani, M. Climatic based consideration of double skin facade system: Natural ventilation performance of a case study with double skin facade in mediterranean climate. In Proceedings of the BS2013: 13th Conference of International Building Performance Simulation Association, Chambéry, France, 26–28 August 2013.
113. Butala, V.; Muhič, S. Perception of Air Quality and the Thermal Environment in Offices. *Indoor Built Environ.* **2007**, *16*, 302–310. [CrossRef]
114. Arata, S.; Kawakubo, S. Study on productivity of office workers and power consumption of air conditioners in a mixed-mode ventilation building during springtime. *Build. Environ.* **2022**, *214*, 108923. [CrossRef]
115. Scheuring, L.; Weller, B. An investigation of ventilation control strategies for louver windows in different climate zones. *Int. J. Vent.* **2021**, *20*, 226–235. [CrossRef]
116. Natarajan, S.; Rodriguez, J.; Vellei, M. A field study of indoor thermal comfort in the subtropical highland climate of Bogota, Colombia. *J. Build. Eng.* **2015**, *4*, 237–246. [CrossRef]
117. Dhalluin, A.; Limam, K. Comparison of natural and hybrid ventilation strategies used in classrooms in terms of indoor environmental quality, comfort and energy savings. *Indoor Built Environ.* **2014**, *23*, 527–542. [CrossRef]
118. Gil-Baez, M.; Barrios-Padura, Á.; Molina-Huelva, M.; Chacartegui, R. Natural ventilation systems in 21st-century for near zero energy school buildings. *Energy* **2017**, *137*, 1186–1200. [CrossRef]

119. Monge-Barrio, A.; Bes-Rastrollo, M.; Dorregaray-Oyaregui, S.; González-Martínez, P.; Martin-Calvo, N.; López-Hernández, D.; Arriazu-Ramos, A.; Sánchez-Ostiz, A. Encouraging natural ventilation to improve indoor environmental conditions at schools. Case studies in the north of Spain before and during COVID. *Energy Build.* **2022**, *254*, 111567. [CrossRef]
120. Zender-Świercz, E. Microclimate in Rooms Equipped with Decentralized Façade Ventilation Device. *Atmosphere* **2020**, *11*, 800. [CrossRef]
121. Stabile, L.; Buonanno, G.; Frattolillo, A.; Dell'Isola, M. The effect of the ventilation retrofit in a school on CO2, airborne particles, and energy consumptions. *Build. Environ.* **2019**, *156*, 1–11. [CrossRef]
122. Heebøll, A.; Wargocki, P.; Toftum, J. Window and door opening behavior, carbon dioxide concentration, temperature, and energy use during the heating season in classrooms with different ventilation retrofits—ASHRAE RP1624. *Sci. Technol. Built Environ.* **2018**, *24*, 626–637. [CrossRef]
123. Khaleghi, A.; Bartlett, K.; Hodgson, M. Factors Affecting Ventilation, Indoor-Air Quality and Acoustical Quality In 'Green' and Non-'Green' Buildings: A Pilot Study. *J. Green Build.* **2011**, *6*, 168–180. [CrossRef]
124. Braham, G.D. Mechanical Ventilation and Fabric Thermal Storage. *Indoor Built Env.* **2000**, *9*, 102–110. [CrossRef]
125. Maas, S.; Da Cruz Antunes, J.; Steffgen, G. Energy efficiency and indoor air quality of seminar rooms in older buildings with and without mechanical ventilation. *Bauphysik* **2019**, *41*, 243–251. [CrossRef]
126. Montgomery, J.F.; Storey, S.; Bartlett, K. Comparison of the indoor air quality in an office operating with natural or mechanical ventilation using short-term intensive pollutant monitoring. *Indoor Built Environ.* **2015**, *24*, 777–787. [CrossRef]
127. Mba, E.J.; Sam-amobi, C.G.; Okeke, F.O. An Assessment of Orientation on Effective Natural Ventilation for Thermal Comfort in Primary School Classrooms in Enugu City, Nigeria. *Eur. J. Sustain. Dev.* **2022**, *11*, 114. [CrossRef]
128. Nardell, E.A. Indoor environmental control of tuberculosis and other airborne infections. *Indoor Air* **2016**, *26*, 79–87. [CrossRef] [PubMed]
129. Homod, R.Z.; Sahari, K.S.M. Energy savings by smart utilization of mechanical and natural ventilation for hybrid residential building model in passive climate. *Energy Build.* **2013**, *60*, 310–329. [CrossRef]
130. Omer, A.M. Renewable building energy systems and passive human comfort solutions. *Renew. Sustain. Energy Rev.* **2008**, *12*, 1562–1587. [CrossRef]
131. Daghigh, R. Assessing the thermal comfort and ventilation in Malaysia and the surrounding regions. *Renew. Sustain. Energy Rev.* **2015**, *48*, 681–691. [CrossRef]
132. Aflaki, A.; Mahyuddin, N.; Al-Cheikh Mahmoud, Z.; Baharum, M.R. A review on natural ventilation applications through building façade components and ventilation openings in tropical climates. *Energy Build.* **2015**, *101*, 153–162. [CrossRef]
133. Perino, M. Short-term airing by natural ventilation—Modeling and control strategies. *Indoor Air* **2009**, *19*, 357–380. [CrossRef] [PubMed]
134. Stavrakakis, G.M.; Koukou, M.K.; Vrachopoulos, M.G.; Markatos, N.C. Natural cross-ventilation in buildings: Building-scale experiments, numerical simulation and thermal comfort evaluation. *Energy Build.* **2008**, *40*, 1666–1681. [CrossRef]
135. Ouyang, Q.; Dai, W.; Li, H.; Zhu, Y. Study on dynamic characteristics of natural and mechanical wind in built environment using spectral analysis. *Build. Environ.* **2006**, *41*, 418–426. [CrossRef]
136. Izadyar, N.; Miller, W.; Rismanchi, B.; Garcia-Hansen, V. Impacts of façade openings' geometry on natural ventilation and occupants' perception: A review. *Build. Environ.* **2020**, *170*, 106613. [CrossRef]
137. Sultan, Z. Estimates of associated outdoor particulate matter health risk and costs reductions from alternative building, ventilation and filtration scenarios. *Sci. Total Environ.* **2007**, *377*, 1–11. [CrossRef]
138. Mukhtar, A.; Yusoff, M.Z.; Ng, K.C. The potential influence of building optimization and passive design strategies on natural ventilation systems in underground buildings: The state of the art. *Tunn. Undergr. Space Technol.* **2019**, *92*, 103065. [CrossRef]
139. Huisman, E.R.C.M.; Morales, E.; van Hoof, J.; Kort, H.S.M. Healing environment: A review of the impact of physical environmental factors on users. *Build. Environ.* **2012**, *58*, 70–80. [CrossRef]
140. Beauchemin, K.M.; Hays, P. Sunny hospital rooms expedite recovery from severe and refractory depressions. *J. Affect. Disord.* **1996**, *40*, 49–51. [CrossRef]
141. Parson, K. *Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance*; CRC Press: Boca Raton, FL, USA, 2014.
142. CTCN Passive House Design. Available online: https://www.ctc-n.org/technologies/passive-house-design (accessed on 8 October 2022).
143. Esposti, R.; Galbusera, G.; Panzeri, A.; Salani, C. *Prestazioni Estive Degli Edifici. Guida Pratica per Capire e Progettare il Comfort e il Fabbisogno Estivo Degli Edifici, 2nd ed*; Associazione Nazionale per l'Isolamento Termico e Acustico (ANIT): Milan, Italy, 2017; Volume 5.
144. *ISO 13788:2012*; Hygrothermal Performance of Building Components and Building Elements—Internal Surface Temperature to Avoid Critical Surface Humidity And Interstitial Condensation—Calculation Methods. International Organization for Standardization: Geneva, Switzerland, 2012.
145. Rossi, M.; Rocco, V.M. External walls design: The role of periodic thermal transmittance and internal areal heat capacity. *Energy Build.* **2014**, *68*, 732–740. [CrossRef]
146. Di Perna, C.; Stazi, F.; Casalena, A.U.; D'Orazio, M. Influence of the internal inertia of the building envelope on summertime comfort in buildings with high internal heat loads. *Energy Build.* **2011**, *43*, 200–206. [CrossRef]

147. Stazi, F.; Ulpiani, G.; Pergolini, M.; Di Perna, C. The role of areal heat capacity and decrement factor in case of hyper insulated buildings: An experimental study. *Energy Build.* **2018**, *176*, 310–324. [CrossRef]
148. Figueroa-Lopez, A.; Arias, A.; Oregi, X.; Rodríguez, I. Evaluation of passive strategies, natural ventilation and shading systems, to reduce overheating risk in a passive house tower in the north of Spain during the warm season. *J. Build. Eng.* **2021**, *43*, 102607. [CrossRef]
149. Mavrogianni, A.; Davies, M.; Taylor, J.; Chalabi, Z.; Biddulph, P.; Oikonomou, E.; Das, P.; Jones, B. The impact of occupancy patterns, occupant-controlled ventilation and shading on indoor overheating risk in domestic environments. *Build. Environ.* **2014**, *78*, 183–198. [CrossRef]
150. Kim, G.; Lim, H.S.; Lim, T.S.; Schaefer, L.; Kim, J.T. Comparative advantage of an exterior shading device in thermal performance for residential buildings. *Energy Build.* **2012**, *46*, 105–111. [CrossRef]
151. Callegaro, N.; Pontillo, S.; Albatici, R. Influenza di modelli di gestione per il funzionamento di sistemi oscuranti interni sul consumo energetico e il comfort luminoso. In *New Horizons for Sustainable Architecture–Nuovi Orizzonti per L'architettura sostenibile, Catania, Italy, 10 December 2020*; EdicomEdizioni Atti ColloquiATe: Monfalcone Gorizia, Italy, 2020; pp. 1068–1083. Available online: https://iris.unitn.it/handle/11572/283955 (accessed on 2 October 2022).
152. Zhao, J.; Du, Y. Multi-objective optimization design for windows and shading configuration considering energy consumption and thermal comfort: A case study for office building in different climatic regions of China. *Sol. Energy* **2020**, *206*, 997–1017. [CrossRef]
153. Callegaro, N.; Endrizzi, L.; Zaniboni, L.; Albatici, R. Management of indoor thermal conditions in heavy and lightweight buildings: An experimental comparison. In Proceedings of the 14th International Conference on Sustainability in Energy and Buildings, Split, Croatia, 16–17 September 2022. *in press*.