BUILDING RESILIENCE TO A WARMING WORLD: A CONTRIBUTION TOWARD A DEFINITION OF "INTEGRATED CLIMATE RESILIENCE" SPECIFIC FOR BUILDINGS

LITERATURE REVIEW AND PROPOSALS.

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ABSTRACT

With the forecast of a warmer world, with longer, more frequent and more intense heat waves, it becomes essential to have buildings that are resilient to a rapidly warming climate and able to withstand extreme temperature events.

This research investigates the concept of buildings' resilience. Specifically, the article collects definitions of resilient building found in 32 scientific articles referring primarily to thermal aspects and seeks to associate each definition with one of the two interpretations of resilience, namely the engineering and ecological ones, mainly identified within the theory on resilience. This aimed to assess whether there is a predominant and – more importantly – a clear understanding of resilience for buildings, to which extent this concept is well defined and clear, which is a topic that, to the best of our knowledge, no study on thermal resilience of buildings seems to have examined to date.

Results showed a significant lack of consensus regarding the interpretation of buildings' resilience within the selected literature. Such lack of consensus highlights the ongoing confusion about the concept of buildings' resilience to the threats posed by the current and future climate; what should this concept include concretely? A certain discrepancy also emerged even between the interpretation used to define resilience and that used for its indicators. Furthermore, the available definitions are observed to be rather generic, not specific to buildings and, in any case, it does not seem easy to make them operative. In addition to the literature analysis, the article proposes a tentative approach, which could usefully arrive at an attempted definition of resilience that is specific to buildings and operative. Starting with buildings, the proposed "bottom-up" approach is innovative compared to the prevailing approach in the literature that starts with definitions of ecological and engineering resilience (top-down) instead. Furthermore, the article delivers a couple of considerations to be accounted for when applying the concept of resilience to buildings: the importance of considering not only extreme events but also climate change understood as an increase in average air temperature and the importance of also including the inherent resilience due to the presence of occupants, whose thermal adaptive behavior can mitigate the risk of power outages by making the building less vulnerable to the impacts of climate change.

By providing an operational tool for researchers, engineers and planners who intend to strengthen the resilience of the building in the face of climate change, the research contributes to achieving a clearer and shared understanding of how the concept of buildings' resilience should be declined.

KEYWORDS:

Resilience; Buildings; Climate change; Global warming; Extreme meteorological events; Heatwaves; Engineering resilience; Ecological resilience; Thermal performance; Adaptive behavior.

NOMENCLATURE

ECO	Ecological resilience
ENG	Engineering resilience
HI	Heat Index
HOS	Hours of Safety
HVAC	Heating, Ventilation, and Air Conditioning
IOD	Indoor Overheating Degree
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
SET	Standard Effective Temperature
TMY	Typical Meteorological Year
UHI	Urban Heat Island

1 INTRODUCTION

This article aims to address the difficulties in interpreting the concept of buildings' resilience within the framework of climate change, with a particular focus on the effects of rising temperatures and the increased frequency of extreme heat events. The scientific community is paying increasing attention to the ensuing effects on the building industry, especially regarding building energy performance. By providing a summary of how climate change affects building performance, this section seeks to contextualise the impact of climate change on built environments. It highlights how important it is to have resilient building designs given the current state of the climate and offers a basic understanding of the resilience concept overall.

1.1 The impact of global warming and extreme temperatures on building performance

According to the Intergovernmental Panel on Climate Change (IPCC), the existence of ongoing global warming is, by now, an indisputable fact as well as that greenhouse gas emissions from anthropogenic activities are the main responsible. It is predicted that during the 21st century, the Earth's surface temperature will continue to increase under all emission scenarios assessed [1]. Such global warming is also responsible for extreme weather events such as hurricanes, winter storms, heatwaves and floods [2] that have become more frequent and severe over the past two decades [3]. According to a report of the United Nation office for Disaster Risk Reduction (UNDRR), indeed, in the period 2000-2019, there has been a rise from 3,656 climate-related events (1980-1999) to 6,681 climate-related disasters [4]. Among meteorological extreme events, heatwaves - for which, it must be said, there is to date no internationally agreed definition

-, have shown an increase in intensity, frequency, and duration in the observational record, both on regional and global scales. [5] becoming one of the prevailing extreme weather occurrences [6, 7]. According to data from Copernicus Climate Change Service, the year 2022 was the warmest year on record for a large part of Europe. The average daily temperature in 2022 marked the highest recorded since 1950. Across Europe, a majority of regions saw a greater occurrence of 'warm daytimes' compared to the average, highlighting the frequent extremes in temperature during the year [8]. According to the IPCC, it is highly probable that heatwaves will become more frequent and endure for longer durations in the near future [1].

The above-mentioned current and future scenarios, which thus paint a trend toward an even warmer world characterized by longer, more frequent, and more intense heatwaves [9, 10, 11], represent a fundamental threat to cities [12]. Global warming and extreme temperature events, in fact, negatively affect the built environment, in particular increasing the energy demand of buildings [13, 14, 15]. As it is well known, buildings are already responsible for consuming a large amount of energy, (they account for approximately 40 percent of final energy consumption [16, 17, 18]), of which that consumed for heating is expected to reduce while that for cooling is expected to increase due to global warming and rising extreme temperatures [2, 19, 20]. In detail, the projected increase in electricity consumption for cooling purposes is expected to exceed 110% by the year 2040 [21]. This is because both these phenomena lead to an increase of the average and peak values of the outdoor air temperature, respectively that, in turn, cause the energy consumption (mainly the electric one) for cooling indoor environments to rise [22, 23, 24]. This, in turn, determines a release of heat from the air conditioning systems into the external environment that records an increase in average air temperature. This increase retroactively induces an increment of the energy demand for climatization because buildings interact with a warmer environment. The negative effects induced by both phenomena are therefore of two types: on one hand, an increase in the amount of (electric) energy consumed for space cooling, and on the other hand an increment of the outdoor air temperature that worsens the Urban Heat Island (UHI) phenomenon [25, 26].

In addition to deterioration in the energy and, therefore, environmental performance of the building, a worsening of the building's indoor performance provided to the occupants can also occur. To make this consideration clearer, one must take into account that buildings respond to heatwaves by raising their indoor temperatures. and this response, if ventilation and air-conditioning systems are present and functioning, cause the peak demand for electricity to increase dramatically during heatwaves [27, 28, 29]. A higher energy demand may in turn lead to a power outage [30, 31, 32, 33, 34], which in turn might result in the occurrence of an overheating condition in the building in summer (or overcooling in winter). Clearly, the overheating case exposes occupants to thermal discomfort and, even worse, increases the risks of heat-related morbidity and mortality [35, 36, 37]. Indeed, it should never be overlooked the fact that heatwaves extend beyond mere discomfort; they can result in illness and, in severe cases, fatalities, particularly depending on the age and health status of the occupants. The elderly and low-income people in urban areas are, for instance, particularly vulnerable to extreme climate events [38, 39, 40, 41]. Hence, it should not be overlooked that the ongoing climate change issue with its consequential more frequent and severe extreme weather, is not merely an environmental problem, as also highlighted by the cited UNDRR report [4].

Figure 1 illustrates graphically the above-mentioned effects of rising temperatures and increasing occurrences of extreme temperatures on the overall performance of buildings. As for this figure, to avoid misunderstanding and/or confusion, the following should be specified: in common use, the term "climate change" mainly refers to a warming of the Earth's climate, i.e. an increase in global mean surface air temperature; while the worldwide occurrence of heatwaves is considered a consequence of climate change [42]. United Nations defines "climate change" as follows: "climate change refers to long-term shifts in temperatures and weather patterns" [43].

However, in the present study, as the buildings (focus of the study) must face both global warming and heatwaves, it was decided to refer to these two phenomena, as "total climate change".

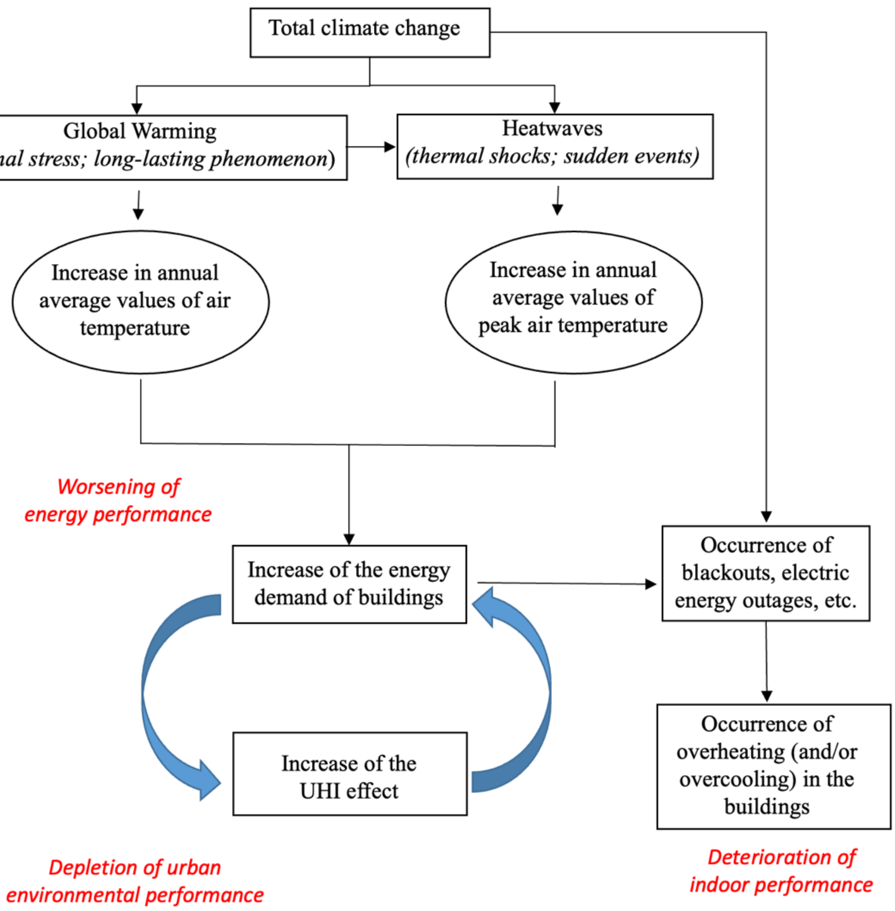

Fig. 1. Effects of rising temperatures and increasing occurrences of extreme temperatures (total climate change) on the energy and indoor performance of buildings.

1.2 The need for thermally resilient buildings

In light of what has just been said, the need arises to have buildings that are climate resilient, no longer only sustainable [44]. In other words, nowadays buildings are required to be capable of guaranteeing comfort conditions to their occupants with low energy consumption (i.e., energy efficient) and low environmental impact (i.e., environmentally sustainable) [45], and to be capable of dealing with the heat threats aforementioned (both stresses/long-lasting and shocks/sudden events) [30, 45, 46]. In practical terms, this latter would mean, for instance, guaranteeing that indoor areas remain inhabitable even when building systems are not operating normally during disruptive events [31].

To this end, current design and retrofit principles of building envelopes should thus be rethought by extending the traditional sustainability-oriented view to the concept of resilience to climate change [45]. In this regard, it should however be noted that research dealing with the integration of sustainability and resilience for buildings still presents knowledge gaps, particularly concerning circumstances where the two aspects are synergistic or antagonistic [44, 47]. The traditional approach to the design of Heating, Ventilation, and Air-Conditioning (HVAC) systems serving buildings should also be reviewed because, it generally takes into account the Typical Meteorological Year (TMY) in which extremes are inadequately depicted [30, 32], which could result in buildings not being able to cope with increasingly frequent and severe extreme events [38]. This would mean that during the building design stage, a preliminary analysis of the ongoing climate change should be performed [2] with the aim of determining how future climate conditions will affect the energy consumption of the given building, and so how the given building will cope with climate changes that it will face during its lifetime. This new approach is useful for the proper identification of suitable actions to mitigate and adapt to "total climate change" [30, 48, 49, 50].

Resilience in its general connotation (i.e., not specifically referring to buildings) is a concept that is related to the ability of a system to cope with adverse situations. This concept started from being characterized with a relatively narrow focus, meaning the capacity of a system to rebound or regain equilibrium after a disturbance, moving to - through application to other fields - a more developed concept that encompasses not only bouncing back but also adaptability and transformation [51]. These two interpretations of resilience define the two views currently recognized in the scientific literature, referred to by Holling [52] as "engineering resilience" (ENG, here) and "ecological resilience" (ECO, here), respectively. It is no coincidence that the two major fields of application of this concept are precisely engineering and ecology. The following subsection discusses the general concept of resilience in more detail.

1.3 The general concept of "resilience"

The term "resilience" was first introduced in materials science in the early 19th Century, [53, 54]. Precisely, the term was used by Tredgold [55] to delineate a characteristic of timber and elucidate why certain wood varieties could withstand abrupt and intense loads without fracturing. Building upon this, Robert Mallet expanded on the notion of resilience in the mid-19th century, introducing the concept of "the modulus of resilience" as a metric for evaluating materials' capacity to endure harsh conditions.

Nowadays the term resilience is being applied in various fields other than engineering, such as ecology [52, 56], psychology [57], sociology [58], business [59] and economy [60, 61] - assuming different connotations and thus different definitions according to pertinent ambit's specificities, demonstrating thus the flexibility of the term [45]. For instance, Holling, who first applied the term resilience to ecology, defined the resilience of an ecosystem as the measure of its ability "to absorb changes of state variables driving variables and parameters and still persist", while he defined stability as "the ability of a system to return to a temporary disturbance. The more rapidly it returns and with the least fluctuation, the more stable it is" [56]. In addition, Holling stated as follows: "resilience determines the persistence of relationships within a system".

Despite numerous definitions of resilience available in the literature, however, mainly two different ways of conceiving resilience have emerged. Holling [52] defined these as "engineering resilience" and "ecological resilience", respectively. It is not by accident that the main fields of resilience implementation are engineering and ecology [62].

To provide readers with a better understanding of these two ways of conceiving resilience, excerpts from some scientific articles in the relevant literature, which the present authors believe are useful to clearly capture the differences between the two resilience visions, are listed in Table 1.

Table 1. Excerpts of scientific articles concerning the two interpretations of the resilience concept.

	Engineering Resilience (ENG)	Ecological Resilience (ECO)
Holling, 1986 [52]	"… concentrates on stability near an equilibrium steady state, where resistance to disturbance and speed of return to the equilibrium are used to measure the property…"	"… emphasizes conditions far from any equilibrium steady state, where instabilities can flip a system into another regime of behavior—that is, to another stability domain … In this case, the measurement of resilience is the magnitude of disturbance that can be absorbed before the system changes its structure by changing the variables and processes that control behavior…."
Pickett et al., 2004 [63]	"… the ability of systems to return to their stable equilibrium point after disruption. The entire theoretical apparatus and connotation of the term is focused on stable equilibrium conditions……"	"… the ability of a system to adapt and adjust to changing internal or external processes … The emphasis is not on reaching or maintaining a certain end point or terminal condition, but on staying "in the game…"
Benè et al., 2012 [51]	"…the ability of a system to bounce back or return to equilibrium following disturbance…"	"… the ability not simply to bounce back but also to adapt and to transform…"
Hassler and Kohler, 2014 [64]	"… an approach to maintain stability (i.e. the elastic behaviour of materials over a single equilibrium) …"	"… approach that explicitly acknowledges a dynamic system that changes over time. This dynamic system constitutes a (metaphorical) contemporary blueprint involving multiple equilibria and an adaptive change concept…"
Davoudi, 2012 [54]	"… the ability of a system to return to an equilibrium or steady state after a disturbance … the resistance to disturbance and the speed by which the system returns to equilibrium is the measure of resilience. The faster the system bounces back, the more resilient it is. The emphasis is on return time, "efficiency, constancy and predictability", all of which are sought-after qualities for a "fail-safe" engineering design…"	"… resilience is defined not just according to how long it takes for the system to bounce back after a shock, but also how much disturbance it can take and remain within critical thresholds. Ecological resilience focuses on "the ability to persist and the ability to adapt…"
Krelling et al., 2023 [65]	"…under the first, the equilibrium-centered viewpoint, resilience describes how fast the variables return towards their equilibrium following a perturbation…"	"…the second viewpoint describes multiple equilibria states, with the system being able to adapt and change, reaching a stable state that is not necessarily the same. This second viewpoint …is focused on "maintaining existence of function, while the former engineering approach is focused on maintaining efficiency of function…"

As it can be observed, these two definitions represent two distinct understandings: especially, the first definition, which is the more traditional one and characterized by a narrow focus, is a static kind of interpretation; while the second, which is more elaborated and inclusive [51, 63], is a dynamic kind of interpretation [62]. The difference between these two interpretations essentially lies in the paradigm under which the analyzed system is considered, i.e. whether characterized by one or more equilibrium states [52, 54].

Based on the information in Table 1, expressions commonly used to describe the two resilience views can be derived; for the engineering resilience definition, it can be stated: "maintaining stability", "returning to pre-shock situation", "bouncing back", and "single, stable equilibrium paradigm"; while, for the ecological resilience definition, "shock absorption”, “evolving and adapting”, “transforming”, “adaptive change”, “multiple equilibria paradigm”, and “bouncing fourth”.

1.4 Criticisms encountered and contribution of the paper

As previously mentioned, the interest of the present authors is addressed to buildings and the manner to conceive resilience for these systems. This work particularly focuses on the resilience of buildings to both rising temperatures and extreme temperature events, particularly heatwaves, i.e. on the so-called “thermal resilience”. The other dimensions of resilience such as, for example, structural resilience, fire resilience, and seismic resilience according to the different types of disaster/threat [33] are beyond the scope of the present article.

The thermal resilience of buildings is a topic that has received the attention of the scientific community; in fact, a certain number of pertinent studies (although still quite limited) can be found in the literature. Although some attention has been paid to this topic, however, it should be noted that there is still some confusion about what the concept of building resilient to the threats posed by the current and future climate should concretely include.

In an effort to contribute to the achievement of a clearer and shared vision of how to understand resilience in the case of buildings, the present authors, in addition to literature analysis, propose a new approach to applying this concept to buildings, starting specifically with the phenomena that buildings are required to face (bottom-up). Such a new approach can usefully attain a "tailored" definition of resilience for buildings. In addition, they deliver some considerations in applying the concept of resilience to buildings regarding the importance of considering the whole "building-plant-occupant" system and thus highlight the importance of also including the occupants’ resilience. Furthermore, they stress the need to consider not only the extreme events (thermal shock) that create the damage but also the increase in average outdoor air temperatures (thermal stress) that proceeds over the long term.

Additionally, it should be noted that this study fills a gap in the current literature related to buildings’ thermal resilience. In fact, to the best of our knowledge, no study in this field seems to investigate to what extent this concept is well-defined and clear. Instead, questioning whether there is a clear interpretation/understanding of this concept, in the opinion of the present authors, is a rather relevant issue. Indeed, it could facilitate the identification of appropriate and effective strategies to improve the resilience performance of buildings, as well as the identification of simple and reliable indicators to measure the progress that, hopefully, mitigation and adaptation actions implemented in a building can make.

1.5 Article structure

Based on the above-depicted context, the structure of the paper is as follows: Section 2 delivers criteria used to select the examined literature; Section 3, in order to provide insight into the current advancements in the application of the resilience concept to buildings, illustrates results of a large review of studies concerning buildings, with specific attention to thermal resilience. Specifically, the review mainly aims at identifying (whether it exists) by means of the delivered definition, the currently adopted interpretation when applying the concept of (thermal) resilience to buildings. Section 4 presents a critical analysis of the obtained results with both a proposal of a new approach (specifically starting from the phenomena that buildings have to cope with) and some considerations in applying the concept of resilience to buildings. For the sake of clarity, the logical structure of the study presented here is depicted in Fig. 2.

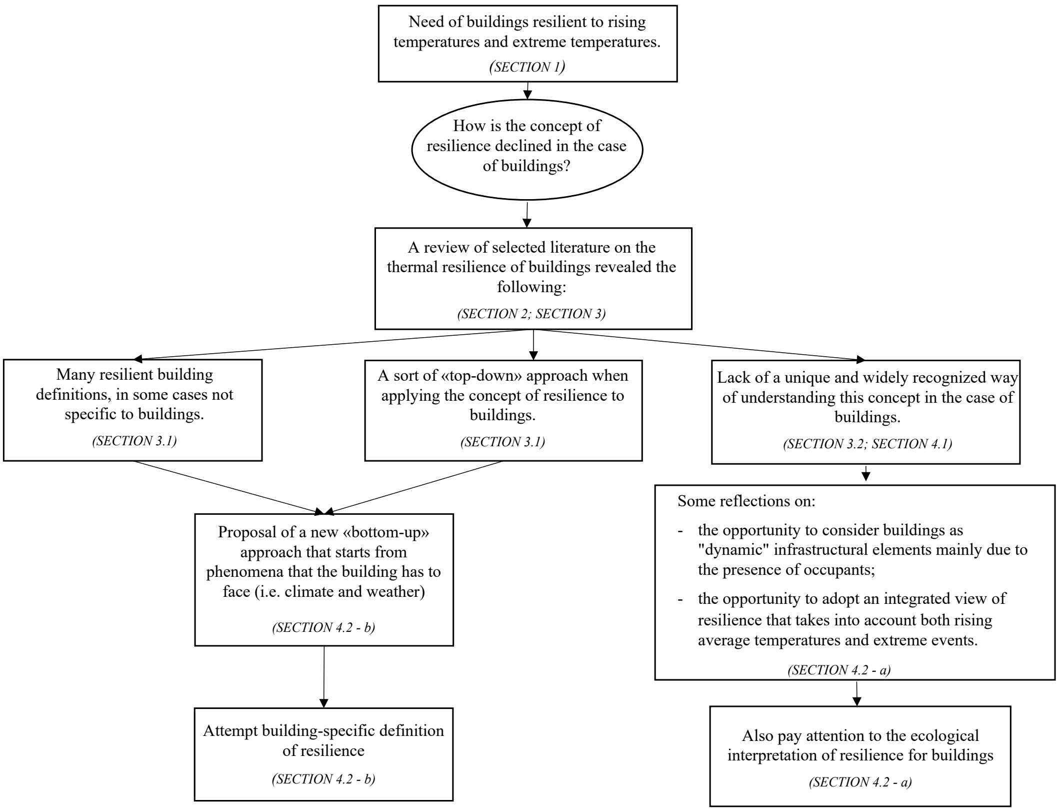

Fig. 2. Logical scheme beyond the work presented here.

2. METHODOLOGY OF SELECTION OF THE LITERATURE STUDIED

As stated earlier, this paper dealt with resilience to rising temperatures and heatwave events, i.e., the thermal resilience of buildings. The present authors tried to understand the resilience concept for building through a review of selected literature, from which point of view it was treated, i.e., through which of the above two interpretations.

The literature search was conducted by querying the main scientific databases (i.e., Scopus, ScienceDirect, WoS, ResearchGrate) using the search strings "building resilience," "building thermal resilience," "building climate change resilience," and "climate change resilience in the built environment". The research carried out showed that the number of works published before 2017 was found to be small and not specifically concerning the aspects of interest for this article. For this reason, the present study has considered only works published in the past eight years. Fig. 3 shows, on the other hand, that since 2017 there has been a gradual increase in interest in the topic under consideration, which has been even more evident, especially in the last two years.

In addition, Fig. 4, which shows the geographic dispersion of papers covered by the literature search, demonstrates (as was to be expected) how the topic of resilience of the built environment in recent years has found strong interest in countries that have historically been more sensitive to issues concerning sustainability, climate change, and energy savings, while it is attracting less interest in countries currently undergoing economic development.

As mentioned earlier, as a first criterion for skimming the articles found, it was chosen to consider papers published from 2017 onward. In detail, the number of papers published before 2017 that were excluded was 2. Then, to further refine the literature base for analysis, articles were specifically considered in which the literal definition of resilient building was also associated with a qualitative and/or quantitative assessment through approaches based on the use of indicators/parameters. In detail, among papers between 2017 and 2023 found with the 4 keywords used, those not considering quantitative or qualitative assessments, which were therefore excluded 18.

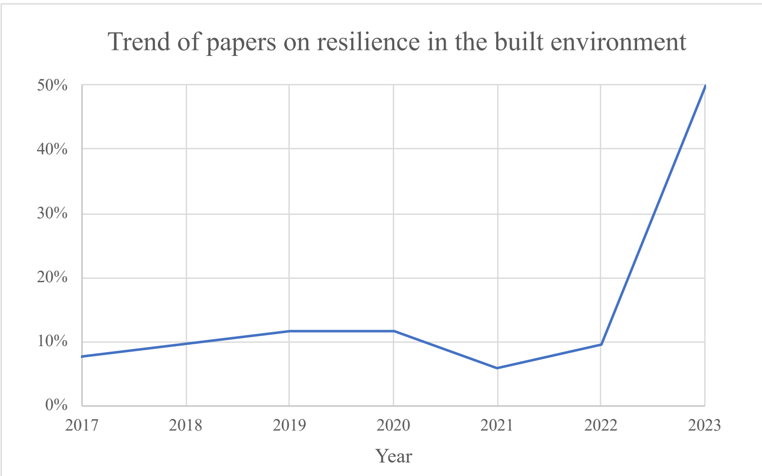

Fig. 3. Trend of papers on the topic of resilience of the built environment from 2017 to present (the percentages on the y-axis are those emerging from the four applied research keys, namely “building resilience", "building thermal resilience", "building climate change resilience", and "climate change resilience in the built environment").

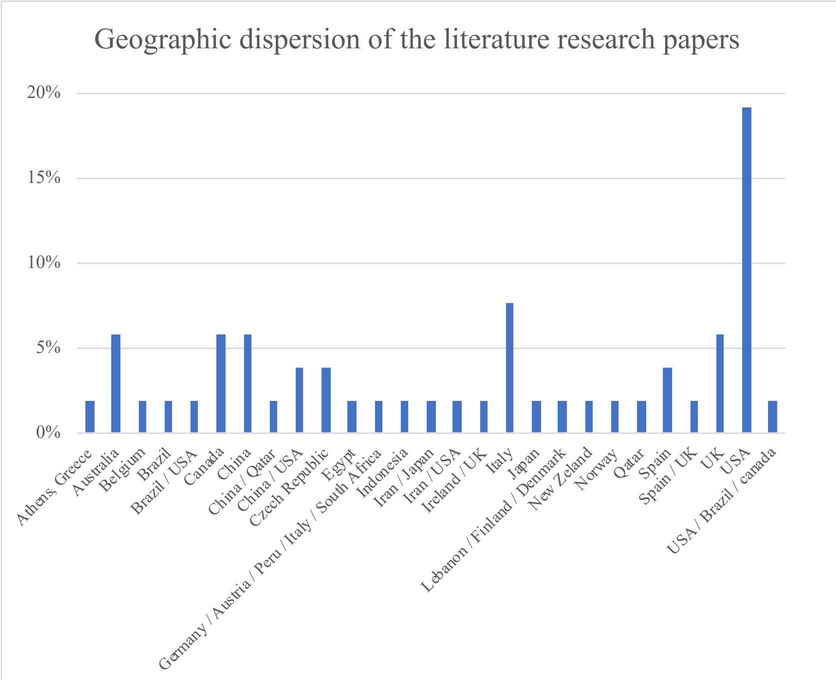

Fig. 4. Geographic dispersion of papers on the topic of resilience of the built environment from 2017 to the present.

The appendix attached to this article, particularly Table A, provides general information on the 32 articles analyzed showing the references, issues mainly treated, and prevalent purposes (the first column indicates a numerical code assigned here to each article).

3. RESILIENCE OF BUILDINGS TO GLOBAL WARMING AND EXTREME TEMPERATURE EVENTS ACCORDING TO THE SELECTED LITERATURE

After a description of selected articles, in this section the authors focus on how thermal resilience of buildings is conceptualized in the literature, highlighting the various interpretations that exist in the selected literature.

3.1 The selected literature: aspects mainly treated, existing definitions and current metrics

The issue of buildings' thermal resilience is a topic that has raised interest in the scientific community, as can be seen in Table A.

Aspects mainly treated – Several aspects are covered on this issue. In this regard, Fig. 5 shows the breakdown of papers by type of issue mainly treated with reference to Table A.

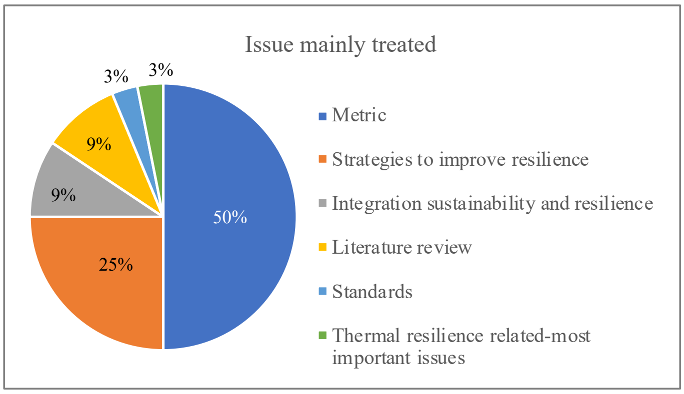

Fig. 5. Breakdown of selected papers by type of issue mainly treated.

It is possible to note that half of the articles analyzed have as their main objective to identify metrics that allow to be able to quantitatively assess the resilience of buildings, related to the different and specific purposes covered (energy, environmental, etc.). In any case, it must be said that, although several procedures exist to date, there still seems to be a lack of one structured resilience assessment of urban buildings, that is shared and commonly adopted [65].

It is observed that about a quarter of the analyzed papers are instead mainly directed at qualitatively establishing possible strategies to be implemented for improving resilience in the built environment. About 10 % of the papers have the integration of sustainability and resilience as their main themes, followed by review studies. A very small percentage of authors dealt with standards and regulations, and some other authors instead treat the topic of resilience in a very generic way addressing the most important issues related to thermal resilience of buildings.

Existing definitions – Generally speaking, finding a universally acknowledged definition poses a challenge [49]. In the 32 analyzed papers, many definitions of resilient building and/or thermal resilience of buildings (25 over 32) could be found. Only in a few cases (7 over 32) no definition is provided, despite dealing with the topic of buildings' resilience. Table B of the Appendix lists for each article, extracts indicating precisely the given definitions. Here, by way of example, are only a few definitions: "...ability of a building and its systems to maintain or rapidly return to desired functions in the face of disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity… …resilient building may not resist any disaster, and its function during stress situation can be decreased. However, it is easy to put the building back into operation, even after a stressful situation that would exceed the resistance of a resistant building…" [66]; "…building's ability to withstand or easily overcome the most important threats…." [67]; "...while reducing the environmental footprint of buildings, these green buildings must also withstand external stressors that may arise over the buildings' lifetime..." [45]; "...the building is defined to be resilient if it is able to prepare for, absorb, adapt to and recover from the disruptive event .... the building is able to prepare in the initial state, absorb and adapt during the disruptive event (phase I) and recover after the disruptive event (phase II)..." [68]; "... ability of a building to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events...thermal resilience, which is a building's ability to maintain a comfortable and safe indoor thermal environment for its occupants throughout its lifetime; particularly during extreme weather events arising from climate change or building system disruptions due to technical failure or power outages....” [33]; “...thermal resilience of the built environment can be defined as the ability of a building to withstand disruptive events while maintaining comfortable conditions indoors….” [49].

As it can be seen, the given definitions in some cases appear to be rather generic, not specifically referring to a building, in any case, it does not seem easy to make them operative. Furthermore, there is a sense that the authors started from the definitions of resilience described above (i.e., engineering and ecological) and then "dropped" them on the building system, thus employing their respective characteristic terms. In other words, it seems that the prevailing approach in the literature in applying the concept of resilience to buildings is top-down.

Current metrics - Relative to the type of indicator(s)/criteria/parameter(s), it emerged a prevalence of certain metrics that are indicated by multiple authors. Specifically, those of greatest relevance appear to be the following: Indoor environmental conditions as operative temperature (°C) and relative humidity (%); Heating and cooling thermal performance in terms of energy demand (kWh/m^2); Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) [69]; Standard Effective Temperature (SET), that is a temperature metric that considers indoor air dry-bulb temperature, relative humidity, mean surface radiant temperature, and air velocity, as well as the activity rate and clothing levels of occupants [70]; Heat Index (HI), which combines air temperature and relative humidity to measure the human-perceived equivalent temperature to assess physiological discomfort conditions [71]; and Indoor Overheating Degree (IOD) that is a multi-zonal indicator, which quantifies the severity of indoor overheating risk taking into account severity and frequency of high indoor temperatures, as the summation of the temperature difference between the indoor operative temperature and a preferred comfort temperature [72].

3.2 How is the building (thermal) resilience understood?

Once definitions have been collected from the 32 selected articles, the present authors have tried to provide an answer to the following questions: among engineering (ENG) and ecological (ECO) resilience definitions, is there a predominant definition? If so, which definition is mainly adopted in the case of buildings to date? Answering these questions, according to the authors, is of non-negligible importance for greater awareness and deeper understanding of what resilient building should concretely mean.

Therefore, an attempt was made to associate each definition with one of the cited interpretations of resilience. Results are illustrated synthetically in Table 2. Specifically, it reports for each analyzed article (i) the issue mainly treated, (ii) an indication concerning against what kind of event resilience is treated in the articles, and (iii) how the concept of resilience has been interpreted based on the previously introduced interpretation categories, i.e., ENG, ECO. In some cases, it was not possible to identify a single interpretation of resilience behind the definition, that is, the definition appeared to refer simultaneously in some ways to the engineering definition and in others to the ecological definition. As a result, ENG/ECO was assigned in these cases.

Table 2. Comparison among the interpretations of resilience on which the studied definitions appear to be based for the 32 analyzed documents (information extracted from Table A and Table B).

N.	Authors	Year	Issue mainly treated	Resilience against what kind of event? (as it is stated in the article)	Resilience definition used (ENG or ECO)
1	[73] Lassandro et al.	2018	Metric	Extreme hot temperatures especially in summer)[†].	-
2	[44] Phillips et al.	2017	Strategies to improve resilience	Climate change and its negative impacts	ENG
3	[74] Coley et al.	2017	Metric	Global warming[‡]	-
4	[75] Katal et al.	2019	Metric	Extreme weather[§]	ENG
5	[66] Nehasil et al.	2019	Metric	Climate change and extreme events	ECO
6	[46] Lassandro et al.	2019	Metric	Heatwaves (or rising temperatures in summer)	ECO
7	[76] Ladipo et al.	2019	Metric	Natural disaster[**]	ENG
8	[32] Baniassadi et al.	2019	Strategies to improve resilience	Heat disaster[††]	ENG
9	[77] Shahin et al.	2019	Strategies to improve resilience	Changes occurring in climatic conditions.	ECO
10	[67] Volf et al.	2020	Metric	Climate change and extreme events	ENG/ECO
11	[30] Javanroodi et al.	2020	Metric	Climate[‡‡]	ENG/ECO
12	[25] Samuelson et al.	2020	Strategies to improve resilience	Heat[§§]	-
13	[68] Homaei et al.	2021	Metric	Disruptive event (with a fixed duration)[***]	ENG
14	[13] Rostam et al.	2021	Integration sustainability and resilience	Climate-related extremes[†††]	ECO
15	[45] Roostaie et al.	2022	Integration sustainability and resilience	Disturbing forces of weather events or other disasters.	ENG/ECO
16	[78] Tavakoli et al.	2022	Literature review	Future events, overheating risk	ENG/ECO
17	[34] Zeng et al.	2022	Strategies to improve resilience	Heatwaves	-
18	[28] Flores-Larsen et al.	2022	Metric	Heatwaves	ECO
19	[79] Lopez-García et al.	2022	Metric	Heat, overheating	-

[†] It is considered the following period July 23-26.
[‡] It is studied the variability of the studied historical annual weather time series particularly those concerning the daily mean outdoor temperature and the running mean outdoor temperatures.
[§] In detail, it is investigated the resilience against the three-day power outage due to the storm.
[**] It is not further specified.
[††] Authors consider the AC loss period coincident with hot weather events.
[‡‡] Typical and extreme climate conditions are considered.
[§§] Specifically, authors consider a power outage scenario, because of the extreme conditions.
[***] It is not specified the type of disruptive event. It is only stated the following: "… disruptive event will affect the thermal performance of the building during and after the disruptive event…."
[†††] "…the responses of the building sector against climate-related extremes can be categorized under climate change resilience…"

20	[80] Ismail et al.	2023	Metric	Power outage disruption‡‡‡	ENG/ECO
21	[81] Ji et al.	2023	Metric	Heatwaves	ENG
22	[29] Flores-Larsen et al.	2023	Strategies to improve resilience	Heatwaves	ECO
23	[82] Sheng et al.	2023	Strategies to improve resilience	Heatwave and cold snap with power outages.§§§	ECO
24	[49] Borghero et al.	2023	Strategies to improve resilience	Heatwaves****	ENG
25	[31] Siu et al.	2023	Literature review	Climate change and extreme weather events	ENG
26	[33] Hong et al.	2023	Most important issues regarding thermal resilience of buildings in the face of climate change.	Extreme weather events coincident with power outages.	ECO
27	[65] Krelling et al.	2023	Metric	Extreme events causing power outages††††	ENG
28	[83] Jia et al.	2023	Literature review	Climate change and extreme weather events	ENG
29	[84] Grassie et al.	2023	Metric	Future climate and heatwave periods	-
30	[85] Assaad et al.	2023	Metric	A "shock" that causes a rise in the concentrations of prominent pollutants in the built environment for a certain duration‡‡‡‡.	ENG
31	[2] Baglivo et al.	2023	Standards	An extreme case of a long period without a gas supply§§§§.	-
32	[37] Younes et al.	2023	Integration sustainability and resilience	Heatwaves	ENG/ECO

Information contained in Table 2 has been critically analyzed and a discussion on it is given in the next section.

4. DISCUSSION

This section is divided into two subsections: the first reporting a critical analysis of the results of the selected literature review, and the second in which the authors make - in light of findings - a couple of considerations to be taken into account when applying the concept of resilience to buildings and propose a new "bottom-up" approach to addressing

‡‡‡ "…simulations are conducted … over the summer months of July and August under normal HVAC conditions (set-point temperature at 24 .C), except for the peak summer week where the power outage occurs starting from the first hour of July 30 and remains off until the last hour of August 5 (one week long)…"
§§§ A six-day heat wave in 2015 and a three-day cold snap in 2021 with power outages.
**** Present and future heatwaves
†††† Disruptions that cause overheating.
‡‡‡‡ "…Shocks are defined as extreme unexpected events that occur without prior knowledge of the building residents or designer and thus, no prior action (e.g., preventive maintenance) can be taken to prevent them…"
§§§§ "…the forecasting analyses were carried out considering the years 2030, 2050, and 2070 and three Representative Concentration Pathway scenarios (RCP 2.6, 4.5, and 8.5). The analysis of the results focused on trends of heating, cooling and total thermal performance index from the years 2030–2070…The work analyzed the resilience to climate change of the building envelope…"

buildings' resilience, which starts specifically with the phenomena that buildings face and leads to an operative building-specific definition of resilience.

4.1 Lack of a unique way of understanding the concept of buildings' resilience in the selected literature.

The information in Table 2 highlights the lack of a single, shared vision in the way in which the buildings' resilience has declined. Moreover, in some cases, it was not possible to identify a single interpretation of resilience because the pertinent definition somehow appears to refer simultaneously to the engineering definition and the ecological definition, as stated earlier. In other words, for some definitions, it is not clear the type of interpretation which they rely on. In addition, in certain cases, it was not even possible to assign any of the three suggested categories (ENG, ECO, ENG/ECO).

It is also worth noting that there has been a certain discrepancy between the resilience interpretation used within the same category of issue mainly treated. To try to explore this in more detail, it was therefore decided to analyze the different approaches also in reference to the issue mainly treated in the analyzed papers. In more detail, Fig. 6 was depicted starting from the information contained in Table 2, for the 32 analyzed papers, (a) the allocation of papers by type of resilience interpretation used and (b) the resilience interpretation approach distribution in reference to the issue mainly treated.

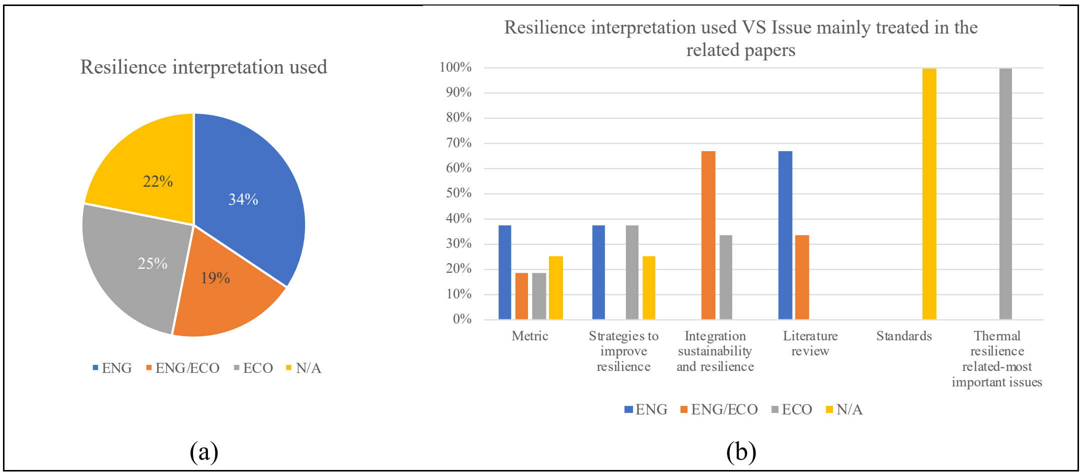

Fig. 6. Allocation of the analyzed papers by type of resilience interpretation used (a) and resilience interpretation distribution in reference to the issue mainly treated.

The pie chart reported in Fig. 6 (a) shows that the ENG interpretation seems to predominate substantially when considering the entire set of papers analyzed. However, the histogram shown in Fig. 6 (b) indicates that the ENG interpretation generally seems to prevail in the papers dealing with buildings' resilience metrics. Moreover, the graph highlights something that would not have been expected, namely, a prevalence of the ENG-ECO circumstance in papers primarily focused on the integration between sustainability and resilience (other than in general literature review studies), and conversely a total lack of such a circumstance in studies concerning precisely strategies to improve resilience.

Furthermore, a certain discrepancy has been noted between the interpretation used to give a definition of resilience and that used in materials and methods: in some articles, a different type of resilience interpretation should be associated with indicators proposed in the selected papers to measure thermal resilience of the building. For instance, in the article, whose code/number is 23 (see Table 2), the definition of resilience proposed is: "…the ability of a building to meet the occupant's needs and provide for a safe, steady and comfortable use in response to changing conditions outside...building energy resilience characterizes the ability to perform building energy services, such as heating, cooling, ventilation, critical plug loads, and shelter, during and in response to a major disruption…". This definition seemingly refers to the ECO resilience interpretation. While, indicators proposed to evaluate resilience are the following: the SET degree hours, which is a temperature parameter that considers indoor air dry-bulb temperature, relative humidity, mean surface radiant temperature and air velocity, as well as the activity rate and clothing levels of occupants [31, 78, 80, 81, 82]; the Heat Index (HI), which combines air temperature and relative humidity to measure the human-perceived equivalent temperature [49, 78, 82]; and the Hours of Safety (HOS), which is a measure of the duration of time a building can maintain safe conditions above a predefined temperature threshold during a cold event [80, 82]. This set of indicators seemingly refers to the ENG resilience interpretation, instead.

Clearly, the presence of different definitions of resilient building that underlie equally different ways of understanding resilience for buildings, together with the aforementioned discrepancy as well as - in some cases - the presence of too far generic definitions generates some confusion regarding how to understand resilience for these components.

It is noteworthy that when the theme of buildings' resilience is treated, the focus is primarily on their ability to withstand extreme weather events. Fig. 7 shows the breakdown of the 32 analyzed papers by type of categories of events against which resilience has been investigated with reference to the information reported in Table 2. Specifically, to simplify the representation, the categories reported in the 5th column of Table 2 ("Resilience against what kind of event?") have been grouped into three macro-categories, that is: "total climate change", "global warming", and "extreme events – heat waves" (the category assignment for the 32 articles is illustrated in detail in Table C of the Appendix). The graph shows that the predominant aspects in reference to which resilience studies have been conducted appear to be those related to extreme events and, among these, particularly the heat waves with a percentage of more than 60%. This is followed by circumstances related to total climate change (25%) and finally global warming (only 9%).

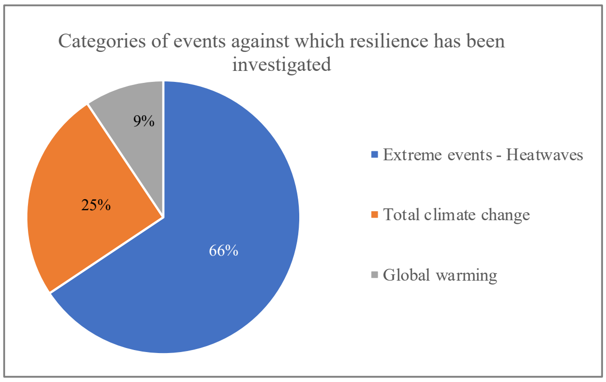

Fig. 7. Breakdown of papers by type of categories of events against which resilience has been investigated.

Fig. 8 reports, for the 32 analyzed papers, the allocation of papers by resilience interpretation used in reference to the categories of events against which resilience has been investigated. It is possible to observe a prevalence of the ENG approach in studies concerning extreme events and heat waves, hence, as previously mentioned, those resulted here as the predominant category. Likewise, in studies considering the resilience against total climate change (i.e. global warming and extreme events), the ENG approach has been mostly used. While papers primarily focused on resilience to only global warming, the ENG/ECO and N/A circumstances have been encountered, revealing a situation of predominant unclearness when it comes to considering only an increase in the mean outdoor air temperature.

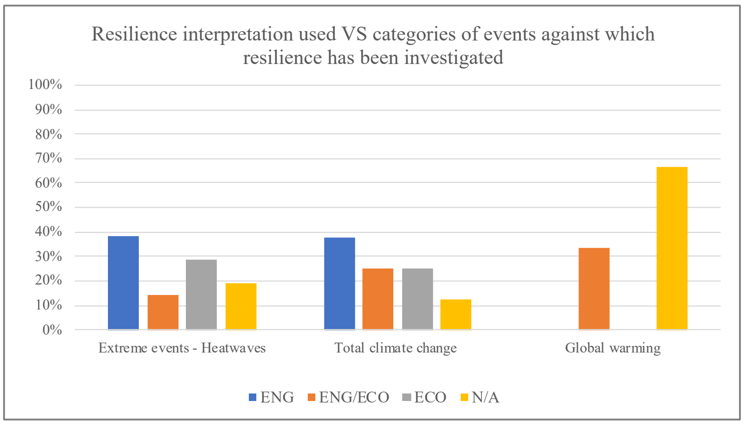

Fig. 8. Distribution of papers by resilience interpretation used with reference to the categories of events against which resilience has been investigated.

Obviously, all this makes the application of the concept of resilience to buildings still a complex task. In the opinion of the present authors, figuring out this issue is of paramount importance, on the one hand, because the concept of resilience to climate change is increasingly coming alongside that of sustainability, establishing itself as a driving force in the planning and design processes of human systems particularly those related to buildings, and on the other hand, because of the strong role that the buildings can play in the path aimed to strengthen the resilience of cities [25, 47, 86, 87]. Having resilient buildings can play a role in diminishing urban vulnerability to extreme heat [73], as they are a predominant component of urban contexts and key nodes as recipients of the various activities that people carry out in them [25, 73, 82, 83].

4.2 Future considerations in applying the concept of resilience to buildings

In an effort to contribute to a shared view on how to understand resilience in the case of buildings, two reflections on the topic are offered below, particularly: (a) on the importance of also paying attention to the theory of ecological resilience in the case of buildings; (b) on a possible new approach in applying the concept of resilience that could usefully arrive at a definition of resilience "specific" to buildings (Fig. 2).

a)

The use of engineering resilience is acknowledged as suitable for the physical and infrastructural components of the urban environment that demand a stable equilibrium. [88]. Indeed, the analysis of the selected literature showed that the ENG interpretation of the concept of resilience seems to predominate substantially when considering the entire set of papers analyzed (Fig.6). This applies to addressing both total climate change and, as expected, extreme weather events (Fig. 8).

However, in the opinion of the present authors, in the case of buildings a circumstance should not be overlooked, namely the fact that buildings are not properly “static” infrastructural elements since the envelopes can be equipped with components and materials that give them adaptive capacity to changing environmental conditions of the surrounding climate [77, 89]. Furthermore, buildings are also characterized by non-technological components, i.e., the occupants[*****], representing a natural component whose thermal adaptive behaviour can contribute to implementing adaptive measures [31, 78], both objectives (such as window opening and shading) and subjective (a personal adaptation, such as clothing change) in response to environmental changes [50, 74]. Moreover, the capacity of occupants to adjust and acclimate gradually to rising or falling temperatures over an extended duration. might induce also a change in indoor thermal requirements for their comfort [27, 74]. In detail, if a majority of residents are willing to compromise on their thermal comfort by slightly increasing the cooling setpoint, peak electricity demands can be markedly reduced, thus mitigating the risk of power outages. [50]. This behaviour is crucial, as informed users can notably enhance comfort through natural ventilation and achieve an average energy consumption reduction of 15% when using air conditioning [49]. The capability to influence occupant behaviour and their adaptive actions is thus of great importance when assessing the thermal

[*****] In addition, the engagement of mixed technologies, for example, green roofs and waste-based materials, which certainly have a natural component embedded with technological components (substrate, etc.), is gaining popularity [90, 91, 92, 93].

resilience of buildings [33]. Therefore, in consideration of all this, in addition to the resilience of the “building-plant” system, the resilience of the occupants should not be neglected [78].

In light of this, buildings can thus reasonably be thought of as “dynamic” infrastructural elements, namely as systems that possess adaptive and transformational capacities and therefore not characterized by a single equilibrium condition but by different states of equilibrium that may be the indoor comfort conditions required by the occupants (that can be regarded as “the equilibrium states of the system”), which likely change along with the changing climate and weather of the site [74]. The above suggests that attention should also be paid to the theory of ecological (as well as engineering) resilience, as also appropriate for buildings in that it can capture their “dynamism”.

Furthermore, the analysis showed that the theme of the climate resilience of buildings is mainly treated with reference to extreme weather events (Fig. 7). Actually, it should not neglect the fact that buildings have to counter not only extreme weather events (which are becoming more intense, frequent, and longer) but they also have to deal with a changing climate, characterized by gradually increasing average outdoor air temperatures (Fig. 1). Therefore, it seems actually reductive to refer the term “resilience,” solely, to the building’s ability to tolerate (withstand), adapt and recover its function (i.e., ensure indoor conditions of comfort for occupants) in the shortest possible time, when subjected to an extreme temperature event, i.e., to adopt the engineering interpretation of resilience. Rather, the term resilience – when applied to buildings – should also account for the climate change understood as an increase in average air temperatures, thus adopting a view of resilience that takes into account both phenomena (integrated view).

Therefore, a resilient building is intended here as one that can provide high comfort performance with low energy consumption, despite being subjected to slowly and gradually changing climatic conditions (adaptive capacity), and at the same time can be able to withstand and quickly reestablish adequate internal comfort conditions in the event of thermal shocks (resilient in the engineering sense of the term).

Such a view recalls the ecological interpretation of resilience that indicates, in fact, resilient a system that is not only resilient in the engineering sense of the term but is also capable of adapting to changing conditions and self-regulating (Table 1). Therefore, this last consideration suggests that attention should also be paid to the theory of ecological resilience as equally appropriate for buildings; in fact, it is capable of taking into account not only extreme events but also climate change understood as an increase in average temperatures.

b)

As mentioned earlier, in the literature, the prevailing way of applying the concept of resilience to buildings seems to be a "top-down" approach, and the resulting definitions appear to be rather generic, and poorly calibrated to buildings. Instead, the present authors wondered whether a bottom-up approach should be taken, one that starts with buildings and particularly their needs. In this way, they believe that a building-specific and also constitutionally operational definition of resilience can usefully be achieved.

Adopting a bottom-up approach involves, as a first step, identifying the adversities that buildings must withstand. In this regard, as mentioned above, buildings in our cities will have to face a climate that is slowly and progressively tending to be warmer as a result of ongoing global warming and with increasingly frequent and longer periods of the year characterized by progressively extreme outdoor air temperature weather conditions. As a second step, it would be necessary to detail the characteristics, both in terms of envelope and system that the building must possess to withstand the identified adverse conditions (stress and shocks), always providing comfort conditions for its occupants and at the same time guaranteeing energy efficiency. In this regard, the envelope needs to allow a high degree of decoupling between the internal and external environments. The plant needs to be characterized by flexibility abilities, prompt response, power adequate to the system life, and a smart management and control system. Based on what was said in consideration (a) of this sub-section, the recognition of the occupants' involvement in resilience seems to be necessary [94]. In other words, also occupants with their thermal adaptability can contribute to determining and/or improving the level of resilience of the building. The compliance of the occupants to engage in such adaptive measures can indeed greatly influence the response habitability of indoor spaces to disruptive events. It needs to incorporate systems for occupants to sense and provide feedback [95]. In other words, it needs to give data/information to the building's occupants, enabling them to gain insights over time and adjust their actions in response to climate and energy loads [77].

With such a "bottom-up" approach, it would be easy to obtain a kind of resilient building profile that, being constitutionally operational, could also serve as a basis on which to build reliable methodologies for assessing the effectiveness, in terms of resilience, of mitigation and adaptation actions taken on a building (or groups of buildings).

Fig. 9 shows, by way of example, a possible flowchart using the approach just described, showing some of the envelope and system characteristics that would make buildings more capable of maintaining comfortable conditions for their occupants while at the same time ensuring energy efficiency, despite ongoing climate change and extreme weather. The scheme also considers occupant participation.

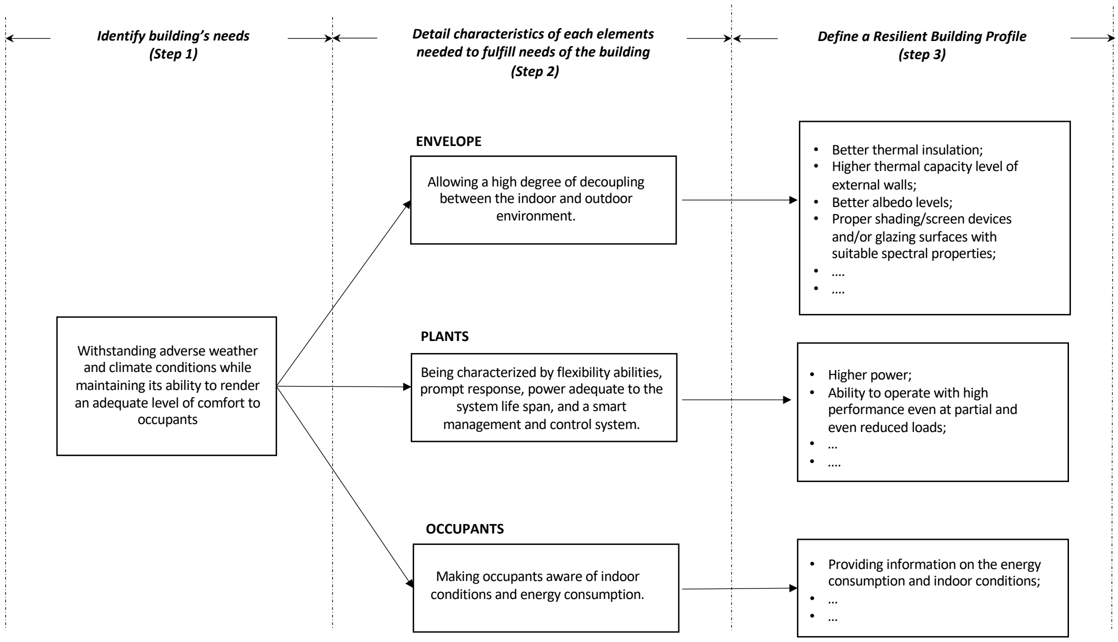

Fig. 9. Logical scheme underlying a bottom-up approach to arrive at a building-specific definition of resilience.

As can be observed, thanks to the proposed approach, it has thus been possible to achieve a definition of climate resilience more targeted ("tailored") to buildings.

5. CONCLUSIONS

This research investigated the concept of buildings' resilience to rising temperatures and increasing occurrences of extreme temperatures. In this section, after summarizing the research conducted and its main findings, the authors provide some recommendations for future research on this topic and outline possible research advancements from the current results.

5.1 Summary and main findings

This paper aims to provide an answer to a crucial question in the building sector, namely how buildings' climate resilience is conceptualized to date. In conclusion, this study proved that, although some attention has been given to this topic, there is still some confusion about what should be concretely understood by thermal resilient building; this confusion is mainly related to the lack of a unique way of understanding this concept in the case of these components, as emerged from the performed extensive literature review.

According to the present authors, a need arises, therefore, for a reevaluation of conceptual frameworks and assessment methodologies. In this regard, in an effort to contribute to the achievement of a clearer and shared vision on how to understand resilience in the case of buildings, the present authors deliver some reflections on: (i) the opportunity to consider buildings as "dynamic" infrastructural elements mainly due to the presence of occupants, which confer adaptive capacity; (ii) the opportunity to adopt an integrated view of resilience that takes into account both rising average temperatures (global warming) and extreme events (heat wave). Relative to point (i), according to the present authors, the concept of a dynamic adaptation to changing climatic conditions is embedded into that of resilience. While relative to point (ii), it has not to be overlooked the fact that in this type of system, there is a kind of inherent resilience due to the presence of the occupants who, through their thermal adaptation behavior, can mitigate the risk of power outages thus avoiding situations of thermal discomfort inside. In our view, occupant resilience should therefore be taken into account because it can reduce the building's vulnerability to rising temperatures and increasing occurrences of extreme temperatures. Based on these two considerations, paying attention also to the theory of ecological resilience in the case of buildings is highly recommended.

In addition, the authors propose a possible new (bottom-up) approach in applying the concept of resilience to buildings that could usefully arrive at an attempted definition of resilience "specific" to buildings, to overcome the presence of rather generic definitions of buildings' resilience. Another advantage of this proposal essentially lies in the fact that the bottom-up approach, starting precisely with the building and its constituent elements, i.e., envelope, systems, and occupants, allows for an in-depth exploration of each them of the requirements needed to make or improve their resilience performance. This approach, in turn, brings the advantage of facilitating the identification of a simple and reliable set of operational indicators of buildings' resilience for each element (building envelope, plant, and occupants).

The main findings of this research work can be summarized as follows:

- a significant lack of consensus regarding the interpretation of buildings' resilience within the existing literature, highlighting the complexity and multifaceted nature of this concept;
- a need for a more cohesive and standardized approach to understanding and operationalizing resilience in the built environment;
- a critical importance of developing a shared understanding of buildings' resilience, particularly in the face of escalating climate change impacts and increasing urbanization pressures;
- current definitions and interpretations of buildings' resilience may not adequately capture the dynamic and adaptive nature of built environments, necessitating a reevaluation of conceptual frameworks and assessment methodologies.

5.2. Findings' implications

From a scientific perspective, the research results, by highlighting a knowledge gap, may help to trigger an advancement of knowledge in the field of building sector resilience to climate change. While, from a practical perspective, the proposed new "bottom-up" approach is intended to be an operational contribution, especially for planners and technicians in their efforts to study solutions and steer the building sector towards a path of ecological and energy transition, in a resilient context, in line with what is indicated in the National Recovery and Resilience Plan (NRRP). Particularly, the potential of the proposed new approach mainly pertains to the possibility for users to decline the concept of resilience in a precise and "tailor-made" way for buildings. This, in turn, will facilitate the identification of a simple and reliable set of operational resilience indicators to quantitatively assess the effects of mitigation and adaptation actions taken with regard to buildings' resilience and thus to allow a clearer reading of the effectiveness, precisely in terms of resilience, of such actions. Also at the application level, both the resilient building profile and any indicators that may be derived from it can also provide useful support in investment decision-making processes and/or for developing guidelines for improving the resilience of the building sector to ongoing climate change.

5.3 Future research and recommendations

It should be noted that, with regard to point (ii), and in particular the suggestion to move toward an integrated view of resilience, one cannot overlook the fact that to date, with the available forecasting tools, designing a building to withstand an increase in average outdoor air temperature is feasible, while designing buildings to withstand future extreme temperature events is not yet. In detail, existing methods for integrating climate projections into research are available, but they are primarily tailored to future "typical" conditions. Further research is required to validate the simulation of extreme weather conditions. [31]. This being the case, we propose for the present design only to withstand an increase in average outdoor air temperature. On the other hand, one advantage of such a design is that the building will be placed in an advantageous position compared to a non-resilient building. This is due to the fact that, despite being subjected to slowly and gradually changing weather conditions, the building will always be able to provide high performance to its occupants with lower energy consumption and, if disturbed suddenly, the building will suffer less loss of indoor comfort performance. In other words, designing buildings to resist the increase in average air temperature will prepare buildings to resist also to extreme events. However, future research of the present authors will explore this aspect further.

Regarding point (i), future research on the inclusion of occupants' adaptive mechanisms to high and low temperatures at the microclimate level for the improvement of resilience characteristics at the building scale, is needed.

As for the proposed "bottom-up" approach, the study showed how its use allows to obtain a building resilient profile (to achieve a definition of resilience specific for buildings) that, being constitutionally operative, could serve as a basis on which identifying simple and reliable methodologies to evaluate the effectiveness, in terms of resilience, of mitigation and adaptation actions taken on a building (or a group of buildings). Future studies of the present authors will try to single out suitable resilience operational indicators for buildings, starting from the buildings' thermal resilience definition here proposed.

A limitation of the study is that only that part of the literature identified through the search keys was considered. Consequently, the results and considerations made concern only those studies tracked according to the specific selection criteria adopted. Therefore, future research on this topic should extend the selection criteria to further search keys to attain an even more comprehensive view.

To conclude, addressing the discrepancies and ambiguities surrounding buildings' resilience is paramount for informing effective decision-making processes, guiding resilient design practices, and enhancing the overall resilience of communities and urban systems. For this reason, moving forward, interdisciplinary collaboration among researchers, practitioners, policymakers, and industry stakeholders is essential to advance knowledge, develop consensus-driven approaches, and implement resilient solutions that address the complex challenges facing built environments.

This study serves as a call to action for the buildings' resilience community to prioritize dialogue, knowledge exchange, and innovation in order to foster resilient, sustainable, and inclusive built environments that can withstand and thrive in the face of future uncertainties and disruptions.

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CRediT taxonomy Giorgia Peri: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. Laura Cirrincione: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. Nicoletta Matera: Formal analysis, Writing – original draft, Writing – review & editing. Domenico Mazzeo: Formal analysis, Writing – original draft, Writing – review & editing. Gianluca Scaccianoce: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

REFERENCES

[1]. IPCC, 2014a: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

[2]. Baglivo C., Congedo P.M., Malatesta N.A., Building envelope resilience to climate change under Italian energy policies, (2023) Journal of Cleaner Production, 411, art. no. 137345. DOI: 10.1016/j.jclepro.2023.137345

[3]. European Commission (2021). Communication from the Commission to the European Parliament, the Council, The European Economic and Social Committee and the Committee of the Regions – Forging a climate resilient Europe – the new EU strategy on Adaptation to Climate Change. Brussels, 24.2.2021 COM(2021) 82 final.

[4]. UNDRR (2020). Report of the United Nations Office for Disaster Risk Reduction (UNDRR), "Human Cost of disasters – An overview of the last 20 years 2000 – 2019". Publication Year: 2020; number of pages: 30. Available at the link: https://www.undrr.org/publication/human-cost-disasters-overview-last-20-years-2000-2019.

[5]. S. Perkins-Kirkpatrick, S. Lewis, Increasing trends in regional heatwaves, Nat. Commun. 11 (1) (2020) 3357

[6]. Lili Ji, Chang Shu, Abdelaziz Laouadi, Michael Lacasse, Liangzhu (Leon) Wang. Quantifying improvement of building and zone level thermal resilience by cooling retrofits against summertime heat events. Building and Environment 229 (2023) 109914

[7]. Klingelhöfer, D., Braun, M., Brüggmann, D. et al. Heatwaves: does global research reflect the growing threat in the light of climate change?. Global Health 19, 56 (2023). https://doi.org/10.1186/s12992-023-00955-4

[8]. https://climate.copernicus.eu/esotc/2022/extreme-heat

[9]. G.S. Jones, P.A. Stott, N. Christidis, Human contribution to rapidly increasing frequency of very warm Northern Hemisphere summers, J. Geophys. Res. Atmos. 113 (D2) (2008) p. n/a-n/a.

[10]. G.A. Meehl, C. Tebaldi, More intense, more frequent, and longer lasting heat waves in the 21st century, Science 305 (5686) (2004) 994-997.

[11]. J.M. Murphy, et al., UK Climate Projections Science Report: Climate Change Projections, Met Office, Hadley Centre, Exeter, 2009.

[12]. Bader, D. A., Blake, R., Grimm, A., Hamdi, R., Kim, Y., Horton, R., and Rosenzweig, C. (2018). Urban climate science. In Rosenzweig, C., W.Solecki, P. Romero-Lankao, S. Mehrotra, S. Dhakal, and S. Ali Ibrahim (eds.), Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. Cambridge University Press. New York. 27–60

[13]. Mehdi Gholami Rostam, Alireza Abbasi. A framework for identifying the appropriate quantitative indicators to objectively optimize the building energy consumption considering sustainability and resilience aspects of Building Engineering 44 (2021) 102974.

[14]. D'Agostino D., Congedo P.M., Albanese P.M., Rubino A., Baglivo C., Impact of climate change on the energy performance of building envelopes and implications on energy regulations across Europe, (2024), Energy, Volume 288, 129886, ISSN 0360-5442. DOI: 10.1016/j.energy.2023.129886.

[15]. Baglivo C., Albanese P.M., Congedo P.M., Relationship between shape and energy performance of buildings under long-term climate change, Journal of Building Engineering, (2024), Volume 84, 108544, DOI: 10.1016/j.jobe.2024.108544.

[16]. International Energy Agency (2019) Global status report for buildings and construction—towards a zero-emission, efficient and resilient buildings and construction sector—UN Environment Programme. International Energy Agency (IEA) 2019. ISBN No:978–92–807–3768–4.

[17]. S. Tsemekidi-Tzeiranaki, P. Bertoldi, D. Paci, L. Castellazzi, T. Serrenho, M. Economidou, P. Zangheri, Energy Consumption and Energy Efficiency Trends in the EU-28 for the Period 2000–2018; JRC Science for Policy Report; Joint Research Centre (JRC): European Commission, Brussels, Belgium, 2020.

[18]. Cirrincione L., Marvuglia A., Peri G., Rizzo G., Scaccianoce G., The European standards for energy efficiency in buildings: An analysis of the evolution with reference to a case study (2019) AIP Conference Proceedings, 2191, art. no. 020049. DOI: 10.1063/1.5138782.

[19]. Congedo P.M., Baglivo C., D'Agostino D., Mazzeo D., The impact of climate change on air source heat pumps, (2023), Energy Conversion and Management, Volume 276, 116554. DOI: 10.1016/j.enconman.2022.116554.

[20]. Congedo P.M., Albanese P.M., D'Agostino D., Baglivo C., The role of total solar energy transmittance for normal incidence of the glazed system in climate change adaptation under Italy energy efficiency policies, (2024), Energy and Buildings, Volume 307, 113944. DOI: 10.1016/j.enbuild.2024.113944.

[21]. https://www.unep.org/resources/factsheet/cooling-and-climate-change

[22]. Marana P, Labaka L and Sarriegi J M 2018 A framework for public-private-people partnerships in the city resilience-building process Safety Sci. 110 39–50.

[23]. Gimenez R, Labaka L and Hernantes J 2018 Union means strength: Building city resilience through multistakeholder collaboration J. Conting. Crisis Man. 26 385–93.

[24]. Loiola C, Mary W and Pimentel da Silva L 2018 Hydrological performance of modular-tray green roof systems for increasing the resilience of mega-cities to climate change J. Hydrol.

[25]. Samuelson H.W., Baniassadi A., Izaga Gonzalez P., Beyond energy savings: Investigating the co-benefits of heat resilient architecture, (2020) Energy, 204, art. no. 117886. DOI: 10.1016/j.energy.2020.117886.

[26]. Mazzeo D., Matera N., Peri G., Scaccianoce G., Forecasting green roofs' potential in improving building thermal performance and mitigating urban heat island in the Mediterranean area: An artificial intelligence-based approach (2023) Applied Thermal Engineering, 222, art. no. 119879. DOI: 10.1016/j.applthermaleng.2022.119879.

[27]. Flores-Larsen S., Bre F., Hongn M., A performance-based method to detect and characterize heatwaves for building resilience analysis, (2022) Renewable and Sustainable Energy Reviews, 167, art. no. 112795. DOI: 10.1016/j.rser.2022.112795.

[28]. Flores-Larsen S., Filippín C., Bre F., New metrics for thermal resilience of passive buildings during heat events, (2023), Building and Environment 230, art. no. 109990, Cited 8 times. DOI: 10.1016/j.buildenv.2023.109990.

[29]. Matera N., Mazzeo D., Baglivo C., Congedo P.M., Will Climate Change Affect Photovoltaic Performances? A Long-Term Analysis from 1971 to 2100 in Italy, (2022), Energies, Volume 15, Issue 24, 9546. DOI: 10.3390/en15249546.

[30]. Javanroodi, K., Nik, V.M., Adl-Zarrabi, B. (2020). A multi-objective optimization framework for designing climate-resilient building forms in urban areas. IOP Conf. Series: Earth and Environmental Science 588 (2020) 032036. DOI:10.1088/1755-1315/588/3/032036.

[31]. Siu C.Y., O'Brien W., Touchie M., Armstrong M., Laouadi A., Gaur A., Jandaghian Z., Macdonald I., Evaluating thermal resilience of building designs using building performance simulation – A review of existing practices, (2023) Building and Environment, 234, art. no. 110124. DOI: 10.1016/j.buildenv.2023.110124.

[32]. Baniassadi A., Sailor D.J., Bryan H.J., Effectiveness of phase change materials for improving the resiliency of residential buildings to extreme thermal conditions, (2019) Solar Energy, 188, pp. 190 – 199. DOI: 10.1016/j.solener.2019.06.011

[33]. Hong T., Malik J., Krelling A., O'Brien W., Sun K., Lamberts R., Wei M., Ten questions concerning thermal resilience of buildings and occupants for climate adaptation, (2023) Building and Environment, 244, art. no. 110806. DOI: 10.1016/j.buildenv.2023.110806.

[34]. Zeng Z., Zhang W., Sun K., Wei M., Hong T., Investigation of pre-cooling as a recommended measure to improve residential buildings' thermal resilience during heat waves, (2022) Building and Environment, 210, art. no. 108694. DOI: 10.1016/j.buildenv.2021.108694.

[35]. S.L. Kingsley, et al., Current and projected heat-related morbidity and mortality in Rhode Island, Environ. Health Perspect. 124 (4) (2016) 460e467.

[36]. P.A. Mendez-Lazaro, et al., Climate change, heat, and mortality in the tropical urban area of San Juan, Puerto Rico, Int. J. Biometeorology (2016) 1-9.

[37]. D. D'Ippoliti, et al., The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project, Environ. Health A Glob. Access Sci. Source 9 (1) (2010).

[38]. Jaafar Younes, Minzhou Chen, Kamel Ghali, Risto Kosonen, Arsen Krikor Melikov, Azin Velashjerdi Farahani, Simo Kilpeläinen, Nesreen Ghaddar. Enhancing sustainability and resilience of elderly dwellings: Optimized refurbishing parameters and air conditioning operation. Energy & Buildings 289 (2023) 113065.

[39]. S. Vandentorren et al., August 2003 heat wave in France: risk factors for death of elderly people living at home, The European Journal of Public Health 16 (6) (2006) 583–591.

[40]. D.O. Åström, F. Bertil, R. Joacim, Heat wave impact on morbidity and mortality in the elderly population: a review of recent studies, Maturitas 69 (2) (2011) 99–105.

[41]. K. Sun et al., Passive cooling designs to improve heat resilience of homes in underserved and vulnerable communities, Energy Build. 252 (2021).

[42]. https://www.un.org/en/climatechange/climate-emergency-heatwaves

[43]. https://www.un.org/en/climatechange/what-is-climate-change

[44]. Robert Phillips, Luke Troup, David Fannon, Matthew J. Eckelman. Do resilient and sustainable design strategies conflict in commercial buildings? A critical analysis of existing resilient building frameworks and their sustainability implications. Energy and Buildings 146 (2017) 295–311

[45]. S. Roostaie, N. Nawari, Ph.D., P.E., F.ASCE, Professor The DEMATEL approach for integrating resilience indicators into building sustainability assessment frameworks Building and Environment 207 (2022) 108113

[46]. Lassandro P., Di Turi S., Multi-criteria and multiscale assessment of building envelope response-ability to rising heat waves, (2019) Sustainable Cities and Society, 51, art. no. 101755. DOI: 10.1016/j.scs.2019.101755.

[47]. Antonio Buggin et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 609 072047.

[48]. Laura Cirrincione, Antonino Marvuglia, Gianluca Scaccianoce, Assessing the effectiveness of green roofs in enhancing the energy and indoor comfort resilience of urban buildings to climate change: Methodology proposal and application, Building and Environment, Volume 205, 2021, 108198, ISSN 0360-1323, https://doi.org/10.1016/j.buildenv.2021.108198.

[49]. Borghero L., Clèries E., Péan T., Ortiz J., Salom J., Comparing cooling strategies to assess thermal comfort resilience of residential buildings in Barcelona for present and future heatwaves, (2023) Building and Environment, 231, art. no. 110043. DOI: 10.1016/j.buildenv.2023.110043.

[50]. Peiping Zheng, Chunxiao Wang, Yanchen Liu, Borong Lin, Huijun Wu, Yu Huang, Xiaoqing Zhou a, Thermal adaptive behavior and thermal comfort for occupants in multi-person offices with air-conditioning systems. Building and Environment 207 (2022) 108432

[51]. Béné, C., Godfrey Wood, R., Newsham, A., Davies, M. (2012), “Resilience: New utopia or new tyranny? Reflection about the potentials and limits of the concept of resilience in relation to vulnerability reduction programmes”, IDS Working Papers, Vol. 2012/405, pp. 1-61.

[52]. Holling, C. S. (1996). Engineering resilience versus ecological resilience. Pages 31-44 in P. C. Schulze, editor. Engineering within ecological constraints. National Academy Press, Washington, D.C., USA. https://unhabitat.org/resilience

[53]. McAslan, Alastair. The Concept of Resilience. Understanding its Origins, Meaning and Utility. Adelaide, Australia: Torrens Resilience Institute, 2010.

[54]. Simin Davoudi, Keith Shaw, L. Jamila Haider, Allyson E. Quinlan, Garry D. Peterson, Cathy Wilkinson, Hartmut Fünfgeld, Darryn McEvoy, Libby Porter & Simin Davoudi (2012) Resilience: A Bridging Concept or a Dead End? "Reframing" Resilience: Challenges for Planning Theory and Practice Interacting Traps: Resilience Assessment of a Pasture Management System in Northern Afghanistan Urban Resilience: What Does it Mean in Planning Practice? Resilience as a Useful Concept for Climate Change Adaptation? The Politics of Resilience for Planning: A Cautionary Note, Planning Theory & Practice, 13:2, 299-333, DOI: 10.1080/14649357.2012.677124

[55]. Tredgold, T. (1818) 'On the Transverse Strength of Timber'. Philosophical Magazine: a Journal of Theoritical, Experimental and Applied Science, Chapter XXXXVII. London: Taylor and Francis.

[56]. Holling, C. S. (1973). Resilience and Stability of Ecological Systems. Annual Review of Ecology and Systematics, Vol. 4, pp. 1-23. Annual Reviews. http://www.jstor.org/stable/2096802.

[57]. Luthans, F., Vogelgesang, G., & Lester, P. (2006). Developing the psychological capital of resiliency. Human Resource Development Review, 5, 25–44. https://doi.org/10.1177/ 1534484305285335.

[58]. Pavićević, Olivera, The resilience concept in sociology. Sociologija, Volume 58, Issue 3, Pages 432 – 449, 2016.

[59]. Galkina Tamara, Atkova Irina, Gabrielsson Peter, Business modeling under adversity: Resilience in international firms. Strategic Entrepreneurship JournalOpen AccessVolume 17, Issue 4, Pages 802 – 829, December 2023.

[60]. Aditya Bagas, Amri Ikhwan, Rethinking Informal Economy Resilience during Crisis: Experience from COVID-19 Pandemic. Indian Journal of Labour EconomicsOpen AccessVolume 66, Issue 3, Pages 711 – 737.September 2023.

[61]. Deng Yue, Jiang Wanyi, Wang Zeyu, Economic resilience assessment and policy interaction of coal resource oriented cities for the low carbon economy based on AI. Resources PolicyVolume 82, May 2023 Article number 103522.

[62]. Giulia Datola,, Implementing urban resilience in urban planning: A comprehensive framework for urban resilience evaluation, Sustainable Cities and Society, Volume 98, 2023, 104821. https://doi.org/10.1016/j.scs.2023.104821.

[63]. Pickett,S.T.A., Cadenasso, M.L., Grove, J.M. (2004). Resilient cities: meaning, models, and metaphor for integrating the ecological, socio-economic, and planning realms. Landscape and Urban Planning, Volume 69, Issue 4, Pages 369-384, ISSN 0169-2046, https://doi.org/10.1016/j.landurbplan.2003.10.035.

[64]. Hassler, U. and Kohler, N. (2014). Resilience in the built environment, Building Research & Information 2014 Vol. 42, No. 2, 119–129.

[65]. Krelling AF, Lamberts R, Malik J, Hong T, A simulation framework for assessing thermally resilient buildings and communities, Building and Environment (2023) https://doi.org/10.1016/j.buildenv.2023.110887.

[66]. Nehasil O., Lupisek A., Volf M., Methodology for assessment of resilience of multifamily residential houses in central Europe, (2019) Journal of Physics: Conference Series, 1343 (1), art. no. 012186. DOI: 10.1088/1742-6596/1343/1/012186.

[67]. Volf M., Nehasil O., Malík Z., Hrabal D., Růžička J., Lupíšek A., Resilient and Environmentally Efficient Residential Buildings - Assessment Method and Interim Outcomes, (2020) IOP Conference Series: Earth and Environmental Science, 588 (3), art. no. 032035. DOI: 10.1088/1755-1315/588/3/032035.

[68]. Homaei S., Hamdy M., Thermal resilient buildings: How to be quantified? A novel benchmarking framework and labelling metric, (2021) Building and Environment, 201, art. no. 108022. DOI: 10.1016/j.buildenv.2021.108022.

[69]. International Standard Organization – ISO UNI EN ISO 7730, 2005 – Ergonomics of the Thermal Environment — Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria, 2005. Geneva, Switzerland.

[70]. ANSI/ASHRAE Standard 55, Thermal Environmental Conditions for Human Occupancy - American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc, 2010.

[71]. Steadman, R.G., 1979: The assessment of sultriness. Part I: A temperature-humidity index based on human physiology and clothing science. J. Appl. Meteor., 18, 861-873.

[72]. Attia S., Benzidane C., Rahif R., Amaripadath D., Hamdy M., Holzer P., Koch A., Maas A., Moosberger S., Petersen S., Mavrogianni A., Maria Hidalgo-Betanzos J., Almeida M., Akander J., Khosravi Bakhtiari H., Kinnane O., Kosonen R., Carlucci S., Overheating calculation methods, criteria, and indicators in European regulation for residential buildings, (2023) Energy and Buildings, 292, art. no. 113170. DOI: 10.1016/j.enbuild.2023.113170.

[73]. Lassandro P., Cosola T., Climate change mitigation: resilience indicators for roof solutions, (2018) International Journal of Disaster Resilience in the Built Environment, 9 (1), pp. 4 – 17. DOI: 10.1108/IJDRBE-11-2016-0046.

[74]. Coley D., Herrera M., Fosas D., Liu C., Vellei M., Probabilistic adaptive thermal comfort for resilient design, (2017) Building and Environment, 123, pp. 109 – 118. DOI: 10.1016/j.buildenv.2017.06.050.

[75]. Katal A., Mortezazadeh M., Wang L.L., Modeling building resilience against extreme weather by integrated CityFFD and CityBEM simulations, (2019) Applied Energy, 250, pp. 1402 – 1417. DOI: 10.1016/j.apenergy.2019.04.192.

[76]. Ladipo O., Reichard G., McCoy A., Pearce A., Knox P., Flint M., Attributes and metrics for comparative quantification of disaster resilience across diverse performance mandates and standards of building, (2019) Journal of Building Engineering, 21, pp. 446 – 454. DOI: 10.1016/j.jobe.2018.11.007.

[77]. Shahin H.S.M., Adaptive building envelopes of multistory buildings as an example of high performance building skins, (2019) Alexandria Engineering Journal, 58 (1), pp. 345 – 352. DOI: 10.1016/j.aej.2018.11.013.

[78]. Tavakoli E., O'Donovan A., Kolokotroni M., O'Sullivan P.D., Evaluating the indoor thermal resilience of ventilative cooling in non-residential low energy buildings: A review, (2022) Building and Environment, 222, art. no. 109376. DOI: 10.1016/j.buildenv.2022.109376.

[79]. López-García E., Lizana J., Serrano-Jiménez A., Díaz-López C., Angela Barrios-Padura, Monitoring and analytics to measure heat resilience of buildings and support retrofitting by passive cooling, (2022) Journal of Building Engineering, 57, art. no. 104985. DOI: 10.1016/j.jobe.2022.104985.

[80]. Ismail N., Ouahrani D., Al Touma A., Quantifying thermal resilience of office buildings during power outages: Development of a simplified model metric and validation through experimentation, (2023) Journal of Building Engineering, 72, art. no. 106564. DOI: 10.1016/j.jobe.2023.106564.

[81]. Ji L., Shu C., Laouadi A., Lacasse M., Wang L.L., Quantifying improvement of building and zone level thermal resilience by cooling retrofits against summertime heat events, (2023) Building and Environment, 229, art. no. 109914. DOI: 10.1016/j.buildenv.2022.109914.

[82]. Sheng M., Reiner M., Sun K., Hong T., Assessing thermal resilience of an assisted living facility during heat waves and cold snaps with power outages, (2023) Building and Environment, 230, art. no. 110001. DOI: 10.1016/j.buildenv.2023.110001.

[83]. Jia S., Zhan D.-J., Resilience and sustainability assessment of individual buildings under hazards: A review, (2023) Structures, 53, pp. 924 – 936. DOI: 10.1016/j.istruc.2023.04.095.

[84]. Grassie D., Dong J., Schwartz Y., Karakas F., Milner J., Bagkeris E., Chalabi Z., Mavrogianni A., Mumovic D., Dynamic modelling of indoor environmental conditions for future energy retrofit scenarios across the UK school building stock, (2023) Journal of Building Engineering, 63, art. no. 105536. DOI: 10.1016/j.jobe.2022.105536.

[85]. Assaad D., Sengupta A., Breesch H., A novel quantitative assessment framework of the IAQ resilience performance of buildings: The resilience score metric, (2023) Building and Environment, 243, art. no. 110669. DOI: 10.1016/j.buildenv.2023.110669

[86]. Bisegna F., Cirrincione L., Lo Casto B.M., Peri G., Rizzo G., Scaccianoce G., Sorrentino G., Fostering the energy efficiency through the energy savings: The case of the University of Palermo (2019) Proceedings - 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe, EEEIC/I and CPS Europe 2019, art. no. 8783774, DOI: 10.1109/EEEIC.2019.8783774

[87]. Napoli G., Corrao R., Scaccianoce G., Barbaro S., Cirrincione L., Public and Private Economic Feasibility of Green Areas as a Passive Energy Measure: A Case Study in the Mediterranean City of Trapani in Southern Italy (2022) Sustainability (Switzerland), 14 (4), art. no. 2407. DOI: 10.3390/su14042407.

[88]. Kathryn Davidson, Thi Minh Phuong Nguyen, Ruth Beilin, Jessie Briggs, The emerging addition of resilience as a component of sustainability in urban policy, Cities, Volume 92, 2019, Pages 1-9, https://doi.org/10.1016/j.cities.2019.03.012.

[89]. A. Gasparella, et al., Analysis and modelling of window and glazing systems energy performance for a well insulated residential building, Energy Build. 43 (4) (2011) 1030–1037.

[90]. Llorach-Massana P., Cirrincione L., Sierra-Perez J., Scaccianoce G., La Gennusa M., Peña J., Rieradevall J., Environmental assessment of a new building envelope material derived from urban agriculture wastes: the case of the tomato plants stems (2023), International Journal of Life Cycle Assessment, 28 (7), pp. 813 – 827. DOI: 10.1007/s11367-023-02152-2.

[91]. Peri G., Licciardi G.R., Matera N., Mazzeo D., Cirrincione L., Scaccianoce G., Disposal of green roofs: A contribution to identifying an "Allowed by legislation" end–of–life scenario and facilitating their environmental analysis (2022), 226, art. no. 109739. DOI: 10.1016/j.buildenv.2022.109739.

[92]. Rizzo G., Cirrincione L., La Gennusa M., Peri G., Scaccianoce G., Green Roofs' End of Life: A Literature Review (2023), Energies, 16 (2), art. no. 596. DOI: 10.3390/en16020596.

[93]. Cirrincione L., Gennusa M.L., Marino C., Nucara A., Marvuglia A., Peri G., Passive components for reducing environmental impacts of buildings: analysis of an experimental green roof (2020) 20th IEEE Mediterranean Electrotechnical Conference, MELECON 2020 - Proceedings, art. no. 9140546, pp. 494 – 499.

[94]. Cirrincione L., Geropanta V., Peri G., Scaccianoce G., Enhance Urban Energy Management and Decarbonization Through an EC-based Approach, (2023) Proceedings - 2023 IEEE International Conference on Environment and Electrical Engineering and 2023 IEEE Industrial and Commercial Power Systems Europe, EEEIC / I and CPS Europe 2023. DOI: 10.1109/EEEIC/ICPSEurope57605.2023.10194675.

[95]. Cirrincione L., Gennusa M.L., Peri G., Rizzo G., Scaccianoce G., Foster Carbon-Neutrality in the Built Environment: A Blockchain-Based Approach for the Energy Interaction Among Buildings (2022), 2022 Workshop on Blockchain for Renewables Integration, BLORIN 2022. DOI: 10.1109/BLORIN54731.2022.10027899.