20th International Conference on Renewable Energies and Power Quality (ICREPQ'22)
Vigo (Spain), 27th to 29th July 2022
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.20, September 2022

Energy resilience in buildings for hot tropical climate conditions: A review

J. Flórez-Reyes[1], G. Osma-Pinto[2]

[1] Department of Electrical, Electronic and Telecommunications Engineering
U.I.S, Universidad Industrial de Santander
Calle 9 Carrera 27, Bucaramanga (Colombia)
Phone number: +57607344000, e-mail: florezjulian@correo.uis.edu.co[1], gealosma@uis.edu.co[2]

Abstract. Buildings allow satisfying several needs of society, although their construction and use imply significant energy consumption and pollutant emissions. In general, they experience temporary or permanent events that could affect the conditions of well-being, safety, and use of equipment in interior spaces from an energy perspective. It is expected that the building can respond to such events by its design features (passive response) or by its systems (active response), which is studied from the energy resilience approach. However, there is little research on this topic. Therefore, this paper conducts a literature review covering definitions, assessment strategies, and case studies, particularly for the tropical zone, to identify and socialize the most relevant findings to facilitate future research.

Keywords. Energy resilience, buildings, automation, tropical zone.

1. Introduction

According to the International Energy Agency, buildings account for approximately 36% of global energy consumption and 24% of greenhouse gas emissions [1,2]. Within the life cycle of a building, the operation stage represents 80-90% of the total gas emissions corresponding to the functionality of the systems to provide comfort to the occupants [3,4].

Buildings should aim to control the usability conditions of the interior spaces (e.g., temperature, illuminance, and humidity) [5,6]. These comfort conditions are affected by external events that vary the level of comfort over time. Such variations should be mitigated to ensure the comfort of the users and the safeguarding of the facilities [7].

Events can be frequent or occasional, temporary (short or long duration) or permanent, such as failures in the supply of a service, earthquakes, cybernetic attacks, increase in the ambient temperature, etc. Buildings can respond to a lesser or greater degree to such events due to their design characteristics or to integrated control systems for their operation.

Building automation systems (BAS) and building management systems (BMS) are designed to automatically manage, monitor, verify, control, operate, and adjust complex mechanical and electrical building systems [3,8].

The BAS/BMS are oriented to ensure the comfort of users and the safety of people and facilities [7,9]. Therefore, the main variables monitored are micro-climatic conditions in the surrounding area, as well as illuminance, space occupancy, user habits, indoor temperature, air humidity, CO_2 concentration, and energy consumption, among others [6–8,10]. Although these systems involve challenges due to the technological complexity (hardware and software) [7].

The versatility of building management and automation favours the resilience or responsiveness of a building to changes in expected or normal operating conditions [7,11,12].

However, there is still little research on exploiting the capabilities of BAS/BMS to cope with unexpected changes in the operating conditions of buildings [7,13]. These systems have mainly two disturbance paths, one with events in the electrical system and the other with a change in the conditions of the system to be controlled. These two tend to be treated separately [7,14–25].

Particularly, buildings located in tropical zones are affected to a greater extent in their energy consumption by climatic conditions, which are quasi-constant throughout the year [17,25–28].

Section 2 presents the methodology used for the literature review concerning the measurement and analysis of energy resilience associated with buildings. Section 3 characterizes the findings and elaborates on the definition of energy resilience, analyzes the contribution of BAS/BMS, and presents resilience assessment strategies. Finally, Section 4 presents the conclusions of this review.

2. Review Methodology

A. Search

This review is based on a search of papers published in databases such as ELSEVIER, IEEE, SAGE, and Tayler&Francis. The keywords considered in the search criteria are Resilience, Building, Energy, Automation, and Comfort. Some of the search criteria are:

Resilien* AND Building
Resilien* AND Building AND Automation
Resilien* AND Building AND Control
Resilien* AND Building AND Energy
Resilien* AND (Building OR Dwelling)
Resilien* AND (Building OR Dwelling) AND Energy AND Comfort

B. Classification of results

A characterization of the papers according to the year of publication, journal, and specific topic is carried out initially. Subsequently, the SCOPUS Preview and VOSVIEWR tools are applied. Finally, in the Fig. 1, we proceed to recognize the definitions of resilience applicable to the energy approach in buildings, evaluation strategies, and case studies for the tropical zone.

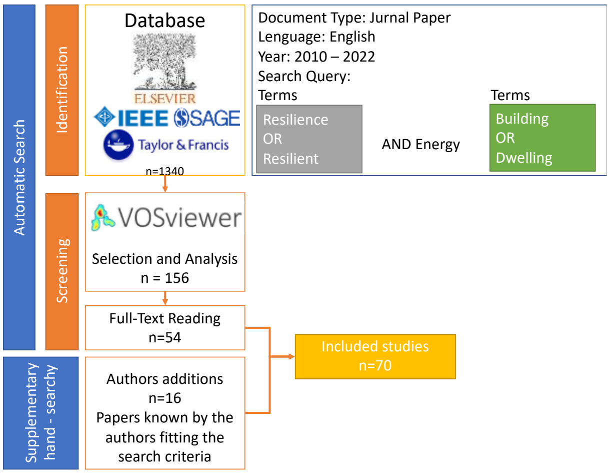


Fig. 1. Papers selection workflow.

3. Review results

A. Results Characterization

After the search for the relevant terms, the results were restricted to those after the year 2010 and publications in journals, and finally excluding the results that are related to the word "seismic". As expressed in this search equation, (TITLE-ABS-KEY (energy AND resilien*) AND TITLE-ABS-KEY (building) AND NOT TITLE-ABS-KEY (seismic)) AND (LIMIT-TO (SRCTYPE, "j") OR LIMIT-TO (SRCTYPE, "p")). With a total of 1,340 documents found. Fig. 2 shows a growing trend of publications since 2010, exceeding 200 since 2019, which shows the validity of this theme.

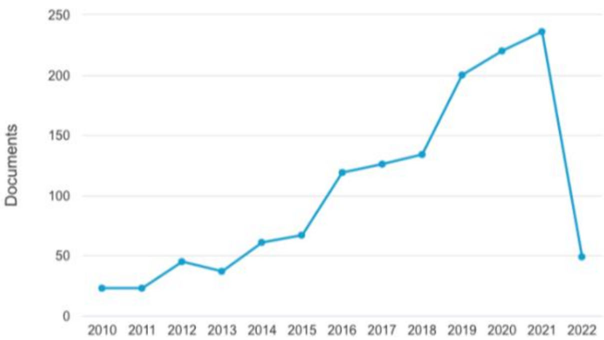


Fig. 2. Documents published by year.

Fig. 3 shows that the largest number of publications corresponds to the United States, the United Kingdom, China, Italy and Canada; meanwhile, the most recent publications correspond to Egypt, Iran, the Philippines and Hungary.

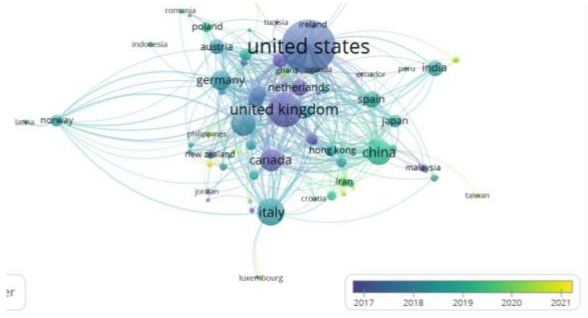


Fig. 3. Publication density by country

Fig. 4 allows identifying the journals with the highest number of publications, such as: Building and Environment, IOP Conference Series: Earth and Environmental Science, Journal of Building Engineering, Energy, Sustainable Cities and Society, Energy and Buildings, and Energy Procedia.

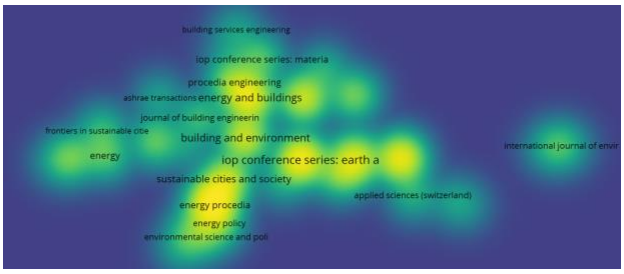


Fig. 4. Publication density by source.

The keyword analysis, shown in Fig. 5, indicates that the most relevant topics in these investigations are climate change, resilience, energy utilization, intelligent buildings, electric power transmission, construction, and heating urban planning, among others.

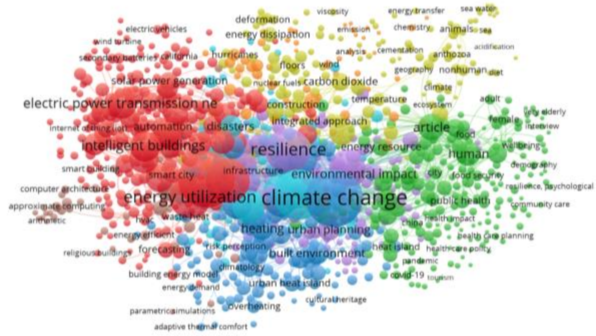


Fig. 5. Keyword density

B. Definitions

Resilience is a concept coming from biology, which has been taken to characterize certain behaviors of physical systems with respect to actions that may disturb the correct operation of the system; however, the relationship between resilience, energy, comfort, and buildings is the subject of study [12,22,29].

This concept is commonly used as a measure of stability, sustainability, and vulnerability. Stability of a system is to effectively combat the development of adaptive means to shocks, disruptions, disruptive events, and changing conditions without losing the prior relationships governing the system components [30,31]. The four characteristic components of resilience are robustness, redundancy, resourcefulness, and speed [32–34].

C. *Stages*

In general, five stages can be identified: pre-disruptive event, post-disruptive event, stable with degraded performance, restorative process, and normal system performance. Fig. 6 relates these stages in time.

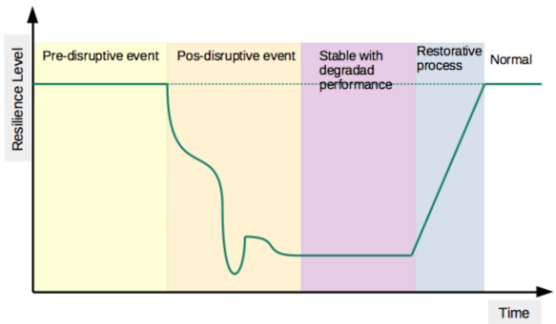


Fig. 6. resilience trapeze.

Various authors propose a resilience analysis scheme, which have similarities as evidenced in Table 1 in the five stages. The discrepancies between these proposals consist mainly of: (i) time of appearance of the incident or event different from the start time of performance degradation [30], (ii) moment of identification of the threat by the system [30,35,36], (iii) final level of performance different from the level existing before the disturbance [30,35].

Table 1. General stages of a resilient system.

Stage			Features
I	Anticipation and preparation	[37]	Pre-event prediction and preparation through planning, which may include the location and estimation of the severity of the event.
	Preparation	[30]	
	Pre-perturbation	[38]	
II	Absorption	[30]	The system seeks to absorb the initial impact and avoid an unwanted effect. The greater the robustness and redundancy, the less the affectation will be.
	Disturbance progress	[38]	
	Resist and absorb	[37]	
III	Degraded state	[38]	The system reaches a stable but degraded operation, whose duration will last until there is a response from it.
	Respond and adapt	[37]	
IV	Recovery	[30]	The restorative actions tend to return the normal operating conditions of the system.
	Restorative state	[38]	
	Get it back	[37]	
V	Adaptation	[30]	Post-event and restoration of performance to a resilient or balanced state.
	Post-restoration	[38]	
	End operation mode	[37]	

D. *Energy Resilience*

Energy resilience is a recent concept, in the stage of self-definition without consensus on the appropriate measurement framework [37], which allows studying the ability of a system to predict, prevent and resist all possible disasters, such as loss of supply, and recover quickly and efficiently . To do this, adaptation measures are applied to mitigate the loss and quickly learn from previous events [29,39,40].

The operation of energy systems must be focused on: i) prevention of supply interruption; ii) mitigation of consequences; iii) reduction of response times to restore, and iv) recovery of supply [41]. This includes measurement based on quantification of the frequency and duration of customer disconnections due to disruptive events and also the number of customers disconnected [42] or the level of degradation received by customers of the energy supply per event [43].

By studying the reliability of a power system in various disaster environments, it can be established that resilience in power systems can be studied at two levels: component level and system level. The first level mainly covers cyber-physical components of the system. The system level is more studied and covers the interactions between its components. [44].

E. *Resilience in buildings*

Champagne y Aktas [45] define the resilience of a building, in the ability to withstand severe weather and natural disasters, along with the ability to recover in a timely and efficient manner if it suffers damage to the built environment, as well as the ability to recover critical infrastructure already control systems as these have a direct impact on the health, safety and communities of the building [34].

In the same page, Joe Clarke [18] establishes guidelines to determine the resilience of a building; establish objectives by type of construction; impose specific disturbances; evaluate specific performance metrics [18]. This approach, based on scenarios, supported by mitigation, vulnerability and anticipation, considers the different threats separately and tries to find partial solutions. [46].

On the other hand, Levite and Rakow point out by defining the energy resilience of a building as the relative capacity of an urban institution to carry out its mission during a shock to the energy system [47]. In the same sense, Osma *et al*. [7] define this concept as the ability to respond to changing scenarios, which maintains the internal operating conditions during the useful life.

F. *Resilience in control systems*

Control systems can be classified into three operational hierarchies [48–52]: Low, direct interaction with physical systems; media, monitoring controller aggregation; and high, monitor and coordinate supply and demand.

Conventionally, a resilient control system (RCS) is considered to be a computer and cybersecurity [50–52] along with robust control, tolerant to faults and fluctuations, thanks to its design, parameters or system operating under a given range of disturbances [53], this perspective is broadened by contemplating unexpected extreme and rare events [36,54].

It is desirable that an RCS maintains awareness of state, performance, and functionality - cybersecurity, physical, functional, and energy security, economic efficiency, dynamic stability, and process conformance [55]. In the framework of resilience, control systems can operate in two initiatives: maintaining their original objectives or changing their nominal objectives to security objectives [52].

Note that undesirable incidents, failures or threats can also happen at the human layer, such as incorrect commands or configurations; in the process layer, like a broken wire; in the automation layer, such as sensor damage and actuator malfunctions [56].

G. *Resilience analysis and assessment*

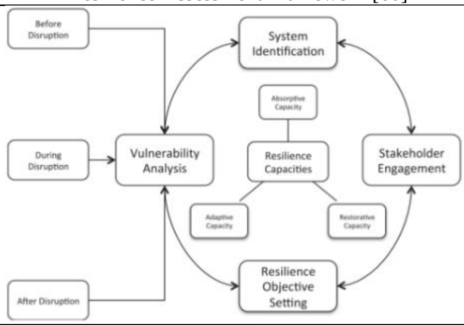
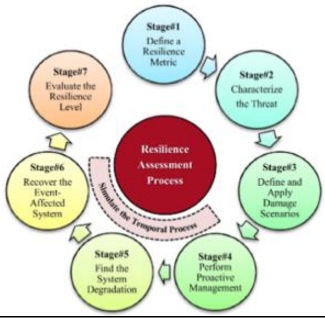
Resilience analysis has been synthesized into several processes evident in the literature. These processes are mostly cyclical, step-by-step processes that seek to inform the reader on how to orient and focus the required analysis independent of the system being addressed. Generally, they are a general guide to the implementation of resilience analysis systems in a system; these processes provide the minimum steps for the correct accomplishment of the analysis [31,37,44,57–59].

As literature findings related to resilience, three analysis processes stand out (Table 2): "resilience analysis process" [31], "resilience assessment framework" [60] and "resilience assessment process" [44].

Sandia National Laboratories [31,37,59] asserts that an appropriate metric should be quantitative, useful for decision making, which may reflect uncertainty, it must consider recovery time, which may take different approaches. Along the same idea, Salim Moslehi *et al.* [57] state that the methods for assessing the resistibility may be the following: (i) structural evaluation methods, (ii) performance-based methods, and (iii) hybrid methods.

In the same line, Salim Moslehi *et al*. [57] state that the applicable resilience assessment methods are: (i) structural assessment methods, (ii) performance-based methods, and (iii) hybrid methods that are a combination of the first two [57].

Table 2. Resilience Analysis Processes.

Resilience analysis process [31]	Resilience Assessment Framework [60]	Resilience Assessment Process [44]
		
Define resilience goals: It is essential to define resilience goals.	***System identification:*** Definition of the system domain; delimitation of fundamental and strategic objectives	***Define a resilience metric:*** An appropriate resilience metric. You must provide normalized values.
Define system and resiliency metrics: This determines the scope and limits of the analysis.	***Vulnerability analysis:*** determine the disruptive events of interest.	***Characterizes the threat:*** Causes, effects and physical (and/or cybernetic) aspects are modelled.
Characterize Threats: Assess the sources of multiple hazards, their likelihood, capabilities, or the strength of the threat.	***Establishment of resilience objectives:*** The normal function of the system will be defined according to the fundamental objectives.	***Define and apply damage scenarios:*** Identify damage scenarios for system components and modules.
Determine the level of disruption: Determine the amount of system damage and performance impact**.**	***Stakeholder engagement:*** Stakeholders are an integral part of resilience analysis and management.	***Carry out proactive management:*** Preparing for possible future problems.
Define and apply system models: Identify the organization of systems.	***Resilience capacities:*** It is evaluated through the set of resilience capacities.	***Find System Degradation:*** Provide a view of the adverse impacts imposed by an event.
Calculate the consequence: The system models become the metrics.		***Recover the system affected by events:*** Define the recovery process
Evaluate resilience improvements: Make operational decisions to improve resilience.		***Evaluate the level of resilience:*** With resilience metric, the expected value will be determined.

Generally, metrics can be grouped into one of two categories: attribute-based and performance-based metrics. Which respectively answer "What makes my system more/less resilient?" and "How resilient is my system?"[59]. Two types of validity are considered for metrics, content "depends on whether an empirical measurement reflects a specific domain of content" construction "refers to the fact that a particular measure is related to other measures"[44,58].

H. Building operation in tropical areas

In the tropical context, the resilience of buildings is subject to a greater extent to the increase in global temperature. Then, the prompt adoption of an updated or new building code that considers indoor thermal comfort requirements, among others, could benefit countries with hot tropical cities [61], together with the use of more resilient envelopes as a strategy to mitigate climate change [62]. As a consequence of the union of resilience in design and systems, a variation in energy demand is caused [63].

4. Conclusions

Historically, resilience has been a concept implemented in mostly natural events, in which the restoration capacity of systems is evaluated. However, resilience is easily extrapolated to other types of events, mainly those that may have high repercussions and uncertainty of occurrence. Identifying quantifiable characteristics for those disruptive events represents the outstanding result of the state of the art studied.

Resilience in buildings has been studied from a seismic-resistant and structural approach. However, since the acceptance of the definition of resilience for dynamic systems, it is evident that the analysis of energy resilience in buildings should be expanded to the definition and consensus of methods of analysis, calculation and evaluation of all the systemic actors of a building, together with a process of integration and unification of criteria that allows the measurement and comparison of resilience levels between buildings.

Using resilience as an evaluative element of the systems is possibly the next step in the analysis of their management and efficiency. By quantitatively establishing a consensus value of resilience, it would be possible not only to determine the resilience of the systems to known events, but also to assess the adaptive, recovery and robustness capacities of the systems.

References

[1] Lu H, Cheng F, Ma X and Hu G 2020 Short-term prediction of building energy consumption employing an improved extreme gradient boosting model: A case study of an intake tower *Energy* **203** 117756

[2] An J H, Bae S G, Choi J, Lee M G, Oh H S, Yun D Y, Lee D E and Park H S 2019 Sustainable design model for analysis of relationships among building height, CO 2 emissions, and cost of core walls in office buildings in Korea *Build. Environ.* **150** 289–96

[3] Fan C, Xiao F, Madsen H and Wang D 2015 Temporal knowledge discovery in big BAS data for building energy management *Energy Build.* **109** 75–89

[4] Administration U S E I 2020 *Annual Energy Outlook 2020 with projections to 2050* (U.S.)

[5] Pham A D, Ngo N T, Ha Truong T T, Huynh N T and Truong N S 2020 Predicting energy consumption in multiple buildings using machine learning for improving energy efficiency and sustainability *J. Clean. Prod.* **260** 121082

[6] Mashayekhi A and Heravi G 2020 A decision-making framework opted for smart building's equipment based on energy consumption and cost trade-off using BIM and MIS *J. Build. Eng.* 101653

[7] Osma G, Amado L, Villamizar R and Ordoñez G 2015 Building Automation Systems as Tool to Improve the Resilience from Energy Behavior Approach *Procedia Eng.* **118** 861–8

[8] Roth J, Brown IV H A and Jain R K 2020 Harnessing smart meter data for a Multitiered Energy Management Performance Indicators (MEMPI) framework: A facility manager informed approach *Appl. Energy* **276** 115435

[9] Barnier F and Chekkar R 2018 Building Automation, an Acceptable Solution to Dependence? Responses Through an Acceptability Survey About a Sensors Platform *Irbm* **39** 167–79

[10] Aghemo C, Blaso L and Pellegrino A 2014 Building automation and control systems: A case study to evaluate the energy and environmental performances of a lighting control system in offices *Autom. Constr.* **43** 10–22

[11] Raza A, Malik T N, Khan M F N and Ali S 2020 Energy management in residential buildings using energy hub approach *Build. Simul.*

[12] Halhoul Merabet G, Essaaidi M, Ben Haddou M, Qolomany B, Qadir J, Anan M, Al-Fuqaha A, Abid M R and Benhaddou D 2021 Intelligent building control systems for thermal comfort and energy-efficiency: A systematic review of artificial intelligence-assisted techniques *Renew. Sustain. Energy Rev.* **144** 110969

[13] Azuatalam D, Lee W, Nijs F De and Liebman A 2020 Energy and AI Reinforcement learning for whole-building HVAC control and demand response **2**

[14] United Nations Environment Programme 2019 *Towards a zero-emissions, efficient and resilient buildings and construction sector. 2019 Global Status report*

[15] Sun K, Specian M and Hong T 2020 Nexus of thermal resilience and energy efficiency in buildings: A case study of a nursing home *Build. Environ.* **177** 106842

[16] Katal A, Mortezazadeh M and Wang L (Leon) 2019 Modeling building resilience against extreme weather by integrated CityFFD and CityBEM simulations *Appl. Energy* **250** 1402–17

[17] Pantua C A J, Calautit J K and Wu Y 2021 Sustainability and structural resilience of building integrated photovoltaics subjected to typhoon strength winds *Appl. Energy* **301** 117437

[18] Clarke J 2018 The role of building operational emulation in realizing a resilient built environment *Archit. Sci. Rev.* **61** 358–61

[19] Hasselqvist H, Renström S, Strömberg H and Håkansson M 2022 Household energy resilience: Shifting perspectives to reveal opportunities for renewable energy futures in affluent contexts *Energy Res. Soc. Sci.* **88** 102498

[20] Tian M W and Talebizadehsardari P 2021 Energy cost and efficiency analysis of building resilience against power outage by shared parking station for electric vehicles and demand response program *Energy* **215** 119058

[21] Samuelson H W, Baniassadi A and Izaga Gonzalez P 2020 Beyond energy savings: Investigating the co-benefits of heat resilient architecture *Energy* **204** 117886

[22] Charani Shandiz S, Foliente G, Rismanchi B, Wachtel A and Jeffers R F 2020 Resilience framework and metrics for energy master planning of communities *Energy* **203** 117856

[23] Zeng Z, Zhang W, Sun K, Wei M and Hong T 2022 Investigation of pre-cooling as a recommended measure to improve residential buildings' thermal resilience during heat waves *Build. Environ.* **210** 108694

[24] Cirrincione L, Marvuglia A and Scaccianoce G 2021 Assessing the effectiveness of green roofs in enhancing the energy and indoor comfort resilience of urban buildings to climate change: Methodology proposal and application *Build. Environ.* **205** 108198

[25] Schünemann C, Schiela D and Ortlepp R 2021 How window ventilation behaviour affects the heat resilience in multi-residential buildings *Build. Environ.* **202** 107987

[26] Osma G, Ordóñez G, Hernández E, Quintero L and Torres M 2016 The impact of height installation on the performance of PV panels integrated into a green roof in tropical conditions *Energy Prod. Manag. 21st Century II Quest Sustain. Energy* **1** 147–56

[27] Cárdenas-Rangel J, Osma-Pinto G and Ordóñez-Plata G 2018 Herramienta metodológica para la evaluación energética mediante simulación de edificaciones en el trópico *Rev. UIS Ing.* **18** 259–68

[28] Osma-Pinto G and Ordóñez-Plata G 2019 Measuring factors influencing performance of rooftop PV panels in warm tropical climates *Sol. Energy* **185** 112–23

[29] Mola M, Feofilovs M and Romagnoli F 2018 Energy resilience: Research trends at urban, municipal and country levels *Energy Procedia* **147** 104–13

[30] Sharifi A and Yamagata Y 2016 Principles and criteria for assessing urban energy resilience: A literature review *Renew. Sustain. Energy Rev.* **60** 1654–77

[31] JP Watson C H and L P W 2015 *Conceptual framework for developing resilience metrics for the electricity, oil, and gas sectors in the United States* (Albuquerque)

[32] Bastan O, Fiedler P, Benesl T and Arm J 2019 Redundancy as an important source of resilience in the

Safety II concept *IFAC-PapersOnLine* **52** 382–7
[33] Amirioun M H, Aminifar F, Lesani H and Shahidehpour M 2019 Metrics and quantitative framework for assessing microgrid resilience against windstorms *Int. J. Electr. Power Energy Syst.* **104** 716–23
[34] Tien I 2018 Resilient by design: The case for increasing resilience of buildings and their linked food-energy-water systems *Elementa* **6** 12
[35] Caputo A C, Pelagagge P M and Salini P 2019 A methodology to estimate resilience of manufacturing plants *IFAC-PapersOnLine* **52** 808–13
[36] Song Z, Ren G, Mirabella L and Srivastava S 2016 A resilience metric and its calculation for ship automation systems *Proc. - 2016 Resil. Week, RWS 2016* 194–9
[37] Lin Y and Bie Z 2016 Study on the Resilience of the Integrated Energy System *Energy Procedia* **103** 171–6
[38] Panteli M, Trakas D N, Mancarella P and Hatziargyriou N D 2017 Power Systems Resilience Assessment: Hardening and Smart Operational Enhancement Strategies *Proc. IEEE* **105** 1202–13
[39] Levite B and Rakow A 2015 Local Energy Resilience *Energy Resilient Buildings & Communities - A Practical Guide* (The Fairmont Press, Inc.) pp 27–50
[40] Zhang H, Bie Z, Li G and Lin Y 2019 Assessment method and metrics of power system resilience after disasters *J. Eng.* **2019** 880–3
[41] Rosales-Asensio E, de Simón-Martín M, Borge-Diez D, Blanes-Peiró J J and Colmenar-Santos A 2019 Microgrids with energy storage systems as a means to increase power resilience: An application to office buildings *Energy* **172** 1005–15
[42] Liu X, Hou K, Jia H, Mu Y, Yu X, Wang Y and Dong J 2018 A quantified resilience assessment approach for electrical power systems considering multiple transmission line outages *2017 IEEE Electr. Power Energy Conf. EPEC 2017* **2017-Octob** 1–5
[43] Roche R, Celik B, Bouquain D and Miraoui A 2015 A framework for grid-edge resilience improvement using homes and microgrids coordination *2015 IEEE Eindhoven PowerTech, PowerTech 2015* 1–6
[44] Gholami A, Shekari T, Amirioun M H, Aminifar F, Amini M H and Sargolzaei A 2018 Toward a consensus on the definition and taxonomy of power system resilience *IEEE Access* **6** 32035–53
[45] Champagne C L and Aktas C B 2016 Assessing the Resilience of LEED Certified Green Buildings *Procedia Eng.* **145** 380–7
[46] Kohler N 2018 From the design of green buildings to resilience management of building stocks *Build. Res. Inf.* **46** 578–93
[47] Levite B and Rakow A 2015 Institutional Planning for Energy Resilience *Energy Resilient Buildings & Communities - A Practical Guide* (The Fairmont Press, Inc.) pp 52–83
[48] Smith J, Pereyda J and Gammel D 2016 Cybersecurity best practices for creating resilient control systems *Proc. - 2016 Resil. Week, RWS 2016* 62–6
[49] Haque M A, De Teyou G K, Shetty S and Krishnappa B 2018 Cyber resilience framework for industrial control systems: Concepts, metrics, and insights *2018 IEEE Int. Conf. Intell. Secur. Informatics, ISI 2018* 25–30
[50] Sridhar S, Ashok A, Mylrea M, Pal S, Rice M and Gourisetti S N G 2017 A testbed environment for buildings-to-grid cyber resilience research and development *Proc. - 2017 Resil. Week, RWS 2017* 12–7
[51] Jones C B, Carter C and Thomas Z 2018 Intrusion Detection Response using an Unsupervised Artificial Neural Network on a Single Board Computer for Building Control Resilience *Proc. - Resil. Week 2018, RWS 2018* 31–7
[52] Prince J J A, Haessig P, Bourdais R and Gueguen H 2019 Resilience in energy management system: A study case *IFAC-PapersOnLine* **52** 395–400
[53] Zhu Q and Başar T 2011 Robust and resilient control design for cyber-physical systems with an application to power systems *Proc. IEEE Conf. Decis. Control* 4066–71
[54] Zhu Q and Basar T 2015 Game-Theoretic Methods for Robustness, Security , and Resilience of Cyberphysical Control Systems *IEEE Control Syst. Mag.* **35** 46–65
[55] Rieger C G 2014 Resilient control systems Practical metrics basis for defining mission impact *7th Int. Symp. Resilient Control Syst. ISRCS 2014* 1–10
[56] Wei D and Ji K 2010 Resilient industrial control system (RICS): Concepts, formulation, metrics, and insights *Proc. - ISRCS 2010 - 3rd Int. Symp. Resilient Control Syst.* 15–22
[57] Moslehi S and Reddy T A 2018 Sustainability of integrated energy systems: A performance-based resilience assessment methodology *Appl. Energy* **228** 487–98
[58] Mendonça D 2015 Measures of Resilient Performance *Resilience-Based Performance: Next Generation Guidelines for Buildings and Lifeline Standards*
[59] Vugrin E, Castillo A and Silva-monroy C 2017 *Resilience Metrics for the Electric Power System : A Performance-Based Approach* (Albuquerque)
[60] Francis R and Bekera B 2014 A metric and frameworks for resilience analysis of engineered and infrastructure systems *Reliab. Eng. Syst. Saf.* **121** 90–103
[61] Gamero-Salinas J, Monge-Barrio A, Kishnani N, López-Fidalgo J and Sánchez-Ostiz A 2021 Passive cooling design strategies as adaptation measures for lowering the indoor overheating risk in tropical climates *Energy Build.* **252** 111417
[62] Da Guarda E L A, Domingos R M A, Gabriel E, Durante L C, Moreira J V R and Sanches J C M 2020 Use of thermal insulation in the envelope to mitigate energy consumption in the face of climate change for mid-western Brazil *IOP Conf. Ser. Earth Environ. Sci.* **410**
[63] Ascione F, De Masi R F, Gigante A and Vanoli G P 2022 Resilience to the climate change of nearly zero energy-building designed according to the EPBD Recast: monitoring, calibrated energy models and perspective simulations of a Mediterranean nZEB living lab *Energy Build.* **262** 112004