Alternative Affordable Solutions in Reducing the Number of Hours with Heat Strain Inside Buildings

Atlas Ramezani – University of Trieste, Italy – atlas.ramezani@phd.units.it
Marco Manzan – University of Trieste, Italy – manzan@units.it

Abstract

Challenges of climate change affect various aspects of human life. This research focuses on the health implications resulting from climate-induced alterations and underlines the vulnerabilities experienced by specific demographic groups, notably the elderly and socioeconomically disadvantaged. These individuals frequently suffer the impact of extreme heat events due to their limited access to cooling technologies, such as air conditioning units, thus exacerbating their vulnerability to heat-related illnesses and diminishing their overall quality of life. Relying on air conditioning systems causes various limitations, including increased energy consumption, exacerbation of greenhouse gas emissions, and the risk of power outages. Moreover, rules and financial problems such as initial and operational costs block widespread adoption, particularly among low-income households.

In response to these problems, this study promotes an affordable alternative strategy focused on utilizing practical yet effective methods, electric fans, window coverings, and natural ventilation to alleviate indoor heat stress and to evaluate their efficacy in enhancing thermal comfort and protecting the well-being of occupants. Numerical simulations were conducted using EnergyPlus and Design Builder software. The simulations focused on a prototypical building, reflecting the common architectural features, representative of multi-family housing built from 1961 to 1975, using the Tabula web tool. The simulations were executed for three cities, Palermo, Pisa, and Trieste in Italy. The analytical framework of this study extends beyond historical weather data, including datasets covering future projections. This comprehensive approach enhances analysis by integrating changing climate conditions.

The findings reveal a significant reduction in hours with heat strain with electric fans emerging as a key tool in mitigating them, even under worst-case scenarios. Natural ventilation and window shading also play significant roles in reducing heat strain hours within apartments. In conclusion, the study emphasizes the urgent need to address the multifaceted impacts of climate change on public health. It advocates for affordable solutions such as electric fans, window coverings, and natural ventilation to combat high internal temperatures and to contribute to broader environmental sustainability goals.

1. Introduction

The ongoing change in climate patterns has led to a consistent rise in ambient temperatures, resulting in notable social and health implications for occupants within built environments. Recent findings from the 2021 Sixth Assessment Report of the IPCC underscore this escalating temperature trend (IPCC, 2021), emphasizing the urgent need to integrate climate considerations into effective building energy policies (Robert & Kummert, 2012). Authorities must prioritize these effects when conducting risk assessments (Manzan et al., 2022), especially given the heightened risk of heat-related health issues stemming from increased temperatures and more frequent heatwaves over the past three decades (Attia et al., 2021).

In response to these challenges, many industrialized countries have usually turned to air conditioning systems to maintain indoor comfort levels and mitigate health risks. However, this approach presents drawbacks, notably regarding energy consumption and infrastructural limitations. The growing demand for space cooling, as highlighted in the 2018 IEA report (IEA, 2018), underscores the need for more sustainable alternatives.

Low-income households, in particular, face significant financial barriers to accessing traditional air conditioning solutions, prompting a shift towards more energy-efficient options like simple electric

Part of
Pernigotto, G., Ballarini, I., Patuzzi, F., Prada, A., Corrado, V., & Gasparella, A. (Eds.). 2025. Building simulation applications BSA 2024. bu,press.
https://doi.org/10.13124/9788860462022

fans. Research by Haddad et al. (2022) underscores the prevalence of fans in low-income housing, offering a cost-effective means of alleviating indoor heat stress. Health concerns, especially in high-temperature environments, further underscore the importance of exploring alternative cooling methods (Manzan et al., 2023).

Studies by Tadepalli et al. (2021) emphasize the potential of ceiling-mounted fans to enhance indoor comfort while reducing reliance on air conditioning. Similarly, the work of Morris et al. (2021) and Tartarini et al. (2022) highlights the safety and efficacy of electric fans, providing valuable insights into their widespread applicability across various climatic conditions by applying the Gagge model (Gagge et al., 1971). They also developed a web platform to assess the usefulness of electric fans (Tartarini et al., 2020).

While fans offer a promising solution for indoor cooling, concerns remain regarding their effectiveness in extreme heat conditions. Research efforts, such as those by Jay et al. (2015), seek to address these concerns and enhance guidelines for fan usage during heatwaves.

In summary, addressing the challenges posed by rising temperatures requires a multifaceted approach that prioritizes energy efficiency, affordability, and public health considerations. By exploring alternative cooling solutions like fans, window shades, and natural ventilation, and integrating climate-responsive design principles, policymakers can mitigate the adverse effects of climate change on indoor environments while promoting sustainability and resilience.

2. Simulation

2.1 Methodology

The efficacy of ventilators in alleviating heat stress caused by elevated temperatures was validated through numerical simulations conducted on a typical building using weather files of three distinct Italian cities: Palermo in the south, Pisa in the central region, and Trieste in the north of Italy (as described in Table 2). The building's geometric properties and thermal attributes were accurately replicated using DesignBuilder software, with simulations executed via EnergyPlus version 9.4. These simulations utilized three climate datasets for each city, including current climate conditions TMY and two projections for future weather patterns, with a specific focus on the summer months of June, July, and August.

2.2 Building Description

The primary characteristics of the building were acquired through the Tabula web tool (TABULA WebTool s.d.), indicating its construction period between 1961 and 1975. It demonstrates qualities of low thermal mass and high transmittance, constituting a five-floor structure described by Lupato & Manzan (2019). Modifications to the geometry were made to show staircases and two apartments per floor. The building encompasses a volume of 3074 m^3 and a total usable surface area of 848.6 m^2, with each apartment occupying 76 m^2. Please see Figure 1 presents the floor plan, which depicts two apartments. The building situated facing south and apartment 1 is oriented towards the east, while apartment 2 has a westward-facing wall. For clarity, each apartment will be denoted by the floor number, beginning with 0 for the Ground floor, followed by the direction, with A1 representing eastward and A2 westward. Hence, the two ground-floor apartments are identified as F0_A1 and F0_A2, respectively. The opaque and transparent structures, along with internal loads, align with those utilized by Lupato & Manzan (2019). Corresponding structures for the uninsulated building are detailed in Table 1. Ventilation considerations include an air change rate of 0.3 ACH, incorporating natural ventilation through window openings. Adjustments to internal loads, opaque and transparent surface characteristics, output variables, and post-processing of results were performed using Python scripts with the Eppy library (2022).

Fig. 1 – Floor plan with the position of two apartments and stairs

Table 1 – Opaque and transparent surface characteristics

	U [W/m²K]	Mass [kg/m²]	U_w [W/m²K]	SHGC [-]
Walls	1.15	194	–	–
Roof	1.10	406	–	–
Floor	0.94	478	–	–
Windows	–	–	2.2	0.7

2.3 Simulated Weather and IDF Files

The simulations utilized three distinct weather files for each city. The first weather file employed was a standard Typical Meteorological Year (TMY), generated from monitored data collected during specific periods: between 1999 and 2008 for Trieste, between 1990 and 2009 for Pisa, and between 2002 and 2009 for Palermo. The geographic coordinates of these cities are reported in Table 2. These TMY files were created following the procedures outlined in the EN ISO 15927-4 technical standard and represent the average climate behavior for each location.

Considering the predicted increase in temperatures and the expected rise in the frequency and severity of heatwaves, for the second and third files two Future Meteorological Year (FMY) were also developed. These FMY were crafted applying the morphing method (Manzan et al., 2023; Belcher et al., 2005), which involves using the TMY data with climate projections obtained from models such as HadGEM2-ES RACMO22E, which for the sake of clarity will be called M1, and MPI-ESM-LR_REMO2009 that will be called M2 (Manzan et al., 2023). The two models were selected among five (Manzan et al., 2022) for having the higher and lower increase in temperatures. For both methods the RCP 8.5 scenario was considered, and future weather data was obtained for the period between 2036 and 2050. Giving rise to a worst-case scenario (M1), and another with a less intense temperature rise (M2).

For each city, we employed two IDF files. The first file outlines the building's configuration without window shades, relying solely on natural ventilation. In contrast, the second IDF file, along with ventilation, considers also that the persons are able to close the external shutters to protect the interior from excessive radiation. To ease recalling each file, the first one will be called NV and the second one SHV. During the post-processing stage, we analyzed these files under two conditions: with and without fans, across three different weather files.

Table 2 – Geographic coordinates of the cities

City	Latitude	Longitude	Altitude
Trieste	45.65	13.78	2
Pisa	43.70	10.40	4
Palermo	38.12	13.35	14

2.4 Biophysical Model

The primary aim of this study is to evaluate the efficacy of a ventilator in improving indoor conditions within a building during high external temperatures. Various biophysical models have been developed by researchers, including Jay et al. (2015) and Morris et al. (2021). However, for this study, we adopted the Gagge model (Gagge et al., 1971) in combination with the methodology proposed by Tartarini et al. (2022), which has been implemented in the Python library *pythermalcomfort* (Tartarini & Schiavon, 2020). Specifically, our analysis utilized the `*fans_heatwaves*` function within this library, which returns several biophysical parameters across different air velocities, providing insights into the impact of fans on the human body.

Solving a balance equation for a system comprising an inner core and an outer skin layer, the Gagge method assesses how environmental factors—such as dry bulb temperature (t_{db}), mean radiant temperature (t_r), air velocity (V), and relative humidity (RH)—as well as clothing level (I_{cl}) and activity (M), influence the sensible and latent heat exchanges between the body and the environment.

Moreover, the *pythermalcomfort* library assists in the acquisition of biophysical parameters that can help in identifying heat strain. Specifically, three parameters—namely, the rate at which regulatory sweat is generated (m_{rsw}), skin wettedness (w), and skin blood flow (m_{bl})—can be compared to threshold values to detect hazardous situations. According to Gagge et al., m_{rsw} depends on the deviation of skin and core temperatures from the minimum regulatory effort values, with an upper limit of 500 mL/h. Skin blood flow is associated with the vasodilation regulatory mechanism, with the threshold set at 80 L/(h m^2), as determined by Tartarini. Skin wettedness (w) serves as an indicator of thermal stress, signaling an occurrence when sweating necessitates more surface area for evaporation than what is available. The maximum allowable value for skin wettedness (w_{max}), according to Gagge, is dependent on air velocity and clothing levels, and this parameter is also provided as output by the `*fans_heatwaves*` function.

2.5 Simulation and Post-Processing

The simulations were conducted for each weather file, each IDF file, and each city, and afterward, the results underwent automated analysis using the eppy and pythermalcomfort library. Utilizing the *fans_heatwaves* function, the time distribution of internal temperature, mean radiant temperature, and humidity, facilitated the extraction of physiological parameters under fan-off and fan-on conditions. These parameters, including m_{rsw}, m_{bl}, and w, were then compared against respective limit values to identify potential heat strain conditions. Fan speeds were adjusted accordingly to achieve fan-off (Va = 0.1 m/s) and fan-on (Va = 0.8 m/s) conditions in each space and then the number of hours with heat strain was calculated for each apartment. In the post-processing stage, we also checked the PMV on different floors and apartments as an indicator of internal thermal comfort conditions.

3. Discussion and Result Analysis

All simulations were conducted specifically during the summer months of June, July, and August, a period characterized by elevated external temperatures that can significantly exacerbate internal heat stress conditions. Upon meticulous analysis of the data, consistent trends were observed across all three cities under investigation. However, due to limitations of space within this document, we have chosen to present only a subset of the results through thoughtfully selected tables and graphs.

Table 3 reports the maximum operative temperature (Tmo) and the number of hours with heat strain for Palermo in four different conditions: with and without a fan, with and without window shades, all projected for the future model HadGEM2-ES RACMO22E for RCP 8.5 between the years 2036 and 2050 (the worst-case scenario, M1). It's quite clear that integrating electric fans into the environment can effectively decrease the hours of heat strain, and similarly, the installation of window shades also contributes to this reduction. The utilization of electric fans and window shades appears to play a significant role in mitigating heat-related discomfort, highlighting their importance in promoting thermal comfort within the space. In the condition without shade and without a fan (NV) in apartment F3_A2, we had 996 hours with heat strain (n_{hs}), which decreased to 282 hours by adding a fan (Fn_{hs}). Similarly, within the same apartment, the presence of window shades (SHV) contributed to a considerable reduction in heat strain hours, from 661 hours (n_{hs}) to 161 hours (Fn_{hs}) with the addition of a simple electric fan.

Table 3 – Maximum operative temperature and number of hours with heat strain for M1, NV and SHV, with/out fan_ Palermo

	NV			SHV		
Flat	**Tmo**	**n_{hs}**	**Fn_{hs}**	**Tmo**	**n_{hs}**	**Fn_{hs}**
F0_A1	37.13	62	20	36.36	39	17
F0_A2	38.36	137	23	36.81	60	20
F1_A1	40.87	330	60	39.98	241	42
F1_A2	42.14	513	106	40.42	278	51
F2_A1	42.60	573	133	41.69	400	86
F2_A2	43.81	806	211	42.07	478	104
F3_A1	43.56	766	186	42.69	576	124
F3_A2	44.50	996	282	42.86	661	161
F4_A1	44.17	465	78	43.44	363	52
F4_A2	45.49	634	121	43.98	403	54

In scenarios without window shades (NV), adding a fan led to an average reduction of 406.2 hours in heat strain across all ten apartments. Conversely, in situations where window shades were present, the average decrease in heat strain hours upon fan installation increases to 278.8 hours. Thus, using a fan proved advantageous in both scenarios, with its effectiveness notably pronounced in conditions without window shades.

The same variables are presented in Table 4 for Trieste in the future weather dataset MPI-ESM-LR_REMO2009, RCP 8.5 for the years 2036-2050 (M2). It is immediately apparent that apartment F3_A2 exhibits the highest number of hours with heat strain across all scenarios: without shade and with shade, and also without a fan and with a fan, respectively, with values of n_{hs} = 1115, n_{hs} = 665, Fn_{hs} = 558, and Fn_{hs} = 202. Thus, we observe that the use of window shades decreases the number of hours with heat strain, as does the use of electric fans.

Table 4 – Maximum operative temperature and number of hours with heat strain for M2, NV and SHV, with/out fan_ Trieste

	NV			SHV		
Flat	Tmo	n_{hs}	Fn_{hs}	Tmo	n_{hs}	Fn_{hs}
F0_A1	36.07	81	0	33.94	8	0
F0_A2	39.91	416	57	35.4	64	0
F1_A1	39.42	472	75	37.1	253	12
F1_A2	43.43	853	367	38.63	419	66
F2_A1	40.97	650	199	38.5	436	64
F2_A2	44.97	1036	501	40.08	566	143
F3_A1	41.69	753	271	39.42	509	106
F3_A2	45.21	1115	558	40.7	665	202
F4_A1	42.05	497	56	40.24	315	8
F4_A2	46.33	826	274	41.68	440	38

Another notable observation is that across all three cities and scenarios, apartment F3_A2 consistently registers the highest number of hours with heat strain. Additionally, in all apartments facing westward (A2), the number of hours surpasses those in apartments facing eastward (A1) on the same floor.

Referring to Table 5, which illustrates the maximum temperature and operative temperatures experienced in each apartment in the simulated building for Pisa for the situation NV and without a fan in scenario M1, it is observed that the maximum temperature (51.06) occurred on July 10th at 20:00 in apartment F4_A2. However, the highest operative temperature (50.88) within the same day was recorded for apartment F2_A2, with a very similar operative temperature (50.82) reached in apartment F4_A2 seven days later, on July 17th. Notably, all these maximum temperatures were observed during the late evening, between 19:00 and 22:00.

Table 5 – Maximum temperature and operative temperature for M1_NV without a fan, the time and date of reaching them_ Pisa

Flat	Tmo	time	Tmp	time
F0_A1	38.01	07/10 20:00	38.34	07/10 20:00
F0_A2	45.06	07/10 20:00	45.48	07/10 20:00
F1_A1	41.64	07/10 20:00	41.84	07/10 20:00
F1_A2	49.35	07/10 21:00	49.49	07/10 20:00
F2_A1	43.15	07/10 20:00	43.29	07/10 20:00
F2_A2	50.88	07/10 21:00	50.99	07/10 20:00
F3_A1	43.65	07/10 20:00	43.76	07/10 20:00
F3_A2	50.68	07/10 22:00	50.65	07/10 22:00
F4_A1	43.25	07/10 20:00	43.36	07/10 20:00
F4_A2	50.82	07/17 19:00	51.06	07/10 20:00

Figures 2 and 3 illustrate the temporal evolution of physiological variables within Apartment F3_A2 under SHV conditions in Pisa, where high summer temperatures prevail, as outlined in Table 6. Figure 2 depicts the scenario without fans, while Figure 3 represents the situation with fans. Notably, the variables m_{rsw} and m_{bl} exhibit minimal changes with fan utilization, remaining comfortably below their respective thresholds of 500 mL/h and 90 mL/(h m²). Conversely, the parameter w, denoting skin wettedness, shows a significant decrease in value with increased air velocity, as evident in Figures 3e) and 2b). Specifically, w attains its maximum of 0.7 in the absence of fans, while it reduces to 0.6 when fans are operational.

Table 6 reports the maximum values of these physiological parameters with and without fan intervention in Apartment F3_A2, alongside the corresponding occurrences of heat strain (n_{hs}). Heat strain predominantly arises from elevated skin wettedness, reaching its peak across all apartments, particularly affecting centrally located units and those facing westward. The use of fans substantially changes this dynamic.

An additional facet of the analysis examines the Predicted Mean Vote (PMV), revealing that across both future weather scenarios (M1 and M2) outlined earlier, a notably high percentage of hours demonstrate a PMV value equal to or greater than 2.

Table 6 – Maximum values for physiological parameters and number of hours with heat strain for the apartment F3_A2_ Pisa

		NV		SHV	
F3_A2		No fan	fan	No fan	fan
TMY	m_{rsw}	63.77	55.13	58.91	50.35
	w	0.70	0.41	0.50	0.27
	m_{bl}	24.04	21.64	22.69	20.39
	n_{hs}	0	0	0	0
M1	m_{rsw}	157.07	191.44	124.63	135.56
	w	0.70	0.60	0.70	0.60
	m_{bl}	80	80	75.13	58.25
	n_{hs}	1484	881	779	204
M2	m_{rsw}	156.53	187.60	129.87	142.62
	w	0.70	0.60	0.70	0.60
	m_{bl}	80	80	80	80
	n_{hs}	1376	1007	948	356

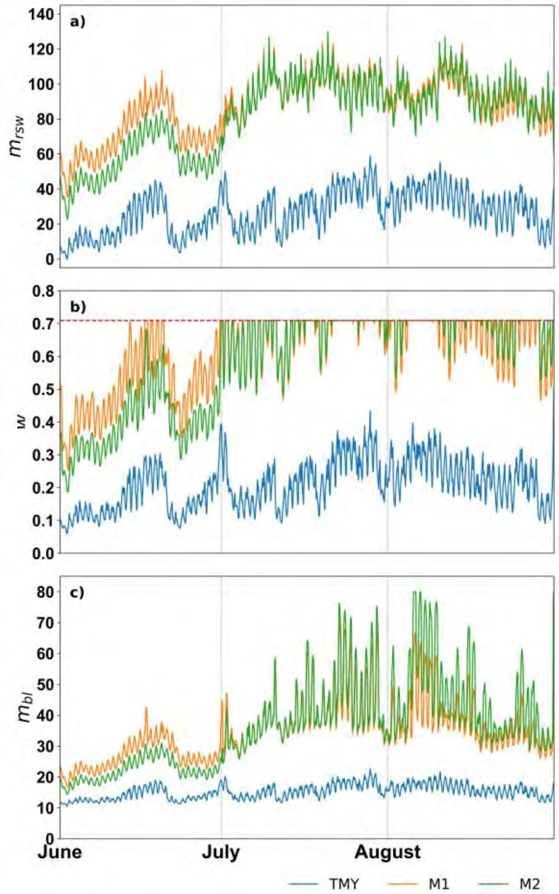

Fig. 2 – The temporal evolution of physiological variables within apartment F3_A2 under SHV conditions in Pisa with no fan

This suggests a significant probability of occupants experiencing considerable thermal discomfort, primarily due to an excessively warm sensation (Fanger, 1972).

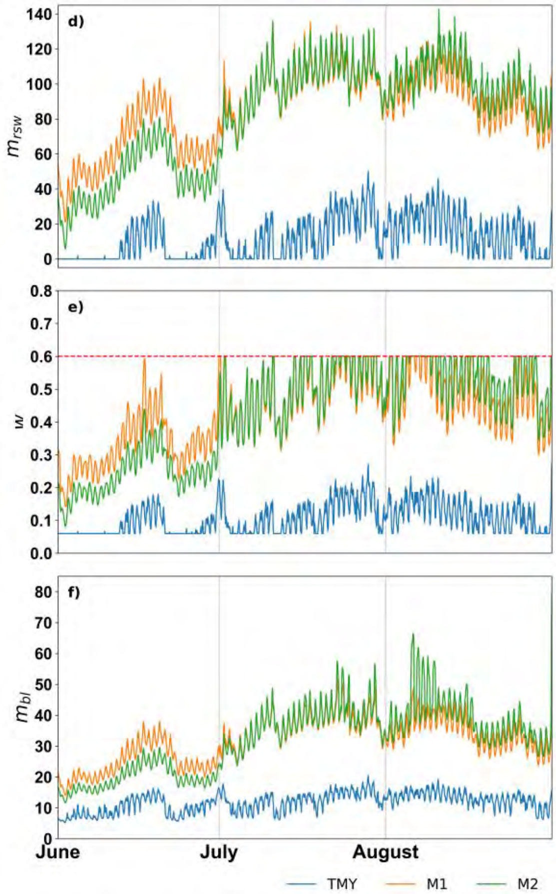

Fig. 3 – The temporal evolution of physiological variables within apartment F3_A2 under SHV conditions in Pisa with fan

Across all three cities, we observed a consistent trend of PMV escalation in M1 (HadGEM2-ES RACMO22E for RCP 8.5) surpassing that in M2 (MPI-ESM-LR_REMO2009, RCP 8.5). However, both scenarios exhibit a significant spike, surpassing that of TMY.

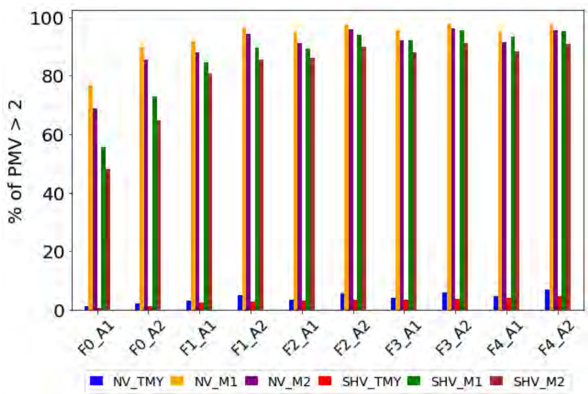

Fig. 4 – Percentage of PMV >=2 in each apartment for all scenarios without a fan_ Trieste

Figure 4 illustrates the variation in three distinct weather files under two conditions, NV and SHV, without the use of a fan in Trieste. It is evident that the percentage of PMV values equal to or exceeding two shows a notable increase in future models, indicating a substantial dissatisfaction with the internal thermal comfort among occupants. This trend in PMV behavior is consistent across all cities, as observed in the other findings.

4. Conclusion

The multifaceted challenges posed by climate change necessitate urgent action to safeguard public health and enhance the resilience of built environments. This study has shed light on the health implications of climate-induced changes, particularly focusing on vulnerable demographic groups such as the elderly and socioeconomically disadvantaged individuals. By delving into the impacts of extreme heat events, it has become evident that limited access to cooling technologies, such as air conditioning units, exacerbates the vulnerability of these groups to heat-related illnesses, thereby compromising their overall well-being.

However, the reliance on air conditioning systems presents its own set of limitations, including increased energy consumption, greenhouse gas emissions, and the risk of power outages, not to mention the financial barriers hindering widespread adoption, especially among low-income households.

In response to these challenges, this study advocates for the adoption of affordable alternative strategies, such as electric fans, window coverings, and natural ventilation, to alleviate indoor heat stress and enhance thermal comfort. Through numerical simulations conducted using Design Builder and Energy Plus software, the efficacy of these methods has been evaluated across different climatic conditions, providing valuable insights into their potential to protect the well-being of building occupants.

The findings of this study underscore the significant role of electric fans in mitigating heat strain, even under worst-case scenarios, along with the complementary benefits of natural ventilation and window shading. On average, the use of electric fans can reduce heat strain hours by 480 hours in M1 NV and 315 hours in SHV across three cities. By reducing the number of hours with heat strain, these strategies contribute to enhancing indoor comfort and promoting broader environmental sustainability goals.

In conclusion, addressing the complicated impacts of climate change on public health requires a holistic approach that integrates affordable and sustainable solutions into building design and policy frameworks. By prioritizing energy efficiency, affordability, and public health considerations, policymakers can effectively mitigate the adverse effects of rising temperatures on indoor environments while fostering resilience and sustainability for future generations.

Nomenclature

Symbols

Fn_{hs}	n_{hs} in FAN_ON situation
I_{cl}	clothing level
M	activity
M1	HadGEM2-ES RACMO22E
M2	MPI-ESM-LR_REMO2009
m_{bl}	skin blood flow
m_{rsw}	regulatory sweat
n_{hs}	number of hours with heat strain
NV	only natural ventilation
RH	relative humidity
SHV	window shade and natural ventilation
TMY	typical meteorological year
t_{db}	dry bulb temperature
Tmo	operative temperature
Tmp	temperature
t_r	mean radiant temperature
V	air velocity
w	skin wettedness
w_{max}	maximum allowable value for w

References

Attia, S., R. Levinson, E. Ndongo, P. Holzer, O. Berk Kazanci, S. Homaei, C. Zhang, et al. 2021. «Resilient cooling of buildings to protect against heat waves and power outages: Key concepts and definition.» *Energy and Buildings* 239.

Belcher, S.E., J.N. Hacker, and D.S. Powell. 2005. «Constructing design weather data for future climates.» *Building Services Engineering Research & Technology*: 49-61.

eppy, Foundation, Python Software. 2022. PyPI. 1 12.

Fanger, P.O. 1972. «Thermal comfort: analysis and applications in environmental engineering.» *Environmental Science, Engineering*.

Gagge, A, J. Stolwijk, and Y. Nishi. 1971. «An Effective Temperature Scale Based on a Simple Model of Human Physiological Regulatiry Response.» *ASHRAE Transactions*: 247-263.

Haddad, S., R. Paolini, A. Synnefa, L. De Torres, D. Prasad, and M. Santamouris. 2022. «Integrated assessment of the extreme climatic conditions, thermal performance, vulnerability, and well-being in low-income housing in the subtropical climate of Australia.» *Energy and Buildings* 272.

IEA, International Energy Agency. 2018. *The Future of Cooling Opportunities for energy- efficient air conditioning.*

IPCC, the Intergovernmental Panel on Climate Change. 2021. *The Sixth Assessment Report on Climate Change 2021: The Physical Science Basis. Synthesis Report, UK & USA: IPCC, Working Group I Contribution to the IPCC Sixth Assessment Report.*

Jay, O., M.N. Cramer, N.M. Ravanelli, and S.G. Hodder. 2015. «Should electric fans be used during a heat wave?» *Applied Ergonomics* 46 part A.

Lupato, G., and M. Manzan. 2019. «Italian TRYs: New weather data impact on building energy simulations.» *Energy and Buildings*: 287-303.

Manzan, M., A. Ramezani, A. Buoite Stella, and A. Pezzi. 2023. «Climate Change and Building Renovation: Effects on Energy Consumption and Internal Comfort in a Social Housing Building in Northern Italy.» *Sustainability* 15: 5931.

Manzan, M., G. Bacaro, A- Nardini, G. Casagrande, A. Pezzi, F. Petruzzellis, E. Tordoni, and G. Fontolan. 2022. «Climate Change Risk and Vulnerabilities Analysis in Trieste SECAP.» *Sustainability* 14.

Morris, N.B., G.K. Chaseling, T. English, F. Gruss, M. Fauzan Bin Maideen, A. Capon, and O. Jay. 2021. «Electric fan use for cooling during hot weather: a biophysical modelling study.» *The Lancet Planetary Health*: 368-377.

Robert, A., and M, Kummert. 2012. «Designing net-zero energy buildings for the future climate, not for the past.» *Building and Environment*: 150-158.

s.d. TABULA WebTool. https://webtool.building-typology.eu/#bm

Tadepalli, S., T.K. Jayasree, V. Lakshmi Visakha, and Sivapriya Chelliah. 2021. «Influence of ceiling fan induced non-uniform thermal environment on thermal comfort and spatial adaptation in living room seat layout.» *Building and Environment* 205.

Tartarini, F., and S. Schiavon. 2020. «pythermalcomfort: A Python package for thermal comfort research.» *SoftwareX* 12.

Tartarini, F., S. Schiavon, O. Jay, E. Arens, and C. Huizenga. 2022. «Application of Gagge's energy balance model to determine humidity-dependent temperature thresholds for healthy adults using electric fans during heatwaves.» *Building and Environment* 207, part B.

Tartarini, F., S. Schiavon, T. Cheung, and T. Hoyt. 2020. «CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations.» *SoftwareX* 12.