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Climatic change mitigation: analysis of electrical fans usage impact on dwellers heat stress

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Abstract. Climate change is responsible for a consistent increase in ambient temperatures, leading to social and health problems for individuals residing indoors. The effect should be seriously considered by authorities, especially regarding people's health; high temperatures can be very dangerous for elder people and in general for vulnerable categories. Mitigation approaches are important in case of heat waves that are expected to increase in frequency and intensity due to climatic change effects. One approach for avoiding such a problem is to install cooling systems, but sometimes this isn't a viable solution, for example in case of low-income families which cannot afford the expense for the installation and the bill costs for running such systems. An alternative solution is using electric ventilators and the main objective of this paper is to revise the effect of electric fans and assess if they can be useful for mitigating the heat effect on people inside buildings. The results showed that the number of hours with people exposed to heat strain, in the worst-case scenario, dropped from 168 without a fan to 13 with an active fan, confirming the positive effect of this system.

1. Introduction

Climate change is responsible for a consistent increase in ambient temperature with significant social and health outcomes for individuals inside buildings. The 2021 Sixth Assessment Report of the IPCC[1] has widely confirmed the escalating trend of temperatures. Consequently, acknowledging climate evolution becomes imperative for devising effective mitigation and adaptation policies concerning the energy performance of buildings [2]. Furthermore, the effects should be seriously taken into account by authorities, when developing risk assessment studies [3] considering with particular attention the effects on people's health. The rising temperatures, coupled with the increased frequency and intensity of heatwaves over the past three decades [4], have rendered high temperatures particularly hazardous. In industrialized countries, the conventional approach to overcome this problem is the installation of air conditioners to maintain comfort temperatures and avoid health problems. In a report of 2018 IEA [5] noted that the use of energy for space cooling is growing faster than for any other end use in buildings and reached a nearly 16 % share in 2021 of final electricity consumption (about 2 000 TWh) [6]. However, this approach presents drawbacks that should be taken into account. The first problem is related to the energy consumption impact. Air conditioners absorb a large amount of electricity, Shen [7] reported that cooling electricity usage will increase by about 25% due to climate change and air conditioning contributing to the increase of global GHG emissions, with the risk of power outages which can jeopardize the cooling effect of air conditioning [4]. The second issue lies in certain limitations regarding the installation of air conditioning plants, particularly the split type, which can be hindered by local regulations prohibiting the placement of visible external units. However, the most pressing social problem pertains to the financial burden associated with purchasing and operating air conditioning units. Low-income households often lack the economic means to afford such devices, especially in the face of escalating energy costs. Haddad et al [8] reported that fans were the most typical cooling devices in low-income housing with only a little share using a split reverse cycle system (7 %). However, health within the building must be a concern for the authorities, especially in the case of high temperatures. Manzan et al, [9] assessed the internal comfort of a social house considering different refurbishing interventions and health models, showing that with high external temperatures and without air conditioning, internal health can be problematic. An economically viable solution for coping with internal health under high temperatures is the use of fans, which consume much less energy than air conditioning systems and can provide some relief.

Tadepalli et al. [10] experimentally analysed the air distribution for ceiling-mounted fans, emphasizing that a correct air distribution reduces thermal discomfort, increases fan use rates, and reduces the need for air conditioning. Additionally, other cost-effective solutions include mobile floor or desk-mounted fans. However, the World Health Organization (WHO) [11] highlights the lack of scientific consensus about the efficacy and safety of electric fans when the ambient temperature is above 35 °C, as it might increase the risk of dehydration. Consequently, some authors have recently performed laboratory and simulation studies to determine the threshold for efficacy and safety of electric fan used in different environmental conditions and locations. Morris et al. [12] developed a biophysical model to define relative humidity and temperatures for the use of fans. They applied the model using weather data from 108 cities worldwide and found that fan use can be universally recommended for effective cooling in northern Europe, north-eastern regions of the USA, Canada, all of South America, and much of southeast Asia. A similar approach has been pursued by Tartarini et al. [13], who applied the Gagge model [14] to demonstrate that electric fans are a safe solution for cooling people. They also developed a web platform to assess the usefulness of electric fans [15]. Jay et al [16] developed an additional model for assessing the usability of fans during heat waves. The authors declared that it is advisable to use fans even for an elderly with a reduced predicted maximum sweat output. Furthermore, they stated that the protective benefits of fans appears to be underestimated by current guidelines.

The effectiveness of ventilators has been tested by the authors using external temperatures only, neglecting the effect of buildings on internal temperatures, which are also influenced by radiation. In this paper, the approach of Tartarini is applied to a building with poor thermal characteristics, testing the effectiveness of ventilators in internal environments. This choice has been driven by the consideration that people who cannot afford the costs for mechanical air conditioning usually dwell in poorly insulated buildings.

2. Methodology

The effectiveness of ventilators in easing the heat stress due to high temperatures was demonstrated through a numerical simulation of a building located in Trieste, northeast of Italy. The building's geometry and thermal characteristics were modeled using DesignBuilder software, and the simulations were conducted using EnergyPlus version 9.4. Building simulations were carried out using different climate data: a current TRY of the city of Trieste, an extreme weather data for the summer period and true data recorded during a hot summer.

2.1. Building description

The main characteristics of the building were obtained from the Tabula web tool [17] which specifies its construction period between 1961 and 1975. The building is characterized by low thermal mass and high transmittance and represents a five floor construction described by Lupato [18], the geometry was modified considering also the presence of stairs and two flats per floor. The building has a volume of 3074 m^3 and a total of usable surface area of 848.6 m^2 while each apartment features a floor surface of

76 m^2. Figure 1 presents the floor plan with two apartments. The building is south facing, so apartment 1 is exposed to east direction, while apartment 2 has a wall exposed to the west. In the following each flat will be identified by the floor, starting from 0 for the Ground floor, followed by the position, A1 for eastward and A2 for westward. Consequently, the two apartments on the ground floor will be referred to as F0_A1 and F0_A2, respectively. The opaque and transparent structures, as well as the internal loads, correspond to those used by Lupato et al. [19]. The structures for the uninsulated building are also reported in Table1. Ventilation is taken into account with an air change rate of 0.3 ACH, this is a simple approach that should be improved in the future to incorporate natural ventilation by allowing for window openings. Internal loads, opaque and transparent surfaces characteristics and output variables were adjusted using the eppy library with python scripts. Post process of the results was carried out again using eppy library [20].

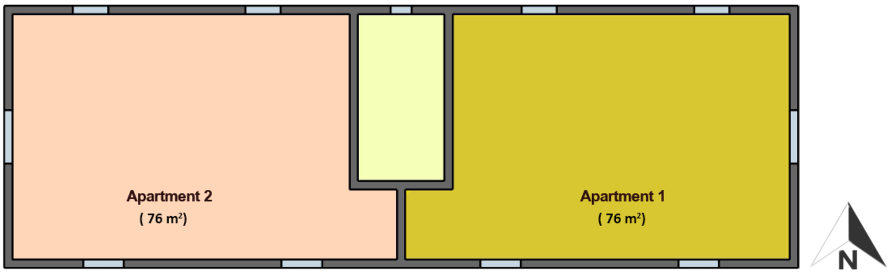

Figure 1. Floor plan with two apartments and stair.

Table 1. Opaque and transparent surfaces characteristics

	U [W/m^2K]	Mass [kg/m^2]	U_w [W/m^2K]	SHGC [-]
Walls	1.15	194	–	–
Roof	1.10	406	–	–
Floor	0.94	478	–	–
Windows	–	–	2.2	0.7

2.2. Weather files

Simulations were performed using four weather files. The first one is a standard Typical Meteorological Year (TMY) generated using monitored data collected between 1995 and 2022, following the procedures outlined in the EN ISO 15927-4 technical standard. The TMY weather file is a representation of the mean behavior of the climate for a specific location. While heat-related issues are of concern during unusual hot conditions, therefore an additional file was constructed which represents an Extreme Weather Year (EWY) generated for the months from May to September applying the approach of Nik [21]. The procedure adopted is similar to the one used to create the TMY data, but instead of looking for the least absolute difference, the years with the minimum difference between the monthly cumulative distribution function and the long-term one were selected. Along with the typical and extreme weather files, also a file with true measured data was generated. Searching the International Disaster Database [22] resulted in a severe heat wave occurred in the summer of 2003 during the months of July and August, therefore, the measured data for that particular months were used to create a direct weather file (2003Y). One of the main concerns about temperature is the foreseen increase in temperatures and the heightened frequency and severity of heat waves, therefore a Future Meteorological Year (FMY) was also developed applying the morphing method [9,23] using the TMY and the projections obtained by the model HadGEM2-ES RACMO22E [9]. The study identified five global-regional models, the one selected represents the model with a major increase in temperature in the range between 2036 and 2050 for the RCP 8.5 therefore represents a worst case scenario.

2.3. Biophysical model
The main objective of this work is to assess the effectiveness of a ventilator in improving internal conditions in a building due to severe external conditions characterized by high temperatures. To this scope several biophysical models have been developed by different authors such as Morris [12] and Jay [16], however in this study the model of Gagge [14] was selected with the approach of Tartarini [13] who implemented the model in a python library *pythermalcomfort* [24]. In this paper the results were obtained using the *fans_heatwaves* function which provides as output several biophysical parameters with different air velocities in order to represent the impact of fans on human body.

The Gagge method solves a balance equation for a system composed by an inner core and an outer skin layer. The energy balance estimates how the environmental parameters, such as dry bulb temperature t_{db}, mean radiant temperature t_r, air velocity V and relative humidity RH along with clothing level I_{cl} and activity M influence the sensible and latent heat exchanges from the body to the environment.

The *pythermalcomfort* library allows also to obtain biophysical parameters that can be used to identify heat strain, to this end three parameters can be compared to limit values in order to identify such dangerous situations. These parameters are the rate at which regulatory sweat is generated m_{rsw}, skin wettdness w, skin blood flow m_{bl}. Following Gagge et al. m_{rsw} depends on the deviation of the skin and the core temperatures from the values of minimum regulatory effort and assume that cannot exceed 500 mL/h. Skin blood flow is correlated to the vasodilation regulatory mechanism and the limit is taken as done by Tartarini as 80 L/(h m^2). Skin wettdness w is a parameter that can be employed to identify thermal stress and this event occurs when sweating requires a greater surface for evaporating than what is available. According to Gagge w_{max}, the maximum allowable value for skin wittedness, depends on the air velocity and clothing levels and also this parameter is provided as output by the *fans_heatwaves* function.

2.4. Simulation
The simulations were performed for each weather file. After each simulation, the post process of the results was carried out using eppy and *pythermalcomfort* library to automate the analysis. The time distribution of internal temperature, mean radiant temperature and humidity represented the input of the *fans_heatwaves* function and permitted to obtain the physiological parameters of interest considering a fan-off and fan-on condition. For each room the retrieved physiological parameters m_{rsw}, m_{bl}, w were compared to the respective limit values in order to identify if a heat strain condition could be observed. Fan-off and fan-on condition were obtained by adjusting the air velocity as an input to the *fans_heatwaves* function. The fan-off condition was obtained with air velocity V_a = 0.1 m/s, while for the fan-on condition V_a = 0.8 m/s was set. It is worth noting that others studies considered higher velocities, Jay et al. [16] used V_a = 4.5 m/s, Morris et al. [12] V_a = 3.5 m/s, however, Tartarini [13] argues that achieving such high air speeds with common ceiling, pedestal, or desk fans might not be easily feasible.

3. Simulation Results
Table 2 reports the maximum temperature and operative temperature reached in the flats of the buildings using the TMY weather file. Inspecting the table, it is of interest to see the substantial difference between the apartments, whereas the west exposed flats experience maximum temperatures that are higher than the east exposed ones, furthermore the time of day when the temperature is reached is again different, with early afternoon for the east exposed and late afternoon for the west exposed. Table 2 reports also the maximum operative temperatures, which follow the same pattern as the air temperatures, but with one day difference. Maximum temperatures were reached on the 10th of August for the west-exposed flat, while the 9th of August for the other cases. Figure 2 presents the time evolution of the physiological variables for the Apartment F4_A2, characterized by high temperatures during the summer as reported in table 2. The figure presents the behavior without fans on the left and with fans on the right. The values of m_{rsw} and m_{bl} are only marginally affected by the use of the fans; moreover, their values are

quite lower than the limits that are respectively 500 mL/h and 90 mL/(h m^2). However, the value of skin wettedness *w* is strongly affected by the presence of the fan, showing a visible reduction with increased air velocity. Figure 2 e) and b) also show the maximum value for skin wettdness which is w_{lim} = 0.7 for the fan-off and w_{lim} = 0.6 for the fan-on condition. Table 3 reports the maximum values of the physiological parameters reached in each apartment without the use of fans. In the same table, the number of hours with heat strain problems n_{hs} is reported. Heat strain is always reached by the skin wettdness *w* parameter that reaches the maximum value. All the apartments share this behaviour, but the most affected are the central ones and those exposed to the west. The scenario changes drastically with the use of the fans, as reported in Table 4, limit value w_{lim} is reached only for Apartment F3_A2 and for one hour only. Similarly, for the future file, the limit value is reached but only for a few hours and again for F3_A2 apartment with n_{hs}=13. It is expected that the problem could be solved by increasing the air velocity. In the most severe scenario (FMY) for F3_A2 flat, with an air conditioning system maintaining a fixed interior temperature of 26 °C, the physiological parameters drop, giving rise to maximum values w = 0.26, m_{rsw} = 46, and m_{bl} = 19.01 far lower than the ones reported in Table 3.

Limit values are reached for the fan-off condition at the end of July and the beginning of August for all the weather files, while for the fan-on condition the limit value is reached only for few hours in August and for the FMY file. As far as the weather data is concerned, the worst condition is the one with FMY, followed by the EMY which showed the highest values with heat strain conditions, the 2003Y is marginally more critical than the TMY.

4. Discussion

The results of the simulations showed that the heat strain can be possible also in a city of northern Italy, such as Trieste. This can occur in buildings characterized by high wall and window transmittance.

The use of different weather files allowed us to identify when heat strain could occur. As expected TMY developed for building energy simulation is not capable to highlight the problem of temperature extremes. For this purpose, the EWY demonstrated to be more efficient in drawing attention to the problem of critical events, using this file, the number of hours with heat strain reached the value of 64. The 2003Y confirmed to be a critical year for heat waves, and the number of hours with heat strain rose to 95. It is impressive to see the effect of climatic change, since using the projected weather data FWY for simulations, the number of hours with heat strain reached the value of 168.

The use of fans resulted in great help in avoiding health problems with high external temperatures. It must be enforced that fans cannot guarantee healthy conditions as mechanical air conditioning does, but they can provide some relief and help to prevent heat strain problems. With the fan-on condition and the EWY, only one hour resulted problematic, also with FWY, the number of hours with heat strain was reduced.

The outcomes of present research are interesting; however, some limitation need to be considered, leaving room for future improvements. No other mitigation actions against high internal temperatures had been considered, such as shutters on windows and natural ventilation with low external temperatures. The biophysical model considered only healthy adult individuals, further research should be extended to include elderly people and adults taking prescription medications that limit thermoregulatory sweating, therefore more vulnerable to heat excess.

Table 2. maximum of temperature and operative temperature for the flats and time. For temperature the maximum is reached the 9th of august, for operative temperature on the 10th of august for apartment 1 and 9th of august for apartment 2

	F0_A1	F0_A2	F1_A1	F1_A2	F2_A1	F2_A2	F3_A1	F3_A2	F4_A1	F4_A2
t	34.9	36.2	37.2	38.6	38.1	39.4	38.4	39.8	38.3	39.4
time	14:00	16:00	14:00	17:00	14:00	17:00	14:00	17:00	14:00	16:00
t_o	34.7	36.0	37.1	38.5	38.1	39.4	38.4	39.7	38.3	39.3
time	13:00	17:00	14:00	17:00	14:00	17:00	13:00	17:00	13:00	17:00

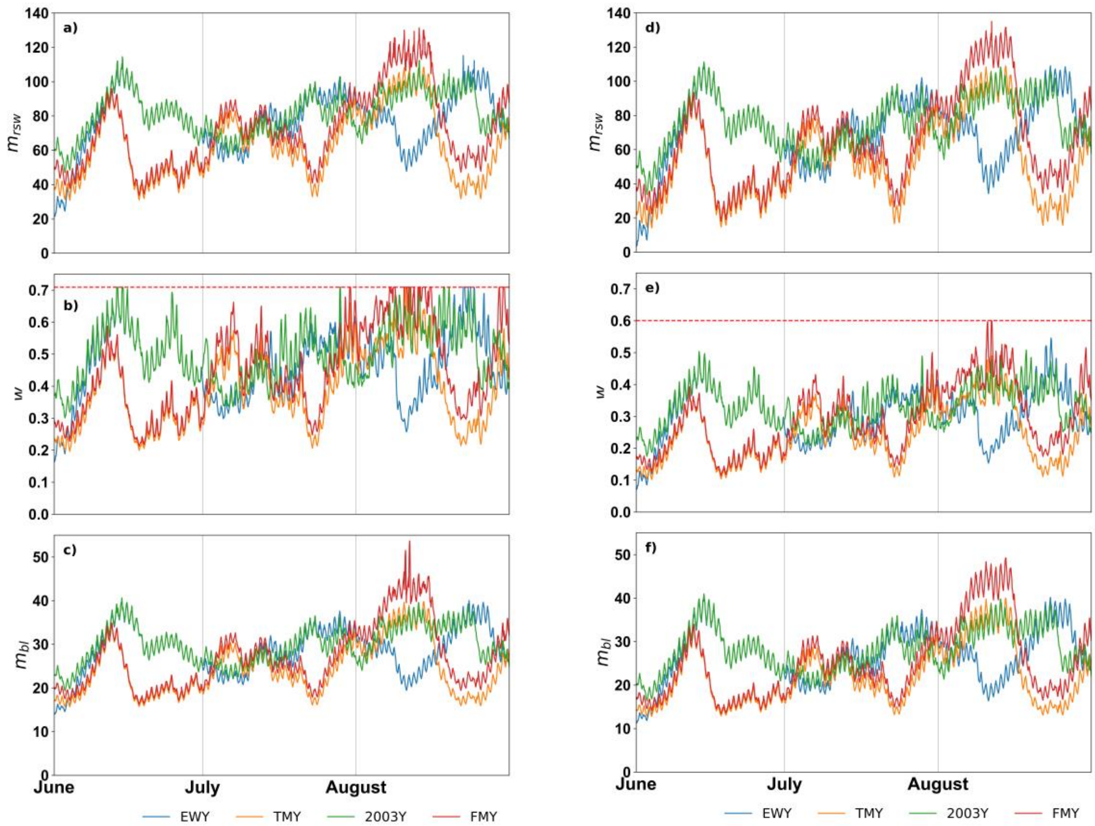

Figure 2. physiological parameters for flat F4_A2, temporal distribution without fan a), b), c) at left and with fan at right d), e) f). Reported values: regulatory sweat m_{rsw} a) and d), skin wettdness w b) and e), skin blood flow m_{bl} c) and f).

Table 3. maximum values for physiological parameters and number of hours with heat strain for the apartments and for each weather file l. fan off condition

		F0_A1	F0_A2	F1_A1	F1_A2	F2_A1	F2_A2	F3_A1	F3_A2	F4_A1	F4_A2
TMY	m_{rsw}	74.86	85.58	91.67	105.92	100.69	114.80	106.04	114.59	99.89	108.62
	w	0.58	0.65	0.70	0.70	0.70	0.70	0.70	0.70	0.68	0.70
	m_{bl}	27.56	31.20	33.40	37.72	36.06	40.60	36.95	41.43	36.48	39.77
	n_{hs}	0	0	0	9	5	15	9	16	0	2
EWY	m_{rsw}	71.07	85.75	87.79	104.01	100.70	115.32	103.60	113.88	101.73	115.18
	w	0.62	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
	m_{bl}	26.30	30.52	32.07	39.19	35.14	45.75	37.54	48.29	37.15	40.38
	n_{hs}	0	2	4	28	19	57	28	64	7	27
2003Y	m_{rsw}	73.25	83.64	90.39	101.93	101.93	115.18	104.10	118.21	102.39	114.26
	w	0.61	0.68	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
	m_{bl}	27.08	30.56	33.00	36.98	35.62	40.71	36.68	42.50	37.41	40.64
	n_{hs}	0	0	2	26	15	83	26	95	0	17
FMY	m_{rsw}	90.61	99.70	113.80	124.39	124.43	135.57	124.14	137.08	125.05	131.3
	w	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
	m_{bl}	32.56	36.78	44.24	55.26	52.13	64.33	54.91	66.93	45.37	53.68
	n_{hs}	8	13	27	84	65	155	82	168	21	62

Table 4. maximum values for physiological parameters for the apartments and for each weather file, fan on condition

		F0_A1	F0_A2	F1_A1	F1_A2	F2_A1	F2_A2	F3_A1	F3_A2	F4_A1	F4_A2
TMY	m_{rsw}	68.85	81.39	88.52	102.10	96.94	111.00	99.81	113.60	98.51	108.95
	w	0.37	0.42	0.46	0.51	0.49	0.54	0.50	0.55	0.45	0.48
	m_{bl}	25.65	29.75	32.26	37.32	35.36	40.80	36.45	41.84	35.96	39.99
EWY	m_{rsw}	64.80	79.22	84.31	99.45	93.17	108.22	97.93	117.62	101.07	110.54
	w	0.39	0.46	0.49	0.56	0.53	0.59	0.55	0.60	0.50	0.54
	m_{bl}	24.38	29.15	30.82	36.45	34.01	39.84	35.81	41.23	36.91	40.67
2003Y	m_{rsw}	67.28	79.41	87.55	100.19	95.84	108.67	99.20	111.85	101.86	111.32
	w	0.39	0.44	0.48	0.53	0.52	0.56	0.53	0.57	0.47	0.50
	m_{bl}	25.21	29.15	31.98	36.66	35.02	39.95	36.28	41.22	37.21	40.98
FMY	m_{rsw}	86.26	98.93	108.45	125.94	125.88	132.15	125.92	135.50	121.05	135.05
	w	0.49	0.54	0.58	0.60	0.60	0.60	0.60	0.60	0.57	0.60
	m_{bl}	31.52	36.17	39.84	45.41	43.60	49.50	45.18	50.90	44.89	49.26

5. Conclusions

One of the main effects of climate change is the increase of temperatures, which can pose a serious problem for individuals who cannot afford the expenses of air conditioning systems and reside in poorly insulated buildings. This study investigates the effectiveness of ventilators in alleviating the impact of high internal temperatures on dwellers. The analysis was performed on a four plus ground floor building featuring ten apartments. The simulations used EnergyPlus with four weather files for the city of Trieste. The generated weather files comprise a standard test reference year, an extreme weather year, a measured year with strong heat waves and a projected future weather to consider the effect of climate change. To assess the effect of high temperatures and the use of ventilators on building occupants, a biophysical model was employed to derive biophysical parameters for identifying heat strain situations. The outcomes of this work have led to several noteworthy conclusions. High temperatures pose significant risks to people inside buildings, even in a city in North-east Italy. Without interventions, severe heat strain problems can be identified, this problem should be taken in serious consideration by municipalities when involved in risk and mitigation analysis. When analysing the risks associated with high internal temperatures using building simulations, the use of standard Typical Weather Files, typically employed for energy analysis, should not be applied, since they represent an average year and therefore extreme conditions are not considered, for this problem the use of extreme files should be encouraged. Future weather files obtained by the coupling of GCM and RCM projections are useful to highlight the problems related to climate change, again the outcomes should be taken into account when carrying on risk and mitigation analysis. First and foremost, electrical ventilators demonstrated to represent a true mitigation action for reducing the risk of heat strain, they performed well in nearly all situations, including a worst-case future scenario characterized by increased external temperatures, therefore, it is hoped that they will be considered by health authorities in guidelines to cope with heat waves phenomena.

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