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Rescheduling Summer Human Tower Exhibitions? Thermal Comfort Increases in the Evening

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Abstract

Outdoor activities are significantly influenced by meteorological conditions. Human tower exhibitions are performed in urban squares. Human towers were recognised as an Intangible Cultural Heritage by UNESCO in 2010. The objectives of this study are (1) to analyse the long-term temperature trend (1951–2024) for four summer human tower exhibitions; (2) to determine to extent to which thermal comfort has worsened over the last 74 years based on the Heat Index (HI); and (3) to assess temperature and thermal comfort in the squares during the selected evening exhibitions. Two of the four human tower exhibitions were recently rescheduled to the evening in response to afternoon heat. Temperatures have increased both in the afternoon and in the evening over the last 74-year period, but the warming is more pronounced in the afternoon. Evening hours have also become warmer, although they still represent a more tolerable thermal condition for outdoor activities. However, thermal comfort has decreased in three of the four human tower exhibitions in recent years. Two sensors recorded relative humidity and temperature data to determine the meteorological conditions during the exhibitions in the squares. The temperature decreased as the exhibition progressed. This pattern was modified by factors such as the presence of clouds and the shade generated by the buildings. HI values above 32 °C (extreme caution threshold) were prevalent in one exhibition. In the other three exhibitions, the values remained within the caution threshold for the majority of the time. Rescheduling the exhibition is one adaptation measure to ensure that human towers are performed safely in the face of climate change.

Keywords: temperature trend; thermal comfort; heat index; intangible cultural heritage; castells

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1. Introduction

Outdoor activities are significantly influenced by meteorological and climatic conditions [1,2]. The impact of weather conditions (air temperature, humidity, etc.) on the health of outdoor workers [3] and on the thermal comfort in sports activities [4,5] has been analysed in the academic literature. Physical work capacity will be affected by ongoing anthropogenic global warming [6,7].

Human tower (castell) exhibitions are usually performed outdoors in an urban square (Figure 1). This Catalan tradition was recognised as an Intangible Cultural Heritage of Humanity by UNESCO in 2010. As cultural events deeply embedded in community identity and reliant on precise coordination and physical exertion, castells are particularly vulnerable to variations in environmental conditions. According to Saladié et al. [8], anthropogenic climate change is responsible for the increased likelihood of a human tower exhibition being performed under unfavourable meteorological conditions. The severity and frequency of extreme meteorological events, such as heat waves, associated with climate change are increasing. Understanding the interaction between human tower performances and meteorological conditions is essential for preserving this cultural heritage while ensuring the safety and well-being of those involved. Olano Pozo et al. [9] analysed the temperature trends for the period 1951–2023 in four of the most emblematic human tower exhibitions. All of them were performed in the summer and scheduled in the afternoon (12:00–15:00). The results showed a clear rise in temperature. The temperature increases varied from 0.3 to 0.4 °C per decade depending on the location.

Figure 1. Human tower exhibition—Firagost (Valls, 8 August 2024). Source: Òscar Saladié.

Understanding thermal comfort requires more than a simple analysis of raw temperature trends. Thermal comfort is inherently complex—shaped by an interplay of direct and indirect factors, including air temperature, humidity, wind speed, solar radiation, individual physiology, psychological perception, cultural norms, and urban morphology [10]. Therefore, for analytical clarity and operational relevance, it is necessary to adopt an index that captures the most salient of these influences in the context of outdoor physical exertion. Aghamolaei et al.'s [11] comprehensive review highlights how outdoor thermal comfort results from the interaction between human-based factors (such as metabolic rate, sweat response, and psychological adaptation) and environment-based variables (such as building materials, vegetation, and urban geometry).

Olano Pozo et al. [9] calculated the Heat Index (HI), also known as apparent temperature, highlighting a worsening of thermal conditions in the selected study cases. The HI allowed the authors to quantify risk and vulnerability in a way that is both methodologi-

cally sound and directly applicable to decision-making and adaptation planning. The HI is a well-established metric that combines air temperature and relative humidity to approximate perceived temperature and physiological heat stress under warm conditions [12]. Although the HI does not capture the full multidimensionality of thermal comfort, it offers a scientifically grounded, widely used proxy that is particularly relevant for assessing health-related thermal strain in outdoor cultural practices such as castells.

However, Olano Pozo et al.'s [9] research is based on ERA5 LAND reanalysis data, downloaded from the Copernicus Climate Change Service (9 km of horizontal spatial resolution), and human tower exhibitions occur in urban squares, which usually suffer from urban heat islands [8]. The built environment modifies weather conditions [13,14]. Urban squares often have limited shade, high thermal inertia of materials, and narrow urban geometries, which contribute to increased heat retention and exposure [15,16]. Additionally, the squares become crowded during the performances with human tower builders and attendees. Figure 1 shows the Plaça del Blat (Diada de Firagost) in Valls on 8 August 2024. The capacity of the Plaça del Blat is 2916 people with a surface of 729 m^2 [17]. The cultural tradition of scheduling summer human tower exhibitions in the afternoon further intensifies the thermal burden. When combined with the significant physical exertion required to build human towers, these conditions increase the risk of heat-related strain among participants and the potential for the human tower to collapse, leading to potential injuries [18].

In light of the limitation mentioned above, Saladié et al. [8] conducted fieldwork and deployed sensors in the squares to examine the temperature patterns during six human tower exhibitions that took place on summer afternoons in 2024. The temperature reached 30 °C in five exhibitions. Heat Index values were within the caution threshold in three exhibitions and within the extreme caution threshold in the other three exhibitions [8].

The scarce academic literature on the relationship between thermal comfort and human tower exhibitions has been focused exclusively on exhibitions scheduled on summer afternoons. Some of them are very emblematic exhibitions, but also some of the most thermally stressful [19]. Although the afternoon remains as the timeslot for some of the most iconic human tower exhibitions (i.e., Valls, June 24; Terrassa, July 7; Tarragona, August 19; Vilafranca del Penedès, August 30), an increasing number of exhibitions are being held in summer evenings (from 18:00 onwards), partly as a response to climatic discomfort and rising awareness of heat-related health risks [20,21]. Evening exhibitions are becoming more common as a form of adaptation aimed at mitigating thermal discomfort and health risks. Changing the beginning of the exhibition is one of the potential adaptation measures highlighted by Saladié et al. [22]. However, no previous analysis has evaluated whether this temporal shift is effectively reducing thermal stress or whether evening events are subject to high levels of heat exposure due to higher relative humidity in the evening than in the afternoon.

This temporal shift highlights the need to better understand how the time of day affects urban microclimates and physiological stress, and how such adaptations may contribute to the long-term sustainability and safety of this emblematic form of intangible cultural heritage. The present research aims to address this gap by analysing the thermal conditions during four human tower exhibitions scheduled in summer evenings. The objectives of this research are threefold: (1) to analyse the long-term temperature trend (1951–2024) for four summer evening human tower exhibitions; (2) to determine to what degree thermal comfort has worsened over the last 74 years; and (3) to assess temperature and thermal comfort in the squares during the selected evening exhibitions. The results will allow us to evaluate whether changing the timing of the exhibitions offers a feasible way to adapt human tower exhibitions to climate change.

2. Materials and Methods

This study focuses on four human tower exhibitions scheduled in summer evenings: Diada de les Cultures (Altafulla, 2nd Saturday of July), Diada de Firagost (Valls, 1st Wednesday of August), Diada de la Festa Major (Llorenç del Penedès, 2nd Sunday of August), and Diada de la Festa Major (La Bisbal del Penedès, August 15). The last exhibition was scheduled in the afternoon until 2023. On 15 August 2024, the exhibition began at 18:00. Figure 2 displays the localization of the towns hosting the analysed human tower exhibitions. These locations were chosen for their representativeness in terms of cultural relevance. The exhibitions were performed in an urban square crowded with attendees and human tower builders.

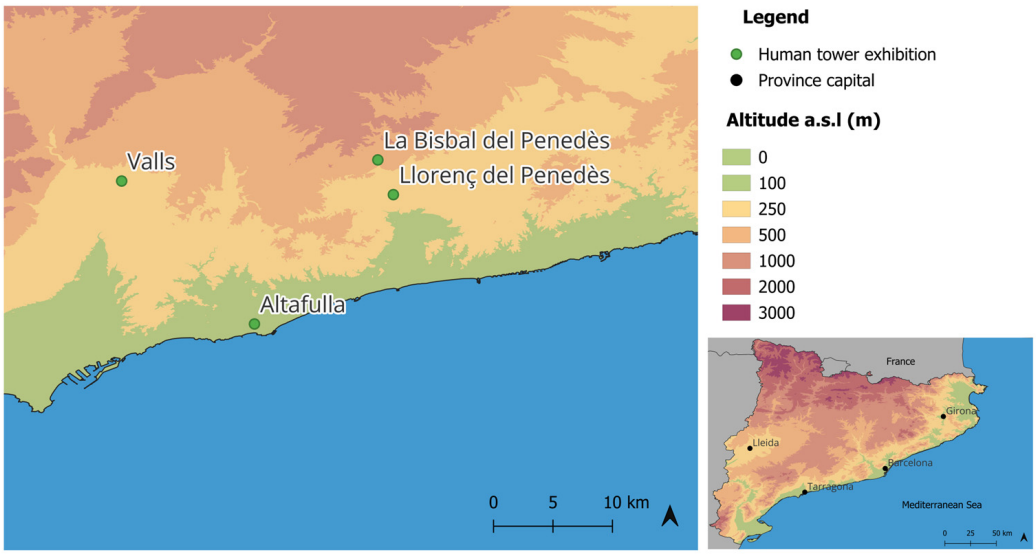

Figure 2. Localisation of the case studies.

Table 1 shows information from each of the four human tower exhibitions. The information includes the date in 2024, the name of the exhibition, the name of the town, the name of the square, the number of teams, and the schedule (UTC+2). As stated by Saladié et al. [8], the duration of the exhibitions is determined by several factors: the difficulty of the towers, the time elapsed between the end of a human tower and the start of the next, the number of teams taking part in the exhibition, and any potential incidents that may occur; for example, the Llorenç del Penèdes exhibition only lasted two hours because it had to be suspended after a human tower collapsed.

Table 1. Castells performances during local festivals in Altafulla, Valls, Llorenç del Penedès, and la Bisbal del Penedès (summer 2024).

Date	Exhibition	Town	Square	Teams	Schedule
July 13	Les Cultures	Altafulla	Plaça del Pou	4	18:00–21:00
August 7	Firagost	Valls	Plaça del Blat	2	20:00–22:00
August 11	Festa Major	Llorenç P.	Plaça de la Immaculada	3	18:00–20:00
August 15	Festa Major	La Bisbal P.	Carrer del Dr. Robert	4	18:00–21:00

The meteorological data used in this study to achieve the Objectives 1 and 2 were obtained from the ERA5 Best Match product, provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) via the Open-Meteo platform [23]. This dataset is based on the ERA5 reanalysis developed by the Copernicus Climate Change Service (C3S). It

represents a merged product that combines data from ERA5 and ERA5-Land to offer the most spatially and temporally consistent estimates at any given location.

The choice of ERA5 Best Match is grounded in both methodological robustness and operational suitability. ERA5, generated by the European Centre for Medium-Range Weather Forecasts (ECMWF), supplies hourly data at ~31 km horizontal resolution and is widely recognised as a leading global reanalysis for climate and weather applications. ERA5-Land, on the other hand, offers enhanced spatial resolution (~9 km) over land surfaces but lacks atmospheric variables above the surface and is not updated in near real time. The Best Match product offered by Open-Meteo integrates both datasets, selecting the most accurate and locally relevant estimate for each variable and time step. This hybrid approach is particularly advantageous for studying localised thermal dynamics in urban settings, where striking a balance between temporal fidelity and spatial detail is crucial. Moreover, the product's accessibility and API-based delivery enable reproducible and transparent data retrieval, which is essential for both research transparency and the future scalability of the methodology.

Except for the La Bisbal del Penedès exhibition, which is fixed to a specific date, the other exhibitions are scheduled according to movable dates based on the calendar. To account for interannual variability in event timing, a specific-date analysis was conducted, focusing on the actual date of the event for each year. For example, the 2nd Saturday of July can be from July 8th to July 14th. This refined approach ensures that the analysis is grounded in the actual performance dates, thus improving the relevance of the climatological assessment.

Following the approach adopted by Olano Pozo et al. [9], temperature and relative humidity data were downloaded for the day of each human tower exhibition over a 74-year period (1951–2024), specifically for the hours when the human towers were performed: Altafulla on 2nd Saturday of July (18:00, 19:00, 20:00, and 21:00), Valls on 1st Wednesday of August 8th (20:00, 21:00, and 22:00), Llorenç del Penedès on 2nd Sunday of August 11st (18:00, 19:00, 20:00 and 21:00), and La Bisbal del Penedès on August 15th (18:00, 19:00, 20:00, and 21:00). The average temperature for each of the 74 days in the four case studies was calculated using the temperatures from the previously mentioned hours. The same procedure was undertaken in the case of the afternoon time slot (12:00, 13:00, 14:00, and 15:00). These data provided four long temporal series to identify temperature variations and trends, allowing comparison between afternoon and evening.

The non-parametric Sen's Slope estimator was applied to detect and quantify monotonic trends in the average data. This procedure computes the median of all pairwise slopes between data points, making it robust to outliers and suitable for datasets that do not necessarily follow a normal distribution. The Mann–Kendall test was applied to assess the statistical significance of the temperature trend. Temperature anomalies were calculated for the 1971–2000 reference period.

The Heat Index (HI) can also be referred to as the apparent temperature. HI was calculated from the recorded temperature and relative humidity (RH) values. This derived metric estimates the perceived temperature based on the combined effects of air temperature and humidity. The HI was computed using a widely accepted regression model derived from Steadman's equations [24], which allows for estimation using only temperature and RH as inputs. The formula applied was [25]

$$\begin{aligned} HI = {} & -8.78469476 + (1.61139411 \times T) + (2.338548839 \times RH) - (0.14611605 \times T \times RH) - (0.012308094 \times T^2) - \\ & (0.016424828 \times RH^2) + (0.002211732 \times T^2 \times RH) + (0.00072546 \times T \times RH^2) - (0.000003582 \times T^2 \times RH^2) \end{aligned} \quad (1)$$

where T is the air temperature in °C and RH is the relative humidity in %. The resulting HI values were then classified into four standard risk categories [26]:

- Caution (26.1–32 °C): fatigue possible with prolonged exposure and/or physical activity;
- Extreme caution (32.1–40 °C): risk of heat cramps or exhaustion; heat stroke possible with sustained effort;
- Danger (40.1–52 °C): likely heat exhaustion or cramps; heat stroke possible;
- Extreme danger (>52 °C): heat stroke is highly likely.

As in the study performed by Saladié et al. [8], the present research utilized two HOBO MX2301A sensors (Figure 3), developed by Onset Computer Corporation (Bourne, MA, USA), for in situ measurements in the squares, thereby achieving Objective 3. The sensors are equipped with a shield to protect them from solar radiation. This sensor measures air temperature in a range of −40 to 70 °C with an accuracy of ±0.2 °C and a resolution of 0.04 °C. It also measures relative humidity between 0 and 100%, with an accuracy of ±2.5% and a resolution of 0.01%. Data were logged at 1 min intervals, allowing for high-resolution tracking of microclimatic conditions during the human tower exhibitions. The Heat Index was also computed by combining relative humidity and temperature values recorded by the sensors.

Figure 3. Meteorological sensor integrated into the screen protector. Source: Òscar Saladié.

Figure 4 displays a picture of each of the four studied squares, highlighting where the sensors were installed. The sensors were placed at a height of approximately 190–200 cm to ensure they did not interfere with the exhibition and minimize the risk of harm to people. This positioning also helps prevent accidental damage to the sensors or vandalism. When the human towers teams occupied the extreme of the square (i.e., Valls—Figure 1), one sensor was installed as close as possible to the human tower teams participating in the exhibition and the other was positioned near the area occupied by the attendees (Figure 4b). When the human tower teams were placed at the centre of the square (i.e., Llorenç del Penedès and La Bisbal del Penedès), the sensors were placed surrounding the human towers (Figure 4c,d). Finally, there were limited options in the case of Altafulla due to the characteristics of the facades (Figure 4a).

Figure 4. Localisation of meteorological sensors in urban squares with sensor 1 (s1) and sensor 2 (s2). (**a**) Atlafulla square exhibition; (**b**) Valls square exhibition; (**c**) Llorenç del Penedès square exhibition; (**d**) La Bisbal del Penedès square exhibition. Source: Jon Xavier Olano Pozo and Òscar Saladié.

3. Results

3.1. Temperature Trends and Thermal Comfort (1951–2024)

Figure 5 shows the mean afternoon temperature (left) and the mean evening temperature (right) in Altafulla, Valls, Llorenç del Penedès, and La Bisbal del Penedès for the respective dates of the human tower exhibitions spanning a 74-year range from 1951 to 2024. As expected, temperature values are consistently higher during the afternoon than in the evening. In Altafulla, on the second Saturday of July, the mean afternoon temperature was 28.4 °C. The temperature exceeded 30 °C 20 times, with a maximum of 34.1 °C, seven times in the last 30 years. The mean evening temperature was 24.9 °C, with a maximum of 29.1 °C. In Valls, on the first Wednesday of August, the mean afternoon temperature was 28.9 °C. The temperature exceeded 30 °C 22 times, with a maximum of 34.9 °C, 22 times in the last 30 years. The mean evening temperature was 22.7 °C, with a maximum of 26.7 °C.

In Llorenç del Penedès, on the second Sunday of August, the mean afternoon temperature was 27.4 °C. The temperature exceeded 30 °C eight times, with a maximum of 33.1 °C, six times in the last 30 years. The mean evening temperature was 22.7 °C, with a maximum of 28.6 °C. In La Bisbal del Penedès, on August 15th, the mean afternoon temperature was 27.9 °C. The temperature exceeded 30 °C 13 times, with a maximum of 35.4 °C, eight times in the last 30 years. The mean evening temperature was 23.8 °C, with a maximum of 27.5 °C. The temperature difference ranges from +3.4 °C in Altafulla to +4.1 °C in La Bisbal del Penedès for exhibitions starting at 18:00. The difference is higher in Valls (+6.2 °C), where the exhibition starts at 20:00.

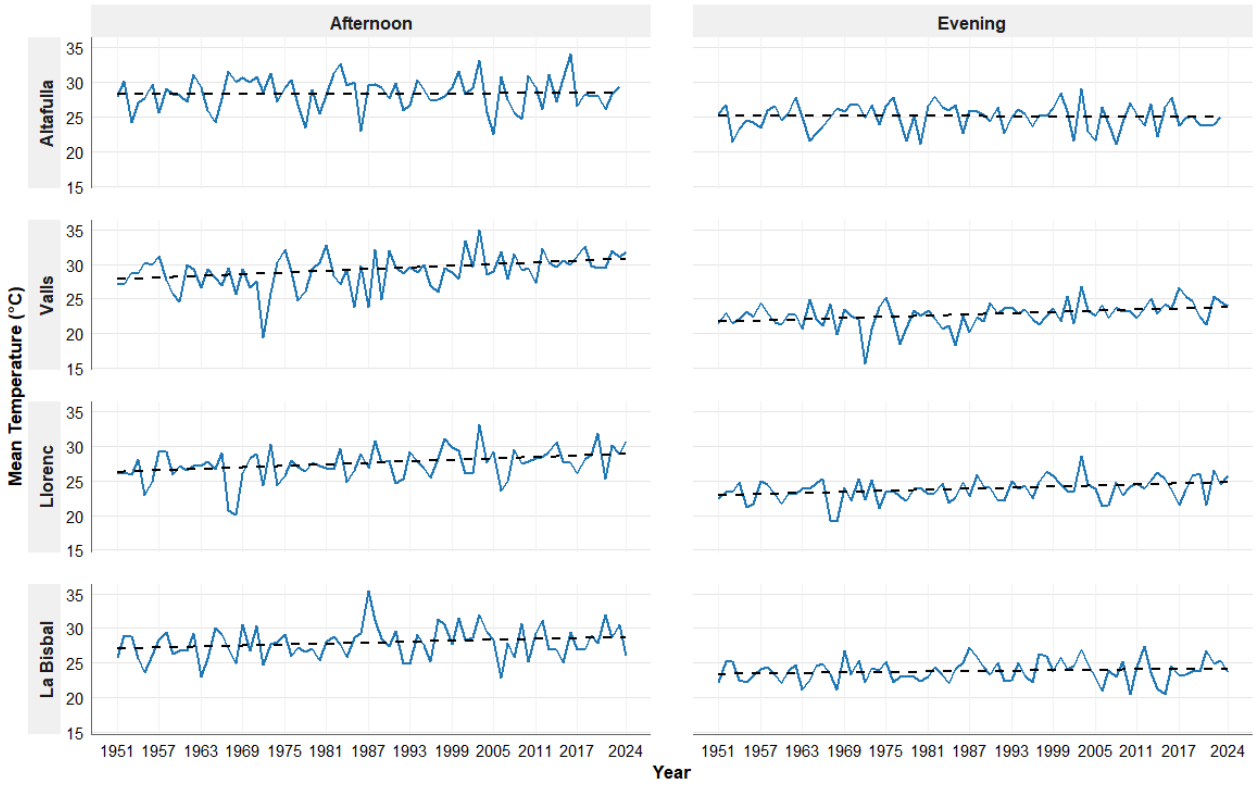

Figure 5. Mean temperature from 12:00 to 15:00 (**left**) and from 18:00 to 21:00 (from 20:00 to 22:00 in the case of Valls) (**right**) on the 2nd Saturday of July in Altafulla; 1st Wednesday of August in Valls; 2nd Sunday of August in Llorenç del Penedès; and 15 August in La Bisbal del Penedès (1951–2024). Dash line shows the trend.

The differences between afternoon and evening temperatures are increasing because the temperature trend is higher in the afternoon than in the evening. The Sen's slope estimate (°C/decade) is depicted in Table 2. The temperature changes are significant at the 0.01 level in the cases of Valls and Llorenç del Penedès. Thermal intensification is higher in the afternoon, but it is also evident in the evening, particularly in inland locations. Trends in La Bisbal del Penedès are also positive but not statistically significant. Altafulla, located on the coast, exhibits a very low and insignificant trend, with a negative trend in the evening period.

Table 2. Temperature trends and confidence intervals (1951–2024).

Place	Date	Time	Sen's Slope	Confidence Interval
Altafulla	2nd Saturday of July	Afternoon	+0.007 °C per decade	−0.272–0.282
		Evening	−0.039 °C per decade	−0.250–0.173
Valls	1st Wednesday of August	Afternoon	+0.403 °C per decade *	0.162–0.638
		Evening	+0.287 °C per decade *	0.124–0.444
Llorenç P.	2nd Sunday of August	Afternoon	+0.355 °C per decade *	0.151–0.565
		Evening	+0.255 °C per decade *	0.090–0.420
La Bisbal P.	15 of August	Afternoon	+0.228 °C per decade	−0.030–0.474
		Evening	+0.109 °C per decade	−0.063–0.280

* Significant trend at 0.01 level.

Figure 6 illustrates the evolution of summer afternoon (left) and evening (right) temperature anomalies for the four municipalities, referenced against the 1971–2000 baseline. Blue and red bars indicate, respectively, years colder and warmer than average. The results reveal a general shift toward positive anomalies in recent decades (Valls and Llorenç del Penedès). From the mid-1990s onward, both sites exhibit a sharp increase in the frequency and intensity of positive anomalies, indicating a sustained warming trend that aligns with statistically significant linear trends previously identified in the dataset. In contrast, Altafulla, located closer to the coast, exhibits a more irregular pattern, with predominantly negative anomalies until the 1990s and only a modest shift toward warming thereafter, likely moderated by the influence of the sea. La Bisbal del Penedès exhibits non-clear behaviour, with the early decades dominated by cooler anomalies and a more variable, less clearly defined pattern in recent years.

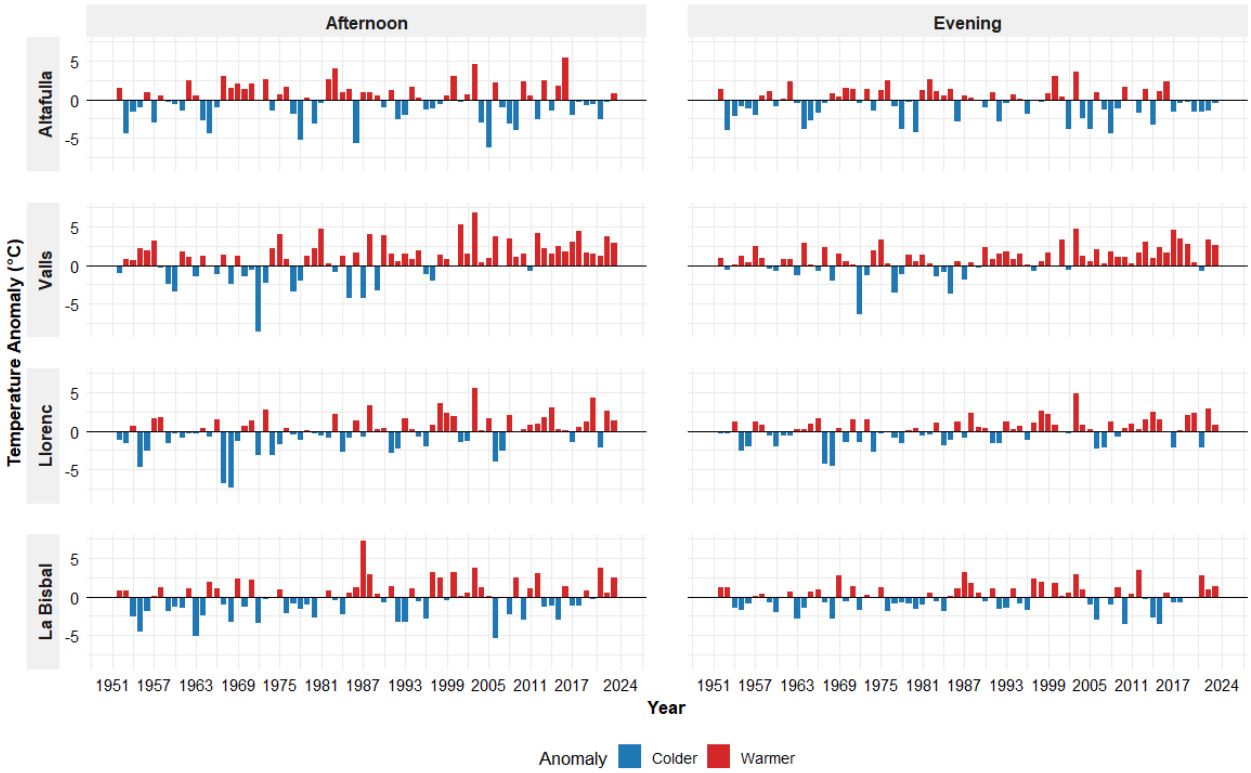

Figure 6. Temperature anomalies from 12:00 to 15:00 (**left**) and from 18:00 to 21:00 (**right**) on the 2nd Saturday of July in Altafulla; 1st Wednesday of August in Valls; 2nd Sunday of August in Llorenç del Penedès; and 15 August in La Bisbal del Penedès (1951–2024).

3.2. Thermal Comfort (1951–2024)

Figure 7 displays the Heat Index (HI) values for the 74-year period (1951–2024) for the afternoon (left) and the evening (right) in Altafulla, Valls, Llorenç del Penedès, and La Bisbal del Penedès, following the thresholds described in Section 2. The four analysed dates are during summer, the warmest season in the Mediterranean region. As expected, HI values are predominantly within the caution range (approximately 80% of the years) for the afternoon (13:00–15:00). There are a few years with HI values below 26 °C and above 32 °C. However, the respective pattern over the 74-year period is different. There is a decrease in HI values below 26 °C in the last 30 years (none in the case of Valls) and, in contrast, an increase in HI values within the extreme caution range (100% in the case of Llorenç del Penedès). The only exception is in La Bisbal del Penedès, where 40% of the total is concentrated in the last 30 years. The upper threshold of the caution range (29–32 °C),

close to the extreme caution range, has been reached 28 times in Altafulla, 32 times in Valls, 25 times in Llorenç del Penedès, and 29 times in La Bisbal del Penedès.

Altafulla (2nd Saturday of July; 12:00–15:00)						
1951	1952	1953	1954	1955	1956	1957
1958	1959	1960	1961	1962	1963	1964
1965	1966	1967	1968	1969	1970	1971
1972	1973	1974	1975	1976	1977	1978
1979	1980	1981	1982	1983	1984	1985
1986	1987	1988	1989	1990	1991	1992
1993	1994	1995	1996	1997	1998	1999
2000	2001	2002	2003	2004	2005	2006
2007	2008	2009	2010	2011	2012	2013
2014	2015	2016	2017	2018	2019	2020
2021	2022	2023	2024			

Altafulla (2nd Saturday of July; 18:00–21:00)						
1951	1952	1953	1954	1955	1956	1957
1958	1959	1960	1961	1962	1963	1964
1965	1966	1967	1968	1969	1970	1971
1972	1973	1974	1975	1976	1977	1978
1979	1980	1981	1982	1983	1984	1985
1986	1987	1988	1989	1990	1991	1992
1993	1994	1995	1996	1997	1998	1999
2000	2001	2002	2003	2004	2005	2006
2007	2008	2009	2010	2011	2012	2013
2014	2015	2016	2017	2018	2019	2020
2021	2022	2023	2024			

Valls (1st Wednesday of August; 12:00–15:00)						
1951	1952	1953	1954	1955	1956	1957
1958	1959	1960	1961	1962	1963	1964
1965	1966	1967	1968	1969	1970	1971
1972	1973	1974	1975	1976	1977	1978
1979	1980	1981	1982	1983	1984	1985
1986	1987	1988	1989	1990	1991	1992
1993	1994	1995	1996	1997	1998	1999
2000	2001	2002	2003	2004	2005	2006
2007	2008	2009	2010	2011	2012	2013
2014	2015	2016	2017	2018	2019	2020
2021	2022	2023	2024			

Valls (1st Wednesday of August; 20:00–22:00)						
1951	1952	1953	1954	1955	1956	1957
1958	1959	1960	1961	1962	1963	1964
1965	1966	1967	1968	1969	1970	1971
1972	1973	1974	1975	1976	1977	1978
1979	1980	1981	1982	1983	1984	1985
1986	1987	1988	1989	1990	1991	1992
1993	1994	1995	1996	1997	1998	1999
2000	2001	2002	2003	2004	2005	2006
2007	2008	2009	2010	2011	2012	2013
2014	2015	2016	2017	2018	2019	2020
2021	2022	2023	2024			

Llorenç P. (2nd Sunday of August; 12:00–15:00)						
1951	1952	1953	1954	1955	1956	1957
1958	1959	1960	1961	1962	1963	1964
1965	1966	1967	1968	1969	1970	1971
1972	1973	1974	1975	1976	1977	1978
1979	1980	1981	1982	1983	1984	1985
1986	1987	1988	1989	1990	1991	1992
1993	1994	1995	1996	1997	1998	1999
2000	2001	2002	2003	2004	2005	2006
2007	2008	2009	2010	2011	2012	2013
2014	2015	2016	2017	2018	2019	2020
2021	2022	2023	2024			

Llorenç P. (2nd Sunday of August; 18:00–21:00)						
1951	1952	1953	1954	1955	1956	1957
1958	1959	1960	1961	1962	1963	1964
1965	1966	1967	1968	1969	1970	1971
1972	1973	1974	1975	1976	1977	1978
1979	1980	1981	1982	1983	1984	1985
1986	1987	1988	1989	1990	1991	1992
1993	1994	1995	1996	1997	1998	1999
2000	2001	2002	2003	2004	2005	2006
2007	2008	2009	2010	2011	2012	2013
2014	2015	2016	2017	2018	2019	2020
2021	2022	2023	2024			

La Bisbal del Penedès (15 August; 12:00–15:00)						
1951	1952	1953	1954	1955	1956	1957
1958	1959	1960	1961	1962	1963	1964
1965	1966	1967	1968	1969	1970	1971
1972	1973	1974	1975	1976	1977	1978
1979	1980	1981	1982	1983	1984	1985
1986	1987	1988	1989	1990	1991	1992
1993	1994	1995	1996	1997	1998	1999
2000	2001	2002	2003	2004	2005	2006
2007	2008	2009	2010	2011	2012	2013
2014	2015	2016	2017	2018	2019	2020
2021	2022	2023	2024			

La Bisbal del Penedès (15 August; 18:00–21:00)						
1951	1952	1953	1954	1955	1956	1957
1958	1959	1960	1961	1962	1963	1964
1965	1966	1967	1968	1969	1970	1971
1972	1973	1974	1975	1976	1977	1978
1979	1980	1981	1982	1983	1984	1985
1986	1987	1988	1989	1990	1991	1992
1993	1994	1995	1996	1997	1998	1999
2000	2001	2002	2003	2004	2005	2006
2007	2008	2009	2010	2011	2012	2013
2014	2015	2016	2017	2018	2019	2020
2021	2022	2023	2024			

no discomfort | caution | extreme caution

Figure 7. Afternoon (**left**) and evening (**right**) Heat Index values in Altafulla, Valls, Llorenç del Penedès, and La Bisbal del Penedès (1951–2024).

The picture is quite different for the evening (Figure 7, right). No year had an HI value exceeding 32 °C (extreme caution range). There is a predominance of green colour (HI $\leq$ 26 °C). Only a few years reached the caution interval in Valls (8.1%), while they are around one fifth of the total in Llorenç del Penedès (18.9%) and La Bisbal del Penedès (20.3%). However, most of these occurrences happened in the last 30 years. The Diada de Firagost begins at 20:00, and Valls is the town farthest from the sea (18 km), in contrast to Altafulla. The Plaça del Plou is situated 1 km from the sea, with 50% of the years falling within the caution interval, distributed over a 74-year period. The upper threshold of the caution range (29–32 °C) has only been reached six times: 1962 (Altafulla), 1976 (Altafulla), 2003 (Altafulla and Llorenç del Penedès), and 2016 (Altafulla).

3.3. Meteorological Conditions in the Squares (2024)

Figure 8 displays the temperature progression for the four human tower exhibitions in each of the two sensors located in the squares. The goal is not to make comparisons between the human tower exhibitions analysed, as they did not occur on the same day (from 13 July 2024 to 15 August 2024), with different durations (2 or 3 h) and even different starting times (18:00 or 20:00) and ending times (20:00, 21:00 or 22:00). Nevertheless, there is a clear and expected pattern: the temperature decreased as the exhibition progressed. This pattern was modified by factors such as the presence of clouds, the shade generated by the buildings, or whether the area where the sensors were located had previously been exposed to solar radiation. The figures also include the maximum, minimum, and mean temperatures for the entire duration of the exhibition, as well as the time when the maximum and minimum temperatures were recorded.

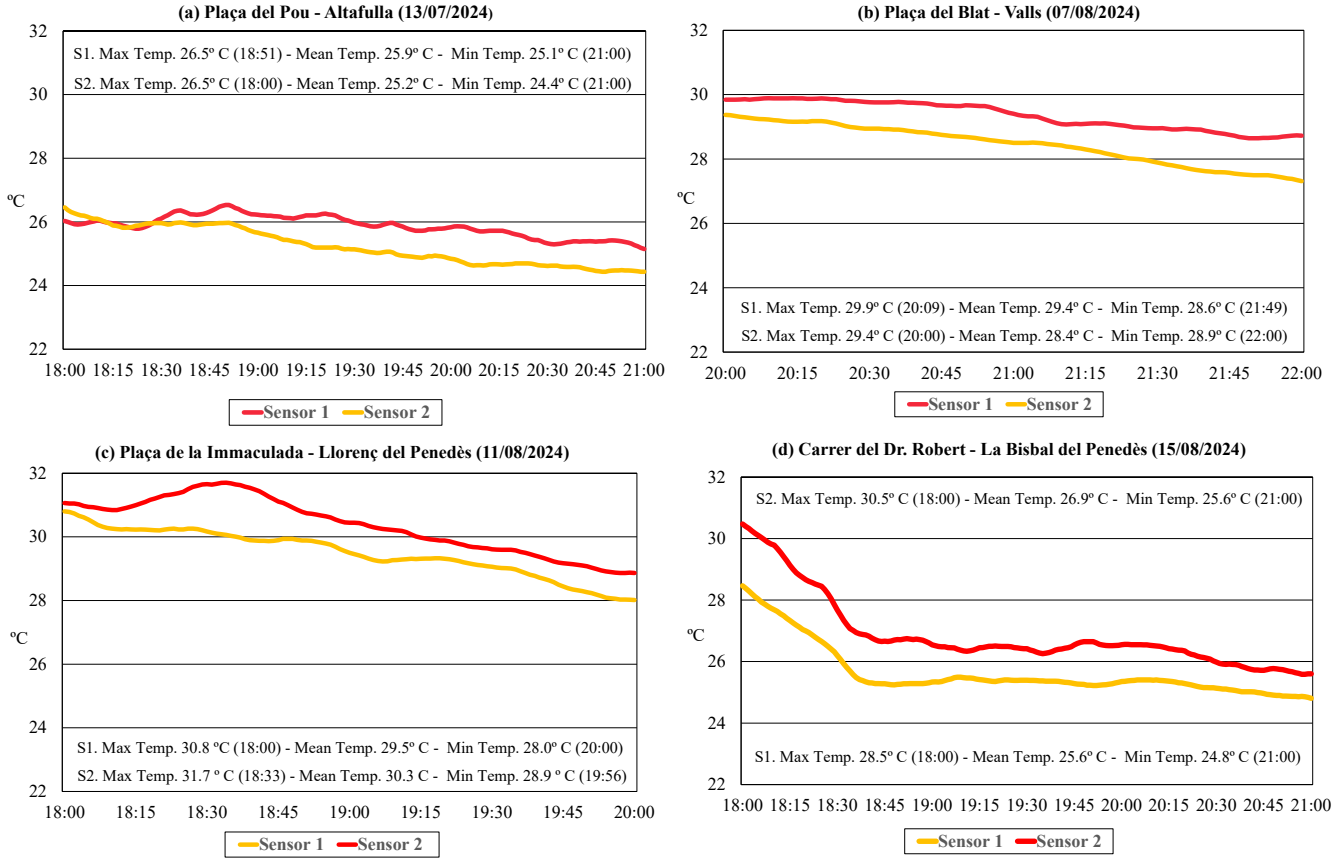

Figure 8. Temperature evolution during human tower exhibitions.

On 13 July 2024, the average temperature at Plaça del Pou (Altafulla) for the exhibition was 25.9 °C in Sensor 1 and 25.2 °C in Sensor 2 (Figure 4a). Clouds partially covered the sky at the beginning of the exhibition. The temperature in S1 remained stable at around 26 °C, increasing when the sensor was exposed to solar radiation. The maximum temperature reached in S1 was 26.5 °C at 18:51. The temperature then began to decline. The maximum temperature in S2 was achieved at the start of the exhibition (26.5 °C) and then decreased until the clouds disappeared. With the sensor exposed to solar radiation, the temperature remained stable around 26 °C until the same time as the maximum peak in S1. The temperature in S2, like in S1, began to decrease (0.5–1 °C higher in S1 than in S2) until the end of the exhibition at 21:00. Sunset was at 21:26.

On 8 August 2024, the average temperature at Plaça del Blat (Valls) for the exhibition was 29.4 °C at Sensor 1 and 28.4 °C at Sensor 2 (Figure 4b). None of the sensors were exposed to solar radiation, as the shade of the buildings covered most of the square, including the area where they were placed, and because sunset occurred at 21:03. The temperature in Sensor 2 gradually decreased throughout the exhibition. In contrast, the temperature in Sensor 1 decreased more smoothly, likely due to the area being exposed to sunlight in the afternoon. This difference in exposure helps explain the variations between the readings of the two sensors.

On 11 August 2024, the average temperature at Plaça de la Immaculada (Llorenç del Penedès) for the exhibition was 29.5 °C at Sensor 1 and 30.3 °C at Sensor 2 (Figure 4c). The maximum temperature at Sensor 1 was reached at the start of the exhibition and gradually decreased as the evening progressed. In contrast, Sensor 2 recorded its maximum temperature at 18:33, reaching nearly 32 °C. Both sensors were exposed to the sun. The temperature variations between the two sensors may be attributed to the differing characteristics of the areas where the sensors were placed: Sensor 1 was in a more open and wider adjacent street and Sensor 2 was in a more closed and narrower adjacent street. Sunset occurred at 20:58.

On 15 August 2024, the average temperature on Carrer del Dr. Robert (La Bisbal del Penedès) for the exhibition was 25.6 °C at Sensor 1 and 26.9 °C at Sensor 2 (Figure 4d). None of the sensors was exposed to solar radiation during the exhibition because the sky was clouded by 18:00. The temperature difference can be explained by the fact that Sensor 2 was exposed to solar radiation before being shaded by the clouds, while Sensor 1 was in the shade of the buildings. The sky became fully clouded a few minutes after the exhibition began, with very light rain (0.3 mm from 18:00 to 19:00 at the nearest automatic weather station in the Catalan Meteorological Service network). The temperature dropped abruptly for almost 45 min, stabilizing around 25.5 °C at S1 and 26.5 °C at S2 for most of the exhibition. The temperature slightly decreased towards the end of the human tower exhibition but was 0.5º higher at S2. Sunset occurred at 20:52.

Figure 9 displays the duration of the human tower exhibitions distributed according to relative humidity (RH) figures recorded by the two sensors. The RH was mostly between 50–60% in the two sensors for three of the four human tower exhibitions (Altafulla, Valls, and La Bisbal del Penedès) and between 50–60% in the Llorenç del Penedès exhibition. Altafulla is the town closest to the sea, and Valls the farthest. The highest and lowest RH figures were recorded in the sensors for La Bisbal del Penedès exhibition, a town located 15 km from the sea, with the sky covered by clouds throughout the exhibition.

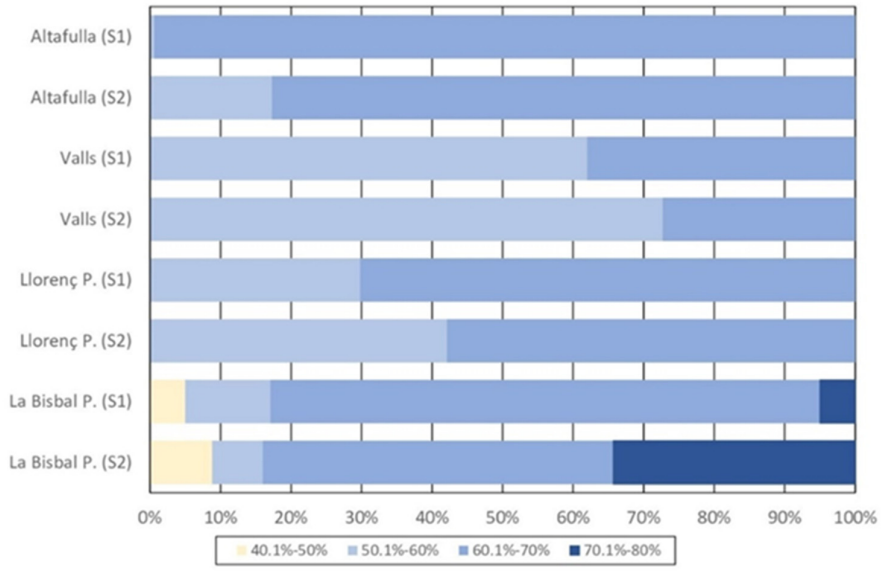

Figure 9. Distribution of the duration of human tower exhibitions according to relative humidity.

Figure 10 displays the Heat Index (HI) values obtained every 15 min, which were calculated by combining the relative humidity and temperature in the urban squares recorded by the sensors. The majority of the human tower exhibition in Altafulla was performed within the caution interval, specifically at the lower threshold. The HI decreased throughout the exhibition, with the last 75 min on Sensor 2 showing HI values below 26 °C. The same pattern was observed in La Bisbal del Penedès. However, the HI at the beginning of the exhibition was close to the upper threshold of the caution interval.

Heat index (°C)								
	Altafulla (13/7/2024)		Valls (7/8/2024)		Llorenç P. (11/8/2024)		La Bisbal P. (15/8/2024)	
	Sensor 1	Sensor 2	Sensor 1	Sensor 2	Sensor 1	Sensor 2	Sensor 1	Sensor 2
Mean	**26.9**	**26.3**	**31.4**	**29.7**	**32.3**	**33.6**	**26.6**	**28.2**
18:00–18:15	27.0	27.1			33.2	33.9	28.4	30.6
18:15–18:30	26.9	26.8			33.1	34.7	27.6	29.7
18:30–18:45	27.3	26.9			32.9	35.0	26.5	28.7
18:45–19:00	27.4	26.8			33.0	34.4	26.3	28.4
19:00–19:15	27.2	26.5			32.1	33.6	26.5	28.0
19:15–19:30	27.2	26.5			32.2	33.1	26.4	28.1
19:30–19:45	27.2	26.2			31.6	32.5	26.4	27.8
19:45–20:00	26.8	26.0			30.6	31.8	26.3	28.1
20:00–20:15	26.8	25.9	31.4	30.2			26.4	27.9
20:15–20:30	26.6	25.7	31.5	30.2			26.2	27.6
20:30–20:45	26.4	25.6	31.6	30.1			26.1	27.1
20:45–21:00	26.4	25.5	31.5	29.8			25.9	26.8
21:00–21:15			31.0	29.7				
21:15–21:30			31.3	29.5				
21:30–21:45			31.2	29.2				
21:45–22:00			31.4	29.0				
No discomfort			Caution		Extreme caution			

Figure 10. Calculated Heat Index by sensors that register every 15 min in the squares.

The entire human tower exhibition in Valls was performed within the caution interval. Most of the values were at the upper threshold of this interval, with small differences between the beginning and end of the exhibition, especially in Sensor 1. In contrast, the majority of the time during the Llorenç del Penedès exhibition was in the extreme caution interval (lower threshold). The exhibition only lasted two hours before it had to

be suspended. Available medical resources (ambulance) in the exhibition had to transport injured human tower builders to the hospital due to a human tower collapse, highlighting the need for medical presence at these events. The exhibition was expected to finish at 21:00, and the HI values from 20:00 to 21:00 (and the mean value for the entire exhibition) probably would have remained within the caution interval. Despite the human tower exhibition starting in the evening, temperatures in the first half of August can exceed 30 °C, and when combined with relative humidity, HI values rise above 32 °C.

4. Discussion

This study aimed to assess the impact of rising temperatures on the thermal comfort of participants and audiences during summer human tower exhibitions scheduled in the evening in summer 2024. Olano Pozo et al. [9] analysed temperature trends between 1951 and 2023 for four emblematic human tower exhibitions scheduled in the summer afternoons (12:00–15:00), reporting an upward trend of 0.3–0.4 °C per decade depending on the location. Saladié et al. [8] have already assessed thermal comfort in urban squares for six human tower exhibitions, but only during the afternoons, not in the evenings. Their results emphasize the increasing vulnerability of afternoon events to thermal stress. Analysis of evening exhibitions (18:00–21:00) complements these previous works, and the three main objectives outlined in the introduction have been achieved, providing complementary insights into the changing climate context of these traditional cultural events and adding to the knowledge of intangible cultural heritage in the face of climate change in Catalonia.

First, the long-term analysis of temperature data from reanalysis (1951–2024) confirms a statistically significant warming trend during the typical hours when evening summer exhibitions are held in two cases. Although absolute temperatures are lower than in the afternoon, a similar warming tendency is also evident. Evening hours have also become warmer, although they still represent a more thermally tolerable window, particularly in coastal towns, where the sea breeze can moderate late-afternoon temperatures. This indicates that rescheduling to evening hours reduces immediate exposure to peak heat but does not entirely remove the influence of long-term warming trends.

Second, the worsening of thermal comfort has been demonstrated using the Heat Index (HI) as a proxy. The increase in HI values over the past 74 years reveals that subjective thermal stress has intensified, particularly during events held around the afternoon. Relative humidity is higher in the evening than in the afternoon. However, thermal comfort decreases in the afternoon because the temperature is significantly higher in the afternoon than in the evening. The HI values combine air temperature and relative humidity derived from reanalysis datasets; however, these values from 1951 to 2024 represent open-area conditions and do not fully capture the thermal experience within urban squares [8]. These spaces, where human towers are traditionally built, are densely packed during exhibitions and influenced by surrounding buildings, shaded areas, and wind corridors. As noted in Section 3.2, assessing thermal comfort at the square level requires localized evaluation [13,15,27]. In 2024, specific conditions were analysed in situ for four evening exhibitions, providing critical insights into the participants' experiences. Performing human tower exhibitions in the evening does not guarantee thermal comfort, especially when people are exposed to solar radiation. Temperatures in the evening have been rising in the last few decades, and relative humidity records are higher in the evening, particularly in towns near the sea. Urban morphology plays a crucial role in shaping thermal environments, and further research is necessary to monitor and model microclimatic variability in performance spaces [10].

Rising evening temperatures, combined with the persistence of urban heat island effects in the evening and after sunset, suggest that additional adaptive measures will

need to be considered to sustain safe and comfortable conditions for both participants and audiences. This was highlighted by Saladié et al. [22] after conducting workshops with two human tower teams. The results of this study provide information to evaluate whether it is better to move exhibitions from midday to evenings. Those adaptation measures must be seriously considered to ensure the well-being and safety of both human tower builders and attendees. Increasing shaded areas, providing access to cool drinking water, and promoting sun protection (e.g., hats and sunscreen) are necessary first steps. More structural adaptations, such as rescheduling exhibitions to evening hours, have already been adopted in some cases—e.g., *Diada de Les Santes* in Mataró, *Diada de la Festa Major* in Llorenç del Penedès, or *Diada de la Festa Major* in La Bisbal del Penedès. The exhibitions have been adjusted to later hours in response to the excessive afternoon heat. However, other measures must be reinforced: pre-existing practices (e.g., water breaks and shaded waiting areas) should be expanded and new ones considered, such as reducing the duration of the exhibitions. Ultimately, the goal is to safeguard participants' health while maintaining the integrity of the tradition. Excessive heat can cause dehydration, dizziness, and heatstroke and, importantly, may also compromise tower stability, increasing the risk of collapse and injury.

Finally, this study raises the broader question of whether maximum temperature thresholds should be defined for outdoor physical activities, similarly to what is being considered in the context of outdoor labour [28] and some sports [29–31]. While evening scheduling mitigates many of the thermal risks, the increase in heat stress indicators suggests that more straightforward guidelines or protocols could enhance safety and preparedness for intangible cultural events in a warming climate.

5. Conclusions

This study has demonstrated that thermal conditions during summer human tower exhibitions in Catalonia have worsened over the past seven decades, with a clear increase in both air temperature and thermal discomfort as measured by the Heat Index. The analysis of four evening exhibitions in 2024 supports the hypothesis that evening hours offer more suitable thermal conditions than midday, although the long-term warming trend affects all periods of the day. Thermal comfort has decreased in three of the four sites in recent years.

However, several limitations must be acknowledged. This study focuses on a single year (2024) and only four exhibitions, which constrains the temporal and spatial generalizability of the findings. Longitudinal analyses spanning multiple years and a broader range of locations—including events held outside the summer season—are necessary to develop a more comprehensive understanding of the evolving thermal risks. Furthermore, the Heat Index used in this study incorporates only air temperature and relative humidity, without accounting for additional meteorological or urban factors, such as solar radiation, wind, shading, or surface materials, which influence real thermal comfort in urban squares. The Heat Index may underestimate thermal discomfort under high solar radiation during the day. Therefore, resulting values should be interpreted cautiously when assessing local thermal stress. Finally, the placement of the sensors in the square (sun versus shade) can introduce a certain bias. The resulting data reflect the environmental conditions where the sensor is positioned.

Another important consideration for future research is the potential impact of late-summer evening thunderstorms, which are relatively common in Catalonia and often coincide with the timing of these cultural events. While evening scheduling reduces heat-related stress, it may also increase exposure to sudden weather instability, with implications for safety and event management. A systematic analysis of precipitation and storm risk

during these timeframes would complement thermal assessments and support more holistic adaptation planning.

Taken together, these findings underscore the urgency of initiating a broader and more inclusive dialogue on how to best adapt human tower exhibitions to a changing climate. This discussion should involve event organizers, casteller teams, and public authorities, with the shared aim of developing culturally sensitive and collectively agreed-upon strategies. These may include schedule modifications, heat mitigation measures, real-time weather monitoring, and emergency protocols.

Ultimately, adaptation is not only about reducing risk—it is about ensuring that human towers, a living tradition recognized by UNESCO as an intangible cultural heritage of humanity, can continue to be performed safely, inclusively, and sustainably in the face of climate change.

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References

1. Wolff, D.; Fitzhugh, E.C. The relationships between weather-related factors and daily outdoor physical activity counts on an urban greenway. *Int. J. Environ. Res. Public Health* **2011**, *8*, 579–589. [CrossRef]
2. Fan, Y.; Wang, J.; Obradovich, N.; Zheng, S. Intraday adaptation to extreme temperatures in outdoor activity. *Sci. Rep.* **2023**, *13*, 473. [CrossRef]
3. Goodman, J.; Humphrys, E.; Newman, F. Working in heat: Contrasting heat management approaches among outdoor employees and contractors. *Saf. Sci.* **2023**, *165*, 106185. [CrossRef]
4. Özgünen, K.T.; Kurdak, S.S.; Maughan, R.J.; Zeren, Ç.; Korkmaz, S.; Yazici, Z.; Ersöz, G.; Shirreffs, M.; Binnet, M.S.; Dvorak, J. Effects of hot environmental conditions on physical activity patterns and temperature response of football players. *Scand. J. Med. Sci. Sports* **2019**, *22*, 912–917. [CrossRef] [PubMed]
5. Fenemor, S.P.; Gill, N.D.; Driller, M.W.; Mills, B.; Casadio, J.R.; Beaven, C.M. The relationship between physiological and performance variables during a hot/humid international rugby sevens tournament. *Eur. J. Sport Sci.* **2022**, *22*, 1499–1507. [CrossRef] [PubMed]
6. Ioannou, L.G.; Foster, J.; Morris, N.B.; Piil, J.F.; Havenith, G.; Mekjavic, I.B.; Kenny, G.P.; Nybo, L.; Flouris, A.D. Occupational heat strain in outdoor workers: A comprehensive review and meta-analysis. *Temperature* **2022**, *9*, 67–102. [CrossRef]
7. Amoadu, M.; Ansah, E.W.; Sarfo, J.O.; Hormenu, T. Impact of climate change and heat stress on workers' health and productivity: A scoping review. *J. Clim. Change Health* **2023**, *12*, 100249. [CrossRef]
8. Saladié, Ò.; Boqué-Ciurana, A.; Sevil, J.; Olano Pozo, J.X. Summer Thermal Comfort in Urban Squares: The Case of Human Tower Exhibitions in Catalonia. *Atmosphere* **2025**, *16*, 666. [CrossRef]
9. Olano Pozo, J.X.; Saladié, Ò.; Boqué-Ciurana, A. Rising Temperatures, Wavering Human Towers? Temperature Trends and Thermal Comfort during Castells Exhibitions in Catalonia (1951–2023). Case Studies in Valls (24 June), La Bisbal del Penedès (15 August), Tarragona (19 August), and Vilafranca del Penedès (30 August). *Climate* **2024**, *12*, 112. [CrossRef]
10. Liu, Z.; Li, J.; Xi, T. A Review of Thermal Comfort Evaluation and Improvement in Urban Outdoor Spaces. *Buildings* **2023**, *13*, 3050. [CrossRef]
11. Aghamolaei, R.; Mehdi Azizi, M.; Aminzadeh, B.; O'Donnell, J. A comprehensive review of outdoor thermal comfort in urban areas: Effective parameters and approaches. *Energy Environ.* **2023**, *34*, 2204–2227. [CrossRef]

12. Steadman, R.G. The Assessment of Sultriness. Part I: A Temperature-Humidity Index Based on Human Physiology and Clothing Science. *J. Appl. Meteorol. Climatol.* **1979**, *18*, 861–873. [CrossRef]
13. Landsberg, H.E. *The Urban Climate*; International Geophysics Series; Academic Press: New York, NY, USA, 1981; Volume 28, 277p.
14. Oke, T.R. The energetic basis of the urban heat island. *Q. J. R. Meteorol. Soc.* **1982**, *108*, 1–24. [CrossRef]
15. Mirabi, E.; Nasrollahi, N. Urban facade geometry on outdoor comfort conditions: A Review. *Eur. Online J. Nat. Soc. Sci.* **2020**, *9*, 655–677. [CrossRef]
16. Mandic, L.; Djukic, A.; Maric, J.; Mitrovic, B. A systematic review of outdoor thermal comfort studies for the urban (re)desing of city squares. *Sustainability* **2024**, *16*, 4920. [CrossRef]
17. Brotons Navarro, X.; Soler García de Oteyza, G. *Enciclopèdia Castellera. Les Places*; 8; Cossetània Edicions: Valls, Spain, 2024; 265p.
18. Rovira–Ricart, E.; Rosset-Llobet, J. Avaluació de l'efectivitat d'un casc per a infants castellers. *Pediatr. Catalana* **2008**, *68*, 217–219.
19. Pérez Got, M. La jornada castellera de La Bisbal del Penedès acaba sin castells de gama extra. *El Periódico* **2023**. Available online: https://www.elperiodico.com/es/sociedad/20230815/jornada-castellera-bisbal-penedes-sin-castells-gama-extra-90988397 (accessed on 5 June 2025).
20. Prats, D. La Bisbal mou els Castells a la tarda. *Rev. Castells* **2024**. Available online: https://revistacastells.cat/2024/01/la-bisbal-mou-els-castells-a-la-tarda/ (accessed on 10 June 2025).
21. Coordinadora de Colles Castelleres de Catalunya. XXVIII Jornada de Prevenció de Lesions en el Mon Casteller. 9 March 2024. Available online: https://castellscat.cat/ca/noticia/325-la-28a-jornada-de-prevencio-de-lesions-en-el-mon-casteller-se-centrara-en-la-sostenibilitat-i-els-riscos-del-canvi-climatic (accessed on 11 June 2025).
22. Saladié, O.; Boqué-Ciurana, A.; Sevil, J.; Olano Pozo, J.X. Medidas de adaptación de las actuaciones castelleras al cambio climático: ¿Qué es más prioritario y viable? In *Cambio Climático y Sociedad: De la Ciencia Básica a los Servicios Climáticos*; Luna Rico, M.Y., González Rouco, J.F., Eds.; Publicaciones AEC: Madrid, Spain, 2025; pp. 379–388.
23. Zippenfenig, P. Open Meteo.com Weather API [Computer Software]. Zenodo. 2023. Available online: https://zenodo.org/records/14582479 (accessed on 25 January 2025).
24. Opitz-Stapleton, S.; Sabbag, L.; Hawley, K.; Tran, P.; Hoang, L.; Hoang Nguyen, P. Heat index trends and climate change implications for occupational heat exposure in Da Nang, Vietnam. *Clim. Serv.* **2016**, *2–3*, 41–51. [CrossRef]
25. AEMET. Tabla de Valores de Sensación Térmica por Calor (Heat Index). Available online: https://www.aemet.es/es/conocermas/montana/detalles/sensaciontermica (accessed on 18 January 2025).
26. National Weather Service. Heat Forecast Tools. National Oceanic and Atmospheric Administration. Available online: https://www.weather.gov/safety/heat-index (accessed on 18 January 2025).
27. Cimolai, C.; Aguilar, E. Heatwave Hotspots: SUHI and Intra-Urban Surface Temperature Mapping in Three Argentine Cities. *Earth Syst. Environ.* **2025**, 1–21. [CrossRef]
28. Lao, J.; Hansen, A.; Nitschke, M.; Hanson-Easey, S.; Pisaniello, D. Working smart: An exploration of council workers' experiences and perceptions of heat in Adelaide, South Australia. *Saf. Sci.* **2016**, *82*, 228–235. [CrossRef]
29. Grundstein, A.; Elguindi, N.; Cooper, E.; Ferrara, M.S. Exceedance of wet bulb globe temperature safety thresholds in sports under a warming climate. *Clim. Res.* **2013**, *58*, 183–191. [CrossRef]
30. Oyama, T.; Fujii, M.; Nakajima, K.; Takakura, J.Y.; Hijioka, Y. Validation of upper thermal thresholds for outdoor sports using thermal physiology modelling. *Temperature* **2024**, *11*, 92–106. [CrossRef]
31. Grundstein, A.; Williams, C.; Phan, M.; Cooper, E. Regional heat safety thresholds for athletics in the contiguous United States. *Appl. Geogr.* **2015**, *56*, 55–60. [CrossRef]