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EDITED BY

Napoleon A. Enteria,
Mindanao State University, Philippines

REVIEWED BY

Roberto Alonso González-Lezcano,
CEU San Pablo University, Spain
Sunil K. Sansaniwal,
Malaviya National Institute of
Technology, India

*CORRESPONDENCE

Aleksejs Prozumants,
✉ aleksejs.prozumants@rtu.lv
Anatolijs Borodinecs,
✉ anatolijs.borodinecs@rtu.lv

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Examining the efficacy of cooling pad technology to address increasing building cooling demand in Latvia

Aleksejs Prozumants*, Anatolijs Borodinecs*, Kristina Lebedeva
and Arturs Palcikovskis

Department of Heat Engineering and Technology, Faculty of Civil Engineering, Riga Technical University, Riga, Latvia

Over the past decades there has been a strong evidence of a temperature rise across the world that has led to a growing concern of more extreme weather patterns and regular seasonal heat waves globally. As such, building occupants are at a continuously growing risk to overheating exposure inside the premises throughout the warm season of the year. This study investigates the utilization of cooling pad technology as a potential solution to enhance cooling efficiency. Compared to traditional cooling methods, the implementation of cooling pads leads to significant reductions in temperature and enhanced humidity control, while consuming relatively lower amounts of energy. The study contains a comprehensive analysis of the climatic conditions in Latvia, focusing on temperature and humidity variations throughout the year over the last decade in three cities—Riga, Daugavpils and Liepaja, that extensively represent the scope of climatic variations across Latvia, featuring coastal and continental climate patterns. This study aims to evaluate the effectiveness and suitability of cooling pad technology in Nordic climate, focusing on three Latvian cities. The novelty of the study lies in its analysis of cooling pad technology's effectiveness in Nordic climatic conditions in addressing the increasing cooling demand. The paper examines the fundamental principles behind cooling pad technology, its impact on chiller performance, and its ability to optimize the cooling process. The utilization of cooling pad technology as an effective means to enhance cooling efficiency across the building stock to improve occupant comfort level and IEQ is highlighted. The results demonstrate 5.47% COP increase during average summer temperature conditions, and 17.78% COP increase in peak summer temperature conditions after implementation of cooling pads. This study contributes to the existing knowledge on cooling technologies, offering practical recommendations for the implementation of cooling pad systems use in Latvia and across the wider Nordic region, which is experiencing the gradual rise in summer temperature and humidity level.

KEYWORDS

building cooling, temperature rise, cooling pads, overheating, indoor climate

1 Introduction

The global community is experiencing a warming at a magnitude that surpasses any observed fluctuations over the past tens of millions of years (Westerhold et al., 2020). Within the European region, the mean annual average temperature has risen by approximately 1.7°C–1.9°C compared to the pre-industrial era (Ji et al., 2023). Furthermore, the most recent decade spanning from 2013 to 2022 exhibits record-breaking statistics, with all 10 years ranking among the warmest years on record (EEA, 2023).

Over the past decades there has been a strong evidence of a temperature rise across the world that has led to a growing concern of more extreme weather patterns and regular seasonal heat waves globally. As such, building occupants are at a continuously growing risk to overheating exposure inside the premises throughout the summer season (CIBSE, 2017; Laouadi et al., 2020a; Qian et al., 2023). Overheating poses significant risks to building occupants, as prolonged exposure to high temperatures can lead to heat-related illnesses, including heat exhaustion and heat stroke, which can be life-threatening. The physiological impacts of overheating on occupants can result in reduced cognitive performance, decreased productivity, and an increased likelihood of accidents, particularly in work and educational environments (McLeod et al., 2022). Vulnerable groups, such as the elderly, children, and individuals with pre-existing health conditions, are particularly susceptible to the adverse effects of overheating, requiring careful consideration of strategies to mitigate these risks in building design and operation (Murtagh et al., 2019; Laouadi et al., 2020b; Ramallo-González et al., 2020; Attia et al., 2023).

While the Baltic region experiences a cool and temperate climate, the summers are characterized by ever increasing temperature averages and prolonged dry weather conditions with no or very little precipitation, which among other widespread economic challenges (in agricultural and industrial sectors) poses serious concerns for building occupants in terms of achieving comfortable indoor temperatures (Jung et al., 2022; Taylor et al., 2023). The Baltic region, known for its cool and temperate climate, has been experiencing a significant shift in weather patterns in recent years. The summers are becoming hotter, with ever-increasing temperatures, posing challenges for maintaining comfortable indoor conditions for building occupants. As the demand for cooling rises, energy efficiency becomes a crucial consideration, particularly in light of escalating electricity prices (Camacho et al., 2023; Sun et al., 2023; Yagi and Managi, 2023) and the need for sustainable practices (Prozuments et al., 2021).

The increase in summer temperatures in the Baltic region can be attributed to a variety of factors, including the global warming, which encompasses the broader concept of climate change. In line with the advent of higher seasonal temperatures, recent scientific investigations suggest that contemporary buildings face an increased susceptibility to overheating due to their architectural characteristics, including increased glazing surface area (Zou et al., 2023) and enhanced building airtightness levels (Laouadi et al., 2020a; Deshko et al., 2021). Glazed facades and windows compromise the thermal resistance of buildings during both cold and warm seasons. Additionally, window frames, as integral components of the building envelope, contribute to further heat loss (Baiburin et al., 2019), which, in conjunction with glazing, may

account for up to 50% of the total building heat loss (Aburas et al., 2019; Tafakkori and Fattahi, 2021). Comparative analyses of building insulation materials conducted by Kumar et al. and Kapoor et al. (Kapoor et al., 2021; D; Kumar et al., 2020) have demonstrated that structures with higher thermal transmittance exhibit greater cost-effectiveness in regions with increased cooling demands, whereas those with lower thermal transmittance are more economically viable in regions with increased heating requirements. In addition to high temperatures, relative humidity (RH) also plays a vital role in occupants' comfort. High humidity levels can exacerbate the discomfort experienced during hot weather, leading to feelings of stickiness and reduced thermal satisfaction (Williams et al., 2020). Therefore, an ideal cooling solution for the Baltic region should consider both temperature reduction and humidity control (Arundel et al., 1986; Psomas et al., 2021).

Achieving improved building energy efficiency requires a multidisciplinary approach encompassing various interrelated factors such as architectural features, building materials, the insulation quality of the building envelope, HVAC (heating, ventilation, and air conditioning) operation, and occupant behavior (Santos-Herrero et al., 2021). Mechanical ventilation systems serve as effective measures for diluting and removing indoor air contaminants, thereby mitigating health risks associated with inadequate ventilation (Godish, 1996; Seppänen, 1999; Engvall et al., 2005). While natural ventilation remains prevalent in many buildings worldwide in terms of fresh air supply and exchange, significant changes in outdoor environments and human behavior, driven by economic growth and global trends, have led to an increased implementation of mechanical ventilation systems in buildings (L. Zhao and Liu, 2020). Furthermore, to minimize heat loss and moisture accumulation in building structural elements, greater attention has been devoted to achieving building airtightness, which significantly contributes to the cost efficiency and feasibility of integrating mechanical ventilation systems into building infrastructure (Jiang and Chen, 2001; Salehi et al., 2017; Fernández-Agüera et al., 2019). HVAC systems account for approximately 40% of energy consumption in the building sector, and as indoor environmental quality requirements continue to become more stringent, this proportion is expected to rise in the future (Cao et al., 2016; Ana Picallo-Perez et al., 2021; Pan et al., 2021). The carbon optimization plan of the European Union sets forth an ambitious target of reducing carbon dioxide emissions from the building sector by 80% by 2050 compared to 1990 levels (Rootzen, 2012; European Commission, 2019). Reaching this target will require major changes in the design, operation and maintenance of buildings and the efficiency of their integrated heating, cooling and ventilation systems (Bardage, 2017; González-Lezcano, 2023). This leads to a growing interest in exploring alternative cooling technologies that can address these challenges while maintaining energy efficiency (Salata et al., 2022).

One promising technology that has gained attention in recent years is cooling pad technology, commonly used in evaporative cooling systems. Cooling pad technology, when implemented before the condenser unit of a chiller, offers several advantages. The use of cooling pads facilitates enhanced heat transfer and improved cooling efficiency by promoting evaporative cooling mechanisms (Laknizi et al., 2021a). This results in reduced energy consumption and

enhanced operational performance of the chiller system, thereby contributing to overall energy efficiency and cost savings (Malli et al., 2011; Sohani et al., 2017a; Tejero-González and Franco-Salas, 2021a; Laknizi et al., 2021b). By leveraging the principles of evaporative cooling, these pads facilitate the cooling process by utilizing the heat exchange before the condenser coil in the chiller system that occurs when water evaporates (Abdullah et al., 2023; Pacak et al., 2023). This results in a reduction in both temperature and humidity, creating a more comfortable indoor environment (Sreeram et al., 2015; Sohani et al., 2017b). This is particularly important in the context of rising electricity prices, as cooling pads allows for cost savings while ensuring comfortable indoor conditions. Additionally, cooling pads have the potential to enhance sustainability by reducing carbon emissions associated with high-energy cooling systems (Laknizi et al., 2019; Tejero-González and Franco-Salas, 2021a; Kapilan et al., 2023; Ndukwu et al., 2023). Furthermore, cooling pad technology offer flexibility in their application, making them suitable for various climate conditions and settings such as residential, commercial and industrial building stock (Franco et al., 2014; Obando et al., 2020). They can be integrated into existing cooling systems or implemented as standalone units, providing adaptability in different contexts (Jain and Hindoliya, 2011; Malli et al., 2011).

Given the aforementioned challenges posed by increasing summer temperatures in the Baltic region, coupled with the need for energy efficiency and improved comfort, it becomes crucial to explore the potential of cooling pad technology to increase the efficiency of cooling systems and, thus, reduce the energy consumption attributed to the operation of these systems (Tejero-González and Franco-Salas, 2021a).

This study aims to investigate the effectiveness of cooling pads in enhancing cooling efficiency and occupants' comfort in the context of the Baltic climate. By conducting experiments and evaluating the performance of cooling pads under controlled conditions, this study aims to provide valuable insights into the benefits and practical implications of adopting cooling pad technology as a viable solution for the region. In addition, this study examines the challenges posed by rising summer temperatures in the Baltic region by examining the potential of cooling pad technology. By considering the importance of temperature reduction, humidity control, and energy efficiency, this study aims to contribute to the existing knowledge on cooling technologies and provide valuable recommendations for the implementation of cooling pad systems in the Baltic climate.

2 Methodology

2.1 Compliance with local regulatory codes

As the summer outdoor temperatures are steadily rising, and there is a higher frequency of recorded heat wave events across Europe (Baldwin et al., 2019; Ramallo-González et al., 2020; Oliveira et al., 2022; Iacobucci, 2023), the building occupants are at an ever increasing risk to overheating exposure which is already emerging as an existing issue in many buildings where no cooling systems are present. With an advent of higher temperature patterns in the summer, the building cooling requirement will be continuously increasing with respect to cooling energy consumption per floor area.

Reg. No. 359 "Labour Protection Requirements in Workplaces" defines the permissible indoor air parameters within the work spaces based on the assigned category of the work environment (I-III), that employers have to comply with.

The category I work environment is not associated with physical efforts or requires very slight or slight physical efforts; Category II work environment is associated with medium or great physical efforts (for example, permanent lifting and movement of weights (up to 10 kg), welding, metal processing works); Category III work environment is associated with heavy work [for example, permanent lifting and movement of weights (greater than 10 kg)].

2.2 Evaporative cooling technology

In the context of the indoor cooling demand, the analysis of summer climate data provides an insight into the environmental conditions that buildings and occupants face. The rising temperatures and humidity levels highlight the urgency to address the increased cooling demand to maintain comfortable indoor environments while ensuring energy efficiency and sustainability (Tejero-González and Franco-Salas, 2021b; Rahman et al., 2023).

The thermal difference (ΔT) that can be obtained by an evaporative cooling pad system is the saturation efficiency (η):

$$\eta = \frac{T_1 - T_2}{T_1 - T_{wb}} \quad (1)$$

where T_1 is the dry temperature of the entering air ($^{\circ}\text{C}$).

T_2 is the dry temperature of the exiting air ($^{\circ}\text{C}$).

T_{wb} is the wet bulb temperature at entry ($^{\circ}\text{C}$).

If the saturation efficiency of the pad η is known for, the thermal difference produced by the pad (ΔT) can be determined by a following equation:

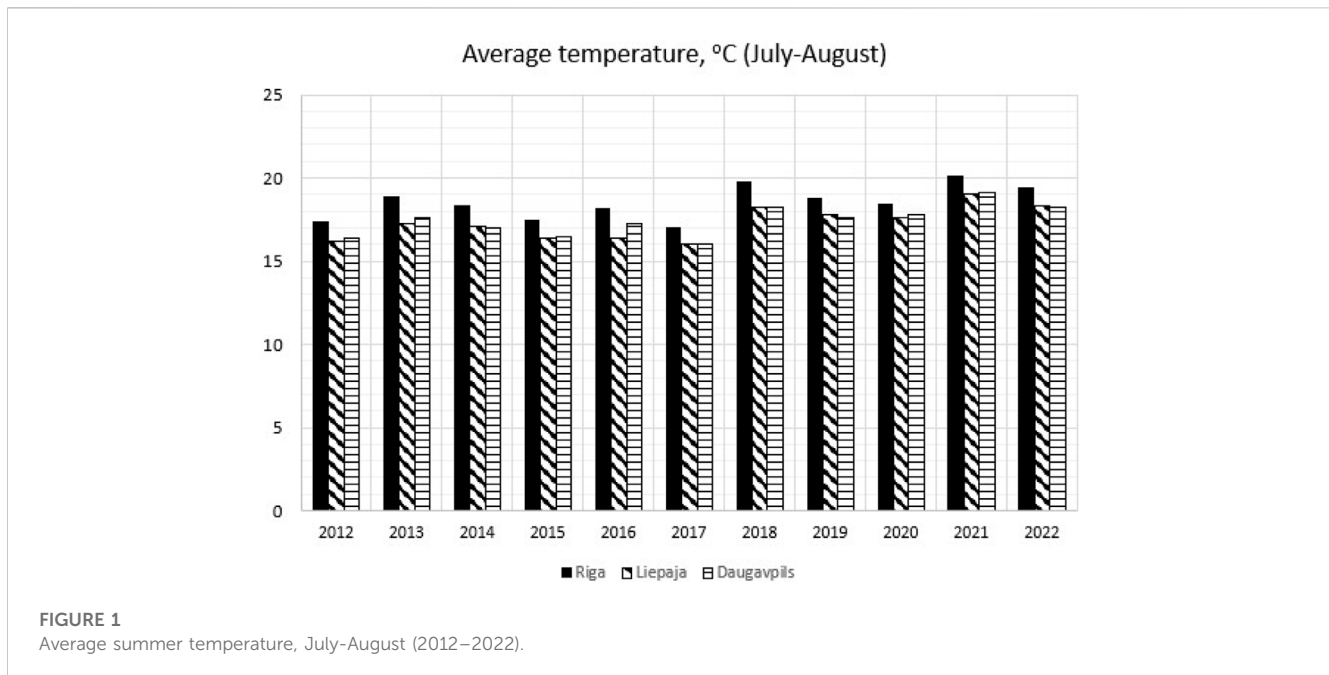
$$\Delta T = T_1 - T_2 = \eta \cdot (T_1 - T_{wb}) \quad (2)$$

The process of air cooling through the evaporation of water is known as adiabatic cooling and is considered an isenthalpic process. Consequently, the ability to cool a stream of air is determined by the difference between the air's dry bulb temperature and the saturation temperature associated with its enthalpy. In practical terms, the saturation temperature is closely approximated by the wet bulb temperature. Therefore, the cooling potential of an air stream can be determined as the difference between the dry bulb temperature and the wet bulb temperature ($T_{dry} - T_{wb}$).

In case of an indirect system the heat transfer from the wetted air mass to the room air supply can be determined by the following equation:

$$Q = m c_p \eta \cdot (T_{dry} - T_{wb}) \quad (3)$$

Eq. 1 and (2) provide a mathematical representation of the evaporative cooling process, allowing to determine the thermal difference (ΔT) achieved by an evaporative cooling pad system. It is important to note that the cooling potential of an air stream depends on factors such as the dry bulb temperature (T_{dry}) and the



wet bulb temperature (T_{wb}). The difference between these two temperatures reflects the extent of cooling that can be achieved in the system. By maintaining a lower wet bulb temperature or increasing the efficiency of the evaporative cooling pad, a greater thermal difference and improved cooling performance can be attained. In the case of an indirect system, where the heat transfer occurs between the wetted air mass and the room air supply, Eq. 3 provides a means to calculate the heat transfer (Q).

Understanding the equations and principles behind evaporative cooling systems enables to optimize system performance for the specific climate conditions. By adjusting factors like air flow rates, pad design, material, and wet bulb temperature control, cooling efficiency can be enhanced to effectively meet the growing indoor cooling demand (Jiansheng et al., 2022; Zhao et al., 2022). Moreover, this optimization not only prioritizes energy efficiency and sustainability but also ensures occupant comfort in the face of rising temperatures and humidity levels in the Latvian climate, as well as the regulatory codes to ensure occupant health and wellbeing.

3 Results

3.1 Summer climate data analysis

The analysis of summer climate data for three Latvian cities—Riga (representing a humid continental climate), Liepaja (representing a coastal climate), and Daugavpils (representing a continental climate). The three cities were selected as they broadly represent the scope of Latvian climatic pattern. The data was derived from the State meteorological weather stations that are deployed to measure outdoor weather conditions. The analyzed climate data reveals an increase in average temperatures and humidity levels over the years, highlighting the increasing average summer temperatures and humidity observed from 2012 to 2022.

3.2 Average summer temperatures

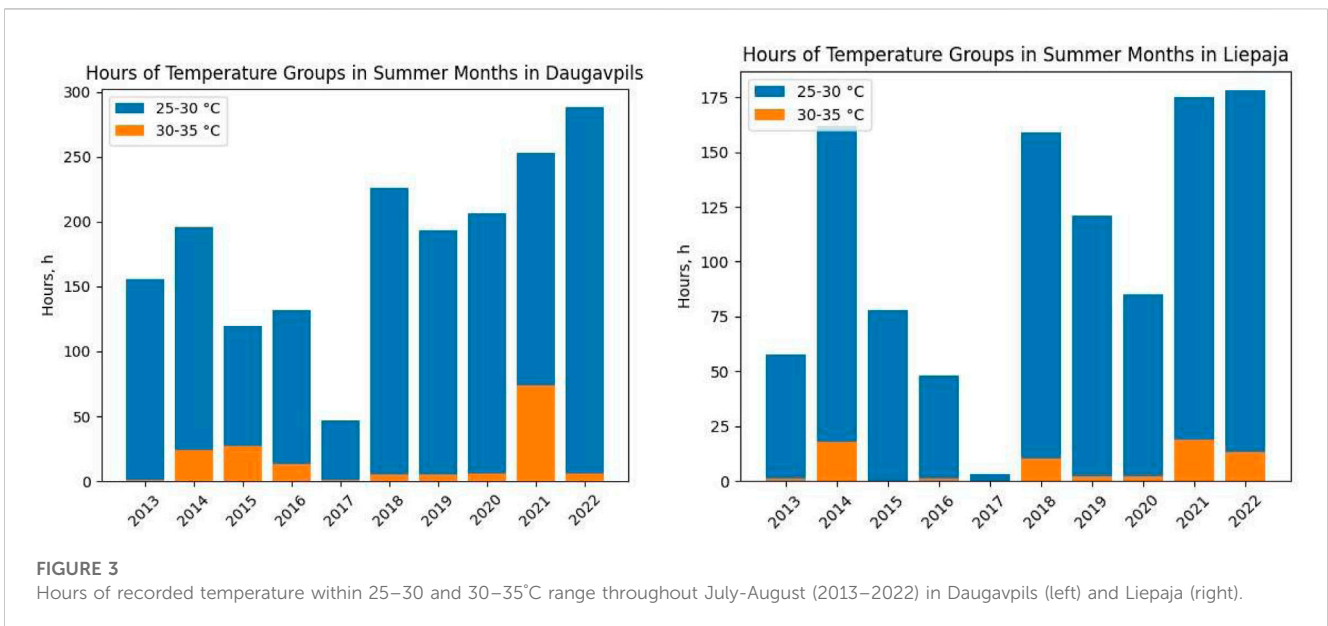
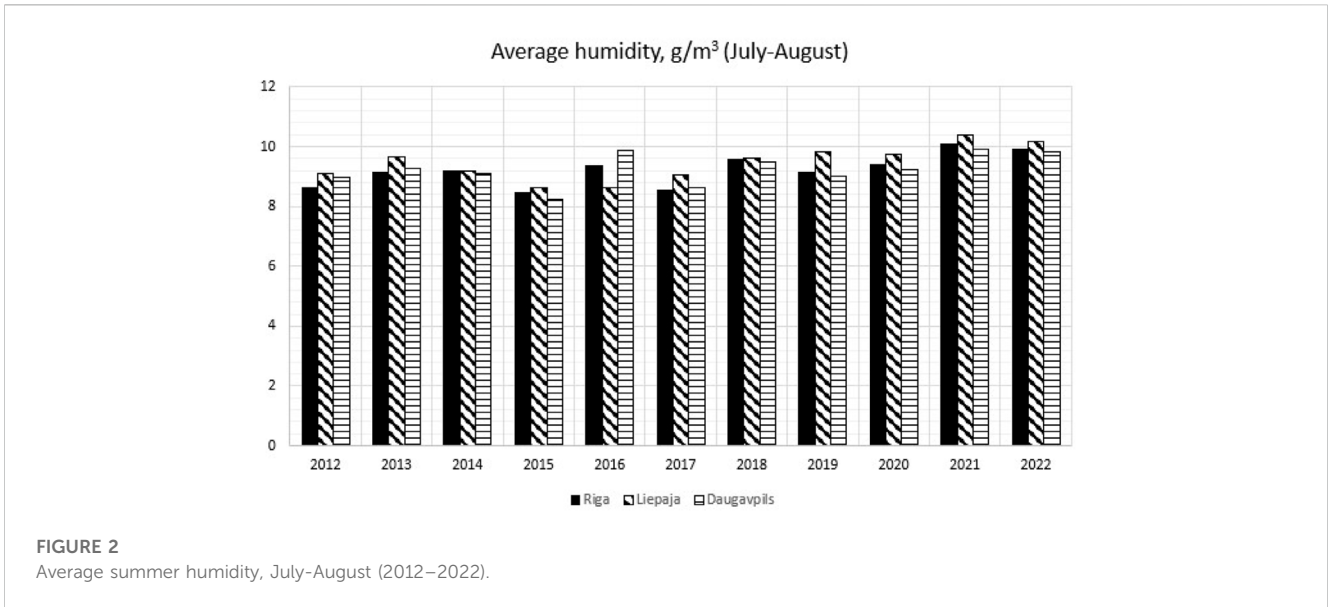
The average summer temperatures in the studied cities demonstrate a clear upward trend, indicative of the warming climate. In Riga, which represents a humid continental climate, the average summer temperature ranged from 17.4°C in 2012 to 19.5°C in 2022. This gradual increase over the analyzed period highlights the rising intensity of heat exposure faced by building occupants during the summer months. Similarly, in Liepaja, which represents a coastal climate, the average summer temperature ranged from 16.2°C to 18.4°C, showing a consistent rise. Daugavpils, with a continental climate, experienced average summer temperatures ranging from 16.4°C to 18.2°C, showcasing a similar dynamic (Figure 1).

The rising temperatures observed in these cities can be attributed to climate change, which is primarily driven by human-induced factors such as greenhouse gas emissions (Gi et al., 2018). As global temperatures rise, the impact on regional climate becomes evident, leading to hotter summers and therefore increased cooling demands (Salata et al., 2022).

3.3 Average summer humidity

The analysis of average summer humidity levels in the studied cities further emphasizes the changing climatic conditions. In Riga, the average summer humidity ranged from 8.6 g/m³ in 2012 to 9.9 g/m³ in 2022, signifying a considerable increase. Liepaja experienced average humidity levels ranging from 9.1 g/m³ to 10.17 g/m³, while Daugavpils witnessed averages ranging from 8.97 g/m³ to 9.83 g/m³ over the analyzed period (Figure 2).

The rising humidity levels pose challenges in maintaining indoor comfort, as high humidity can lead to feelings of stickiness, reduced thermal satisfaction, and the potential for mold growth (Arundel et al., 1986; Hernberg et al., 2014; Attia



et al., 2022). The combination of increasing temperatures and humidity levels underscores the heightened demand for indoor cooling solutions to ensure occupant comfort and wellbeing during the summer season. The need for effective cooling systems becomes more critical as the frequency and intensity of heatwaves continue to rise (Oliveira et al., 2022; Iacobucci, 2023).

3.4 Hourly-measured temperature analysis in the context of heat-wave occurrence

The climate data analysis for the three analyzed cities revealed that the frequency of heat-wave occurrence is increasing every summer, posing significant challenges to maintaining comfortable indoor environments, and necessitating effective cooling solutions.

The analysis of hourly-measured temperature data to investigate the occurrence of heat waves over the past decade was conducted for the three cities. The increasing frequency of temperature recordings exceeding 25°C (deemed as heat-wave threshold) was examined in Daugavpils (continental climate) and Liepaja (coastal climate).

Analysis of the hourly-measured temperature data reveals ratehr similar pattern in both cities (Figure 3.). In Daugavpils, there has been a steady rise in the number of hourly temperature recordings exceeding 25°C since 2019. This indicates a significant increase in the occurrence of higher temperature episodes, potentially leading to prolonged heat waves. On the other hand, Liepaja exhibits fluctuating trends in the hourly count of temperature recordings above 25°C over the years. However, recent observations from 2021 to 2022 demonstrate the two highest count years on record (with almost 175 of recorded temperature hours above 25°C) and

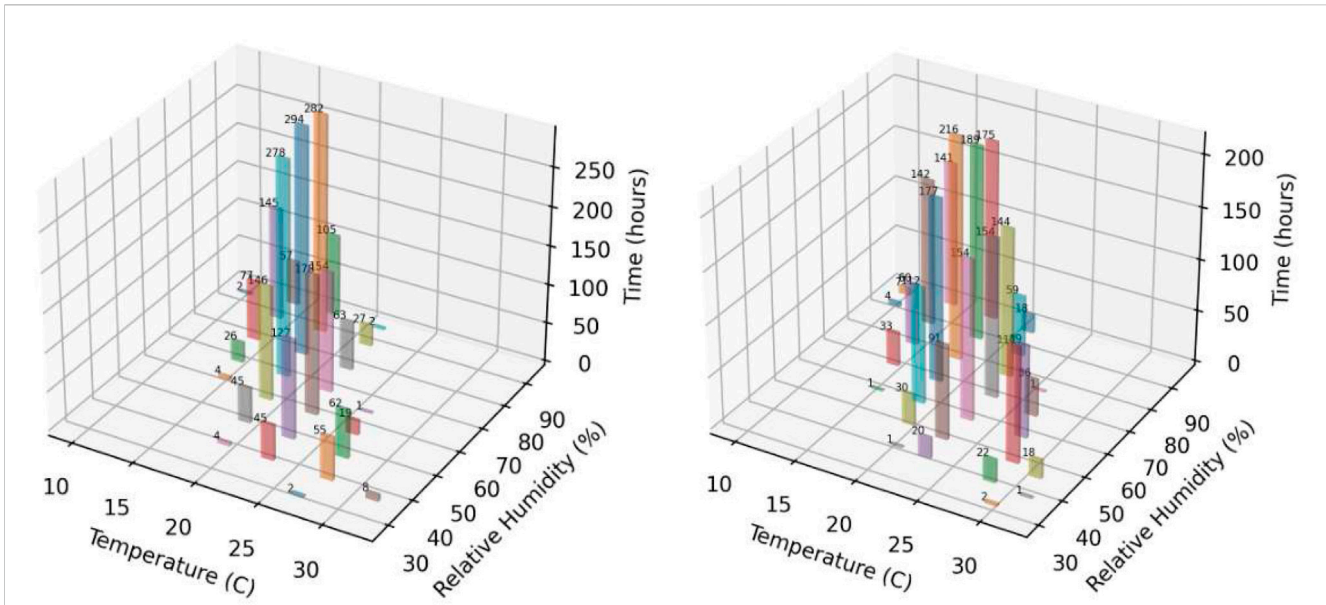


FIGURE 4 Comparative summary of hourly temperature recordings in Riga in 2013 (left) and 2022 (right).

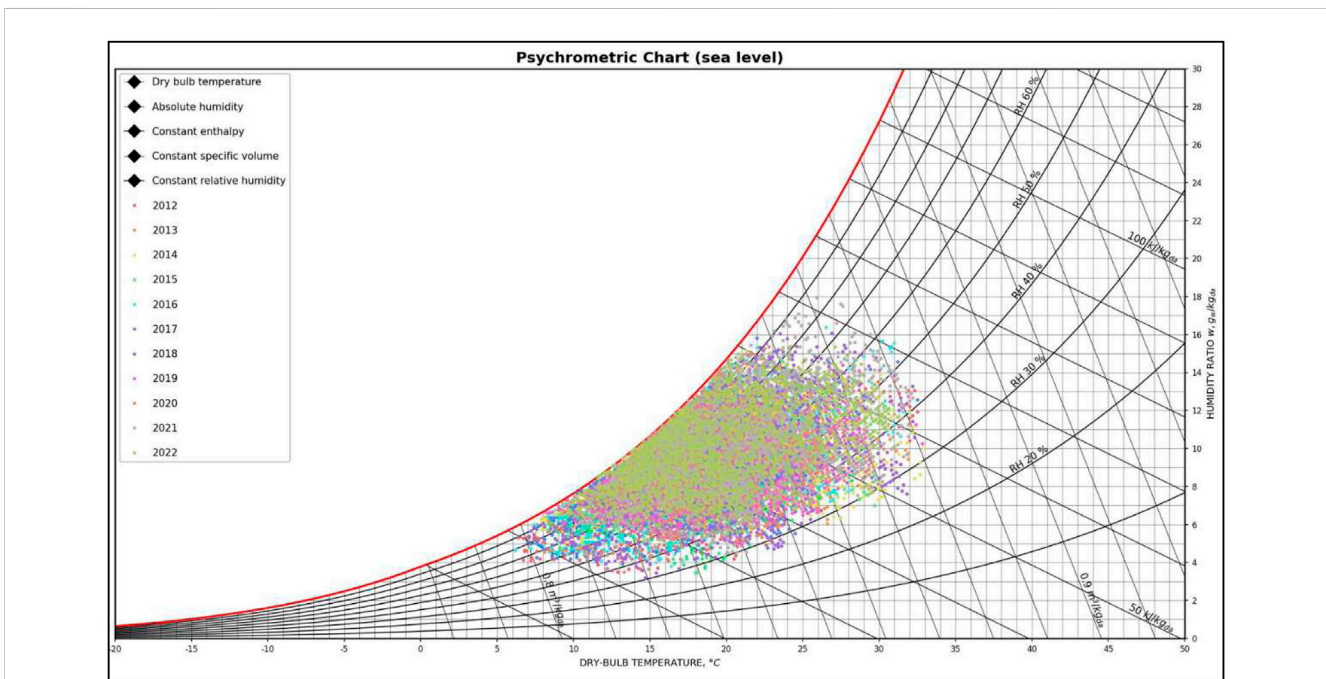


FIGURE 5 Psychrometric chart of hourly temperature and RH recordings in Riga (2012–2022).

suggest a consistent upward trend, indicating a growing occurrence of elevated temperatures and the potential for more frequent heat waves in the future (Figure 3).

The graphs below demonstrate the hourly recorded temperature variations throughout the summer months (July–August) in Riga in 2013 (left) and 2022 (right), (Figure 4). The bar diagrams show that the occurrence of temperature recordings in 2022 exceeding 25°C have increased substantially compared to 2013. In the 2022,

280 recordings were detected of hourly temperature exceeding 25°C, while in 2013 this figure was much lower—147 h, suggesting more frequent heat wave occurrences and thus higher indoor overheating risk.

The psychrometric chart below (Figure 5.) demonstrates the hourly summer temperature recordings over the last decade (2012–2022) which shows that while the average temperature and relative humidity values are concentrated within fairly wide range,

the occurrence of recorded temperature over 25°C and RH over 65% is rather frequent, suggesting that building occupants are at risk of compromised indoor environmental quality if buildings are not equipped with proper cooling systems, or architectural passive design solutions to mitigate heat wave effects.

Given the increasing occurrence of high temperatures and the rising risk of indoor overheating, cooling pad technology emerges as a promising solution to mitigate these challenges. Cooling pad technology offers several advantages in the context of the increasingly warm climate, ensuring occupant comfort and wellbeing during the period of increased outdoor temperature and humidity levels.

The result analysis of hourly-measured temperature data highlights the increasing occurrence of high temperatures over the past decade, particularly exceeding 25°C. Daugavpils exhibits a consistent rise in temperature recordings above this threshold since 2019, while Liepaja and Riga shows fluctuating trends that have recently indicated a steady increase in summer temperature and humidity. In light of these changing climate conditions, cooling pad technology presents an effective solution to mitigate indoor overheating. By implementing cooling pads, an improved indoor comfort, reduced heat-related risks, and increased resilience to heat-waves can be attained.

The analyzed climate data show that throughout the summer months favourable conditions develop in the three examined cities in Latvia to employ evaporative cooling, as this technology is generally more efficient in conditions when the temperature is above 25°C, and RH levels between 40%–70%. RH levels below 70% are generally considered suitable for evaporative cooling—the lower the humidity, the better the cooling effect (Laknizi et al., 2019; Ndukwu et al., 2023; Rahman et al., 2023).

3.5 Chiller COP analysis

The chiller should run at its highest COP to produce the appropriate cooling capacity with a minimum amount of power consumption. Cooling loads, however, usually have a seasonal behaviour (especially in the Baltic climate region) and, in some buildings cooling loads, however, represent an important percentage of the overall energy demand (up to 44%) (Borodinecs et al., 2007; Gulotta et al., 2021; Krumins et al., 2022). Lower outdoor temperatures result in low cooling loads (little use of HVAC systems), so air-cooled chillers are more appropriate, since condensing refrigerant using cool outdoor air is quite efficient. In contrast, higher temperatures entail high cooling loads (strong use of HVAC systems) and, therefore, water-cooled chillers are more efficient because this type of chillers have better performance and higher nominal capacity (so a smaller number of chillers is required to cover high cooling loads (Chen Q. M. K. J. et al., 2022; Kumar et al., 2023)).

Four reference air cooled chiller units were examined to determine the feasibility of adiabatic cooling pad use in air-cooled chillers in Latvian climate conditions. In order to determine the potential of cooling pad technology, the climate dataset of the last recorded summer (2022) in Riga was selected, which was based on average and peak summer temperature and RH data.

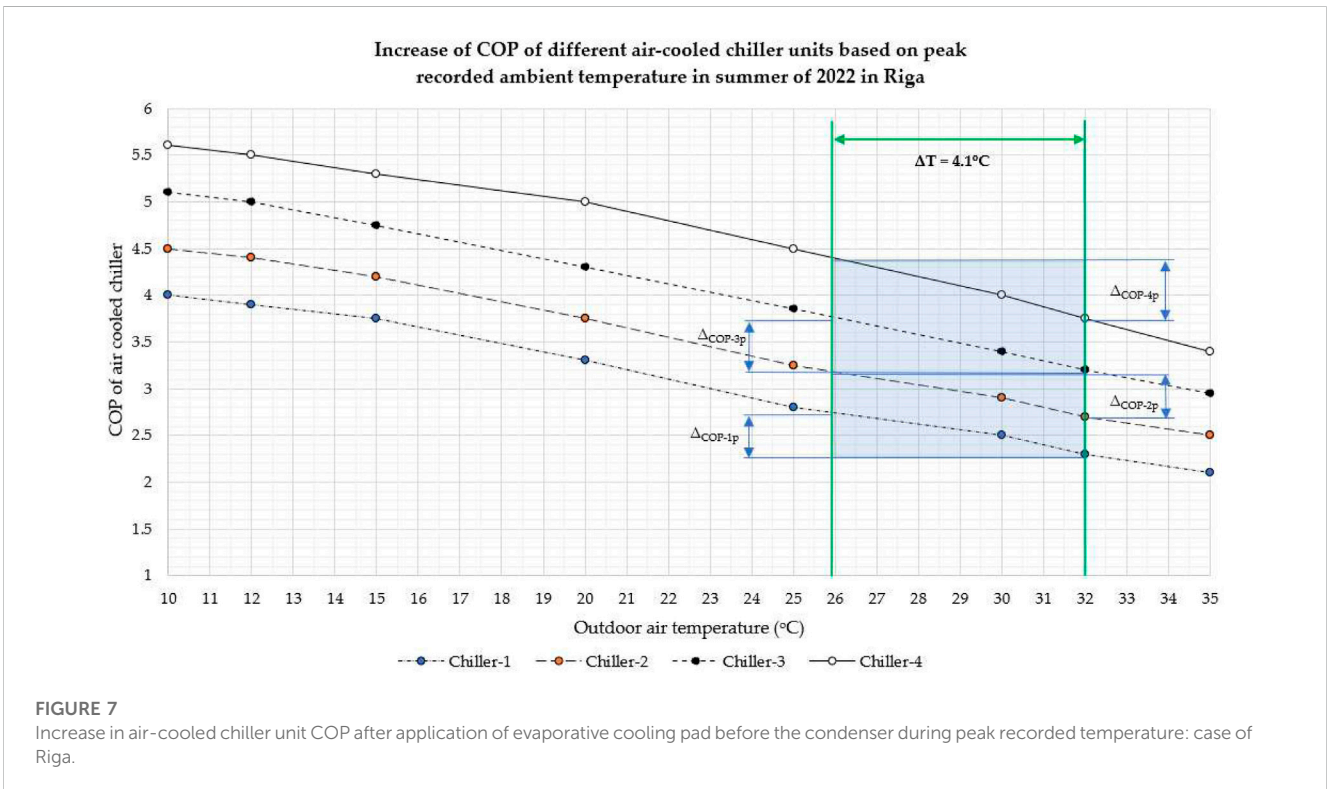
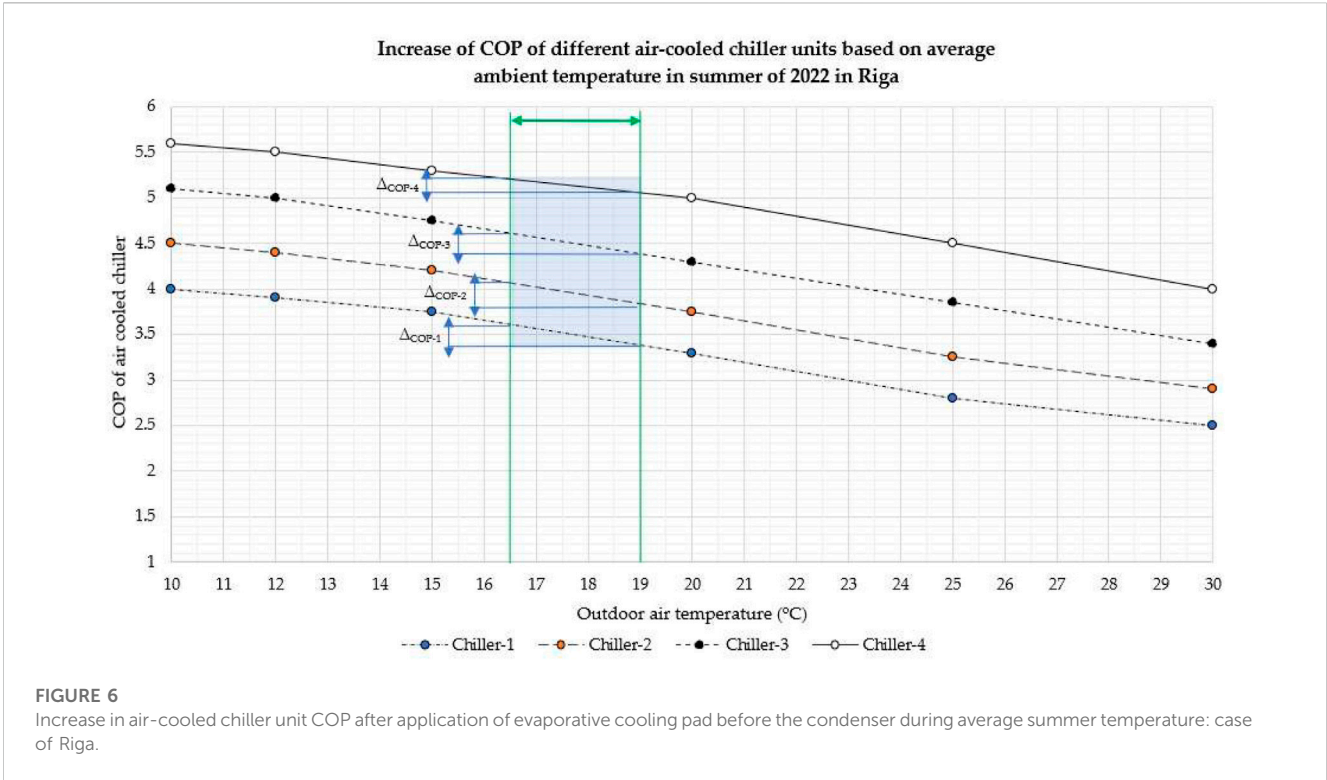
To understand the operation of each chiller with regard to a chiller load ratio or outdoor temperature, which are variables that affect the efficiency of cooling production systems, COP relation to ambient outdoor temperature graph was plotted. If the most recently recorded average summer temperatures are taken into consideration, a preliminary plot can be generated demonstrating the impact of cooling pads on air-cooled chiller performance. Taking the average air parameters in Riga over the summer of 2022 ($t = 19^\circ\text{C}$ and $\text{RH} = 72\%$), as well as the average decrease in the inlet temperature by 2.5°C to after saturation to 90% (Figure 6), the COP value of each unit increases by a certain factor. Figure 6 demonstrates the COP increase after cooling pads application before the air-cooled chiller's condenser unit for four selected chiller units.

According to Figure 4 the peak temperature (32°C) in 2022 in Riga was recorded for 18 total hours with relative humidity around 55%. During adiabatic cooling process via cooling pads, the air mass will be saturated from RH 55% to RH 90%, resulting in temperature decrease to 25.9°C. Figure 7 shows the COP increase for the selected air cooled chiller units in an event of a peak temperature.

Table 1 compares the COP of the chillers during average and peak summer temperatures in Riga in 2022. $\Delta\text{COP}\%$ column shows the percentage increase in COP from due to the temperature decrease after cooling pad employment. It indicates the percentage improvement in efficiency for each chiller. During peak summer temperatures, the COP values are lower, as chillers are less efficient in hotter conditions. While the COP increases very slightly during the average temperature conditions (3.17%–5.47%), at peak conditions, the chiller COP increase is rather substantial (14.29%–17.78%), which implies that during prolonged hot weather conditions ($T > 25^\circ\text{C}$) the use of adiabatic cooling pads may result in considerable energy savings attributed to chiller operation.

4 Discussion

The increasing occurrence of heat waves, as evidenced by the analysis of hourly-measured temperature data, necessitates effective strategies to mitigate the impact of extreme heat on indoor environments. In the context of the increasingly warm climate in across the examined cities in Latvia, passive design solutions may offer promising approaches to mitigate the effects of heat waves and maintain comfortable indoor conditions. Therefore, the integration of architectural passive design solutions along with the highly efficient cooling pad technology, may result in a high combined effectiveness. Incorporating shading devices such as overhangs, louvers, or external blinds can effectively reduce solar heat gain during heat waves (Nikoofard et al., 2011). Designing buildings with proper cross-ventilation and operable windows allows for the influx of fresh air during cooler periods, promoting natural cooling and reducing reliance on mechanical cooling systems (Liu et al., 2023). Optimizing building orientation to minimize direct Sun exposure on the east and west facades can significantly reduce heat gain, while maximizing natural daylighting (De la Paz Pérez et al., 2023). Incorporating high thermal mass materials like concrete or stone into the building structure can help absorb and store excess heat during the day and release it during cooler periods, regulating indoor temperatures and reducing the need for active cooling (Kuczyński



and Staszczuk, 2020; Lu et al., 2021). Implementing proper insulation in walls, roofs, and floors helps reduce heat transfer and minimize heat gain during heat waves. It provides a thermal barrier, preventing excessive heat penetration into the building

(Deng et al., 2019; Shan et al., 2019). Opting for cool roofs that reflect sunlight rather than absorbing, can significantly reduce heat absorption and minimize the urban heat island effect. Cool roofs have higher solar reflectance and thermal emittance properties, as

TABLE 1 Indoor parameters during warm period of the year in accordance with Republic of Latvia Cab. Reg. No. 359 “Labour Protection Requirements in Workplaces”.

Parameter			
Work category	air temp. (°C)	RH (%)	air movement (m/s)
I	20.0–28.0	30–70	0.05–0.15
II	16.0–27.0	30–70	0.1–0.4
III	15.0–26.0	30–70	0.2–0.5

TABLE 2 COP dynamic in the respective reference chiller units.

	Chiller-1	Chiller-2	Chiller-3	Chiller-4
COP ₁	3.48	3.84	4.4	5.04
COP ₂	3.62	4.05	4.62	5.2
ΔCOP	0.14	0.21	0.22	0.16
ΔCOP _%	4.02%	5.47%	5.00%	3.17%
COP _{1-peak}	2.38	2.7	3.2	3.75
COP _{2-peak}	2.72	3.18	3.74	4.4
ΔCOP _{peak}	0.34	0.48	0.54	0.65
ΔCOP _{%peak}	14.29%	17.78%	16.88%	17.33%

well as a capability to significantly raise roof’s albedo (by 60%–65%) (Lu et al., 2023), saving up to 8% on energy demand in cool, temperate climates (Bamdad, 2023). Incorporating green spaces, trees, and vegetation around buildings can help create shading, reduce ambient air temperatures, and improve outdoor microclimates. This natural landscaping also enhances air quality and provides a visually pleasing environment. Utilizing high-performance glazing with low solar heat gain coefficients (SHGC) and proper shading strategies can minimize heat transfer through windows while allowing for daylighting and views (Pereira et al., 2022; Araújo et al., 2023). Utilizing passive solar design principles, such as strategically locating windows and utilizing thermal mass, can optimize solar heat gain during cooler periods while minimizing overheating during heat waves (Borodinecs et al., 2012; Albayyaa et al., 2019). Incorporating reflective surfaces, such as light-colored exterior finishes or pavement, can help reduce heat absorption and lower surface temperatures, mitigating the urban heat island effect (El-Hattab et al., 2018; Aboelata and Sodoudi, 2019).

By incorporating these passive design solutions, buildings can effectively mitigate the effects of heat waves, reduce reliance on mechanical cooling, and provide comfortable and sustainable indoor environments. While, due to increasing summer temperature, mechanical cooling systems are the necessity to ensure healthy indoor climate, consideration of passive solutions may play a key role in reducing the energy use of the mechanical cooling equipment. The passive design solutions, in conjunction with cooling pad technology, can effectively mitigate the effects of heat waves and their impact on building occupants, ensuring improved indoor comfort, reduced energy consumption, and

enhanced resilience to rising temperatures. The combined approach of passive design and cooling pad technology demonstrates the potential for sustainable and energy-efficient solutions to address the challenges of indoor overheating in the face of increasing heat wave occurrences (Yew et al., 2018; Vaseghi et al., 2020; Zavrl et al., 2022; Mayrhofer et al., 2023a).

The analysis of hourly-measured temperature data in Latvia highlights the increasing summer temperatures and the consequent higher demand for cooling, as previously discussed. In addressing these challenges, the findings from study (Kousar et al. (2021) offer valuable insights on optimizing the operation of evaporative cooling systems, such as cooling pads, in mitigating indoor overheating during heatwaves. The study highlights the importance of factors like air face velocity, pad thickness, and pad type (material and configuration), that can effectively increase the performance of the cooling pad. The influence of pad thickness on the cooling capacity and energy efficiency (COP) is complex, as larger thicknesses can enhance temperature drop and cooling capacity but also increase pressure drop and fan requirements (Malli et al., 2011; Tejero-González and Franco-Salas, 2021a).

The study conducted by Abdullah et al. (2023) provide valuable insights into the energy-saving potential and viability of different enhanced evaporative cooling systems compared to conventional cooling methods, facilitating the discussion on cooling pad efficacy in Nordic regions. These findings align with the previously discussed climate data in Latvia, indicating the increasing demand for cooling solutions. Enhanced evaporative cooling systems offer a promising alternative, addressing challenges associated with high humidity and offering energy efficiency improvements (Tejero-González and Franco-Salas, 2021a; Abdullah et al., 2023). The impact of various enhanced evaporative cooling technologies on total power consumption is highlighted, emphasizing the need for selecting appropriate technology for specific applications and different climate zones. These systems demonstrate the potential to enhance energy efficiency, aligning with sustainable development goals related to energy efficiency, climate action, and sustainable consumption and production. The potential of evaporative cooling systems as alternatives to conventional cooling methods is very high. The combination of effective evaporative cooling systems with separate dehumidification systems has demonstrated improved performance and the potential to achieve thermal comfort.

The increasing occurrence of high temperatures and heat wave events across the world require proactive measures to mitigate

indoor overheating risks. By implementing cooling pad technology alongside architectural passive design solutions, optimal indoor comfort, reduced heat-related risks, and enhanced energy efficiency can be achieved. These findings highlight the importance of adopting innovative cooling strategies to ensure sustainable and resilient building environments in the face of changing climatic conditions. The integration of architectural passive design solutions, such as shading devices, natural ventilation, insulation, cool roofs, green spaces, and reflective surfaces, complements the efficacy of cooling pad technology in mitigating the effects of heat waves (Schnieders et al., 2015; Kohler et al., 2017; Harkouss et al., 2018). Passive design strategies, when integrated with cooling pad technology, create a symbiotic relationship that optimizes indoor comfort and energy efficiency. Natural ventilation enhances airflow and evaporative cooling, while shading devices and cool roofs mitigate solar heat gain, collectively reinforcing cooling pads' temperature-reducing effects. As such, one review study suggested that building cooling demand could be reduced by up to 82% in combined passive/active cooling scenarios. Furthermore, ambitious combined (active + passive) building cooling strategies could reduce cooling demand by 68%–73%, resulting in a stagnation of the energy demand for space cooling between 2030 and 2050 (Mayrhofer et al., 2023b). This holistic approach ensures a balanced and sustainable solution to address indoor overheating and improve occupant wellbeing, which is in line with other literature investigating a combination of active and passive cooling strategies. (Schnieders et al., 2015; Chen Y. et al., 2022; Yang et al., 2022; González-Lezcano, 2023).

Further advancements, such as hybrid system development and simplification of design, are needed to enhance the viability and practicality of these alternative cooling systems. These efforts will contribute to providing environmentally friendly, economically viable, and energy-efficient alternatives to traditional vapor compression systems in response to the increasing demand for cooling in buildings. Also, the evaluation of air psychrometric conditions, including both dry bulb temperature and air humidity, is crucial for accurate system performance assessment. Neglecting air humidity can lead to incomplete analysis. Optimization of water flow rates should consider factors such as air velocity, psychrometric conditions, pad material, and salt deposition risks (Fouda and Melikyan, 2011; Sellami et al., 2019a; Sellami et al., 2019b; Lakhnizi et al., 2021a).

5 Conclusion

The current study comprehensively evaluated the applicability of cooling pad technology within Nordic climatic conditions through analysis and comparison of climate conditions in three Latvian cities. The analysis of climate data for three Latvian cities, Riga, Liepaja, and Daugavpils, demonstrated an increasing pattern in average summer temperatures and humidity levels over the past decade. These findings highlight the growing challenges posed by rising temperatures and the need to address the rising demand for mechanical cooling in buildings. In this context, cooling pad technology is viewed as a promising solution to effectively mitigate indoor overheating and maintain comfortable indoor

environments during periods of high outdoor temperatures and humidity.

The hourly-measured temperature data analysis demonstrates a significant occurrence of temperature recordings exceeding 25°C, indicating the frequent occurrence of heat wave events. This underscores the increased risk of compromised indoor environmental quality for building occupants in the absence of proper cooling systems. The psychrometric chart analysis for Riga revealed the prevalence of temperature over 25°C and relative humidity over 65%, facilitating the importance of implementing adequate cooling systems or passive design solutions to mitigate the effects of heat waves. The findings of this study indicate that integration of cooling pad before the condenser unit will result in an increase of chiller COP (5.47%) during average summer temperature conditions, and a substantial increase in COP (17.78%) during peak summer temperature conditions (Table 2).

This study underscores the significance of innovative and efficient cooling strategies in meeting the challenges of increasing global cooling demand. In addition to the findings, it is imperative to consider policy frameworks that incentivize the adoption of these solutions and address potential barriers such as upfront costs, regulatory alignment, and technology scalability to facilitate their widespread implementation, thereby fostering resilient and sustainable building environments. Regulatory building codes are an effective policy measure for reducing energy consumption in buildings. Many countries have been adopting more stringent building energy codes over time, which have resulted in more efficient building stock in those countries.

However, further research and development are required to optimize these systems for different climates. Incorporating long-term field studies in representative locations across Nordic countries could provide valuable insights into the technology's real-world performance and adaptability. Additionally, assessing the economic feasibility and scalability of implementing cooling pad systems on a larger scale, while considering regional regulations and incentives, would contribute to a holistic understanding of their suitability and potential benefits in Nordic climates.

As the global climate change results in more intense and frequent heat waves across the world, the imperative to employ efficient cooling solutions in buildings becomes very topical. With a collective commitment to innovative and efficient cooling solutions, stakeholders can shape a future where resilient, energy-efficient buildings redefine humans' relationship with the environment and improve occupant wellbeing.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

AP: Writing–review and editing, Data curation, Formal Analysis, Methodology, Writing–original draft. AB:

Conceptualization, Data curation, Funding acquisition, Project administration, Resources, Supervision, Validation, Writing–review and editing. KL: Investigation, Methodology, Resources, Writing–review and editing. AP: Resources, Software, Visualization, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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