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Summertime overheating in apartments with glazed balconies: a Finnish study

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ABSTRACT

Apartment overheating is increasingly an issue due to rising global temperatures, likely exceeding 2°C in Finland over the next few decades. This overlooked issue in Nordic housing is exacerbated by building characteristics ill-suited to keeping cool indoor environments, such as lack of solar shading or large operable windows and the use of glazed balconies. However, there is limited empirical evidence on summertime overheating in glazed-balcony apartments in the Nordic climate. To bridge this gap, this exploratory case-study investigation assessed summertime overheating in 10 apartments with glazed balconies in Finland during the summer of 2025 and investigated how occupant behaviour affected overheating risk. *In-situ* temperature measurements were collected in the balcony and apartment spaces alongside semi-structured interviews and balcony-use diaries. Findings highlighted that apartments built to the current Finnish building code failed to meet overheating criteria, and the presence of a glazed balcony was one of several variables linked to apartment overheating. Glazed balconies became uncomfortably hot for extended periods, limiting the intended year-round usability. Moreover, the balcony door was often the apartment's sole purge ventilation route and was found to be ineffective. These findings are increasingly relevant internationally as glazed balcony solutions are gaining adoption in other contexts.

PRACTICE RELEVANCE

There is a pressing need to implement overheating mitigation strategies for glazed balconies, as well as the apartment more generally, to reduce associated risks. Designers and manufacturers must provide robust balcony-glazing solutions with proven operability that support pet-safe intensive ventilation, shading, furniture placement and everyday usability. Apartment window systems outside of the glazed balcony should also enable large and safe openings for effective natural ventilation. Indirect factors to be considered include: (1) updating regulatory climate datasets to consider current and future climate scenarios; (2) the balcony glazing should systematically be drawn with 'glazing fully open' as the default state during design ensuring usability in this condition; and (3) occupant behaviour should be supported through explicit guidance, including recommending to fully open balcony glazing during warm periods.

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1. INTRODUCTION

It is now undeniable that annual average global mean near-surface temperature will reach and exceed 1.5°C warming in the upcoming years (WMO 2025). In Northern Europe and Finland, characterised by cold winters and cool summers (FMI n.d.-a), this will translate into above-average precipitation and intensified temperature increases (WMO 2025). Consistent with these projections, Ruosteenoja & Jylha (2022) predict that warming will continue in Finland over the next few decades and will most likely exceed 2°C.

These changing environmental conditions are likely to pose challenges related to building overheating (*i.e.* indoor temperatures exceeding comfortable thresholds), thereby affecting populations' health and wellbeing and contributing to increased mortality and inequities (Ebi *et al.* 2021). Perceived summertime overheating is reported across Europe; however, it remains overlooked in Northern Europe and may be exacerbated by building characteristics ill-suited to keeping cool indoor environments. In Finland, the proportion of the population living in dwellings that are not comfortably cool during summer is surprisingly similar to that in Spain or Italy and higher than in France (Thomson *et al.* 2019).

Several studies in Finland report increased overheating risk in apartments (Farahani *et al.* 2024b), while also highlighting the lack of consistent measured data to assess room-level indoor temperatures during heatwaves in cold climates (Kravchenko *et al.* 2026). In Finland, and increasingly internationally (Coelho Pagel *et al.* 2019), a common housing feature is the addition of glazed balconies that span the facade and form a double-skin layer around apartment buildings (Jegard *et al.* 2024). This is motivated by usability, noise reduction and energy performance benefits. More than three-quarters of apartment balconies constructed by 2010 in Finland were estimated to be glazed (Hilliaho 2017), a solution that has since become standard in new apartment construction (K. Hilliaho, personal communication, 28 March 2024), making it a long-established context that warrants the evaluation of glazed balconies. While previous research suggests glazed balconies may negatively influence indoor thermal comfort in summer (Heikkilä 1996; Hilliaho 2017; Jegard *et al.* 2024, 2026), evidence associating glazed balconies with indoor overheating has only emerged recently (Bhattacharjee *et al.* 2023; Jegard *et al.* 2024; Kravchenko *et al.* 2026; Ribeiro *et al.* 2020). For the balcony space itself, overheating is a major barrier to use (Jegard *et al.* 2024), and projected temperature increases are likely to intensify this problem unless addressed. At the time of writing, no study existed of *in-situ* monitoring of summertime temperatures in Finnish glazed balconies, nor of the adjacent apartments in Nordic contexts. This knowledge gap is particularly relevant for more recent residential construction, where improved insulation and airtightness may increase susceptibility to overheating during summer (Sukanen *et al.* 2023). Moreover, limited empirical evidence exists on how occupant habits and behaviour interact with glazed balcony characteristics to influence overheating outcomes. To address this gap, this paper undertakes exploratory case-study research to investigate summertime overheating in 10 apartments with glazed balconies in Finland during the summer of 2025, and how certain design and balcony characteristics and occupant behaviour may affect overheating outcomes.

The paper is structured as follows. The research background is introduced, followed by the research methods, presentation and discussion of the results, and outlining key findings and final conclusions.

1.1 BACKGROUND

1.1.1 Defining summertime overheating in Finland and current evidence

The Finnish Meteorological Institute (FMI) describes three heat warning thresholds (FMI n.d.-b): (1) a hot day (> 27°C maximum; 20°C mean); (2) a very hot day (> 30°C maximum; 24°C mean); and (3) an extremely hot day (> 35°C maximum; 28°C mean). Heatwaves are defined as a period of four or more consecutive hot days (Farahani *et al.* 2024a). Summertime predictions for Finland under the RCP4.5 scenario—a moderate climate scenario with ~2°C warming—show more hot and very hot days, longer heatwaves, and at least one extremely hot day per summer (Kim *et al.* 2018).

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In Finland, newly built apartments need to comply with summer-season indoor temperature criteria defined in the Finnish building code, intended to ensure thermal comfort and mitigate overheating risk. For residential buildings, recommended design temperatures are 23 ± 1°C (Ministry of the Environment, Department of the Built Environment 2010). Room temperatures should not exceed 27°C for more than 150 degree-hours (°C h) between 1 June and 31 August, where degree-hours represent the intensity of heat exposure (cumulative magnitude and duration) above the threshold (Ministry of the Environment, Department of the Built Environment 2017). Additionally, there is a maximum indoor temperature limit of 32°C required for residential buildings and 30°C for elderly care homes (Ministry of Social Affairs and Health 2015). The requirements can be achieved through active or passive design solutions, including internal shading although dependant on user behaviour. Meanwhile, the legislation sets out that:

> opening of openable structures in the building envelope (*e.g.* ventilation windows, windows or balcony doors) must not be taken into account as a ventilation efficiency measure.
>
> (Liljeström & Hurme 2012: 10; authors' translation)

These requirements have been shown to lower overheating risk in studies (Farahani *et al.* 2024b). However, calculations are based on the test reference year 2012 (TRY2012), which is unlikely to be representative of recent or near-future conditions given rapid climate change. In fact, newly built projects are already failing to meet the requirements for current summer temperatures, highlighting the need to incorporate more recent future climate projections (Velashjerdi Farahani *et al.* 2024). While the FMI has developed future test years (2030, 2050 and 2100), these are not yet incorporated into Finland's building code.

Recent studies have highlighted increasing summertime overheating risks in apartment buildings in Northern Europe (*e.g.* Bhattacharjee *et al.* 2023; Elsayed *et al.* 2024; Farahani *et al.* 2024b; Kravchenko *et al.* 2026). Smaller apartments face an even higher risk (Farahani *et al.* 2024b), which is concerning given their prevalence in new Finnish housing (Pelsmakers *et al.* 2022). In Pirkanmaa (subarctic climate), a field study of five apartments without balconies reported significant summertime overheating, specifically in apartments with limited opportunities for purge ventilation (Elsayed *et al.* 2024). Similarly, in Helsinki (humid continental climate), field measurements across 6000 apartments revealed overheating during summer and significant overheating during a hot summer, particularly in older apartments (Farahani *et al.* 2024b).

Typically, in Northern Europe, residential buildings have been designed to optimise winter heating demand rather than meet increasing summer cooling needs, which are projected to increase significantly (Tognon *et al.* 2026). This may jeopardise Finland's goal of carbon neutrality by 2035, increase summer electricity demand and exacerbate energy-related inequalities (Taylor *et al.* 2023; Thomson *et al.* 2019). Prior simulation studies indicate the potential of passive measures and combining passive and active solutions in balancing heating and cooling demand (Sukanen *et al.* 2023; Tognon *et al.* 2026). In Finnish apartments, enabling natural ventilation through openable windows can significantly reduce overheating risks based on simulation studies (Kravchenko *et al.* 2026; Sukanen *et al.* 2023). Night-time ventilation can be more effective than external or internal shading, provided that diurnal temperature variations are sufficiently large to make passive night-time cooling an effective strategy (Sukanen *et al.* 2023), while cross-ventilation has been shown to be the most efficient natural ventilation type (Jiang *et al.* 2023). Other building features such as orientation and characteristics of the urban micro-environment (*e.g.* building density, greenery, solar radiation levels, *etc.*) are also acknowledged for their influence on the indoor climate and overheating risk (Kravchenko *et al.* 2026).

1.1.2 Glazed balcony implications

Glazed balconies are known to create a greenhouse effect (Hilliaho 2017); however, because these in-between spaces are unaffected by building regulations, they have been overlooked when assessing impacts on apartment indoor conditions. In Finland, summertime thermal discomfort associated with glazed balconies has been preliminarily studied (Heikkilä 1996;

Hilliaho 2017), but subsequent research remains limited. Increasingly, other studies suggest links between glazed balconies and indoor overheating (Bhattacharjee *et al.* 2023; Jegard *et al.* 2024; Kravchenko *et al.* 2026; Ribeiro *et al.* 2020), highlighting consequences for indoor environment quality, energy use, usability and residents' wellbeing. However, these studies largely lack field measurements. Kravchenko *et al.* (2026) find that fully opening balcony windows for additional ventilation significantly reduce indoor temperatures, while closed or partially opened glazing exacerbate overheating. In modelling for energy regulation compliance, windows must be assumed to be closed to account for a worst-case scenario for occupant behaviour, and the opposite assumption is made for balcony glazing where calculation guidance specifies that 'openable balcony glazing can be assumed fully open' (Liljeström & Hurme 2012: tab. 3: 10; authors' translation).

In warm climates, open balcony structures can be effective in reducing overheating (Chan 2015). By contrast, glazed balconies can increase overheating risk in adjacent apartments as shown in field studies in warm climates where glazing limits natural ventilation (Coelho Pagel *et al.* 2019; Grudzińska 2021; Ribeiro *et al.* 2024). Nevertheless occupant behaviour can substantially modify thermal outcomes, with regular opening and closing of the glazing improving temperature regulation (Ribeiro *et al.* 2024). Similar conclusions have been made in simulation studies under Nordic conditions (Bhattacharjee *et al.* 2023; Kravchenko *et al.* 2026), highlighting the limited availability of measured indoor-temperature data. In a Nordic context, Hilliaho *et al.* (2016) is the only study reporting field measurements of glazed balconies along with apartment indoor temperatures. The study monitored 22 balconies in Tampere and found that glazed balconies were, on average, 5°C warmer than outdoor air (compared with only 2°C for unglazed balconies) over the measurement period (mid-July to mid-May), excluding some of the warmest periods. However, these measurements demonstrate buffer-effect benefits for colder seasons and potential heating-energy savings. Temperature differences were attributed to structural airtightness, solar radiation and airing the apartment through the balcony door. While this research is highly relevant, it does not directly assess overheating risk of the balcony or the living spaces during summer. Moreover, although occupant behaviour is considered via balcony-glazing openness, only one opening state was used. Finally, as the measurements were conducted in the period 2009–10, they do not reflect recent warming trends, highlighting the need for updated field measurements to study current apartment overheating risk.

1.1.3 Occupant behaviour

In residential buildings without active cooling, as is typical in Finland, occupant behaviour plays a critical role in summer overheating risk. Internationally, studies highlight this dependence together with the importance of human–building interactions (Balvedi *et al.* 2018; Ribeiro *et al.* 2024). A scenario-based modelling study by Kravchenko *et al.* (2026) shows that fully opening balcony glazing can reduce indoor overheating by up to 4.5°C, confirming the potential of occupant-operated passive measures. However, these actions alone may be insufficient during extreme heat events and may not reflect typical behavioural patterns. Sukanen *et al.* (2023) similarly note that passive measures depend on occupant willingness or ability. Hilliaho *et al.* (2016) find that residents often underestimate the contribution of glazing to balcony overheating and may exacerbate it by keeping the glazing closed in summer. Jegard *et al.* (2024) identify additional barriers to opening the balcony glazing, including concerns about falling pets, exposure to weather and dirt, and effort or time required. While summer user behaviour may offer overheating risk-mitigation potential, it depends on what design enables or hinders; particularly concerning balcony glazing in Finland, it remains uncharacterised and poorly understood.

1.1.4 Adaptability

Despite the growing summertime overheating problem, identified as the primary reason for limiting balcony use (Jegard *et al.* 2024), the widespread use of balcony glazing in Finland since the 1980s is not without reason. Balcony glazing increases balcony usability, particularly in spring and autumn, and is valued by residents (Jegard *et al.* 2024). Moreover, as a non-

integrated facade element, glazing supports housing adaptability and may allow the balcony to function as an extension of the home, or as a flexible 'slack space' (Peters & Masoudinejad 2022). Balcony glazing may also enhance comfort and outdoor use for individuals who might otherwise struggle to go outside, such as older adults and people with physical or mental disabilities. Overall, adaptable balcony solutions, including balcony glazing, help to achieve optimal outcomes in terms of functionality, resident wellbeing and energy efficiency.

Given the increasing risk of overheating and emerging evidence linking glazed balconies to indoor and balcony overheating, this study uses empirical data to provide a better understanding of glazed balconies, occupant behaviour and indoor thermal conditions in Nordic residential buildings.

2. RESEARCH METHODS

This study investigated summertime overheating and occupant behaviour in 10 Finnish apartments with glazed balconies during the summer of 2025, combining *in-situ* temperature measurements, semi-structured interviews and balcony-use diaries. Continuous air-temperature data were analysed against the Finnish overheating criteria to compare simulated (design-stage) expectations with observed *in-situ* performance. This approach provided an empirical basis from which to study overheating in glazed balconies and adjacent indoor spaces where *in-situ* evidence remains limited (Sadeghi *et al*. 2024).

2.1 CASE STUDY SELECTION

The sample consists of 10 apartments, coded CS1–CS10 (Figure 1), across Turku, Helsinki, Tampere and Oulu covering common balcony typologies (see also Jegard *et al*. 2026). The different locations provide a comprehensive geographical representation of the four main urban areas in Finland (Figure 2). Residents were recruited via a call circulated by housing companies and via researchers' networks. Participants were shown study information and privacy notices, providing informed consent before data collection. This small convenience sample was nevertheless purposively selected to capture variation between balcony and apartment characteristics and to explore how these, alongside occupant behaviour, affected overheating outcomes, and to provide insights between cases constructed between 1970 and 2020.

2.2 MONITORING CAMPAIGN

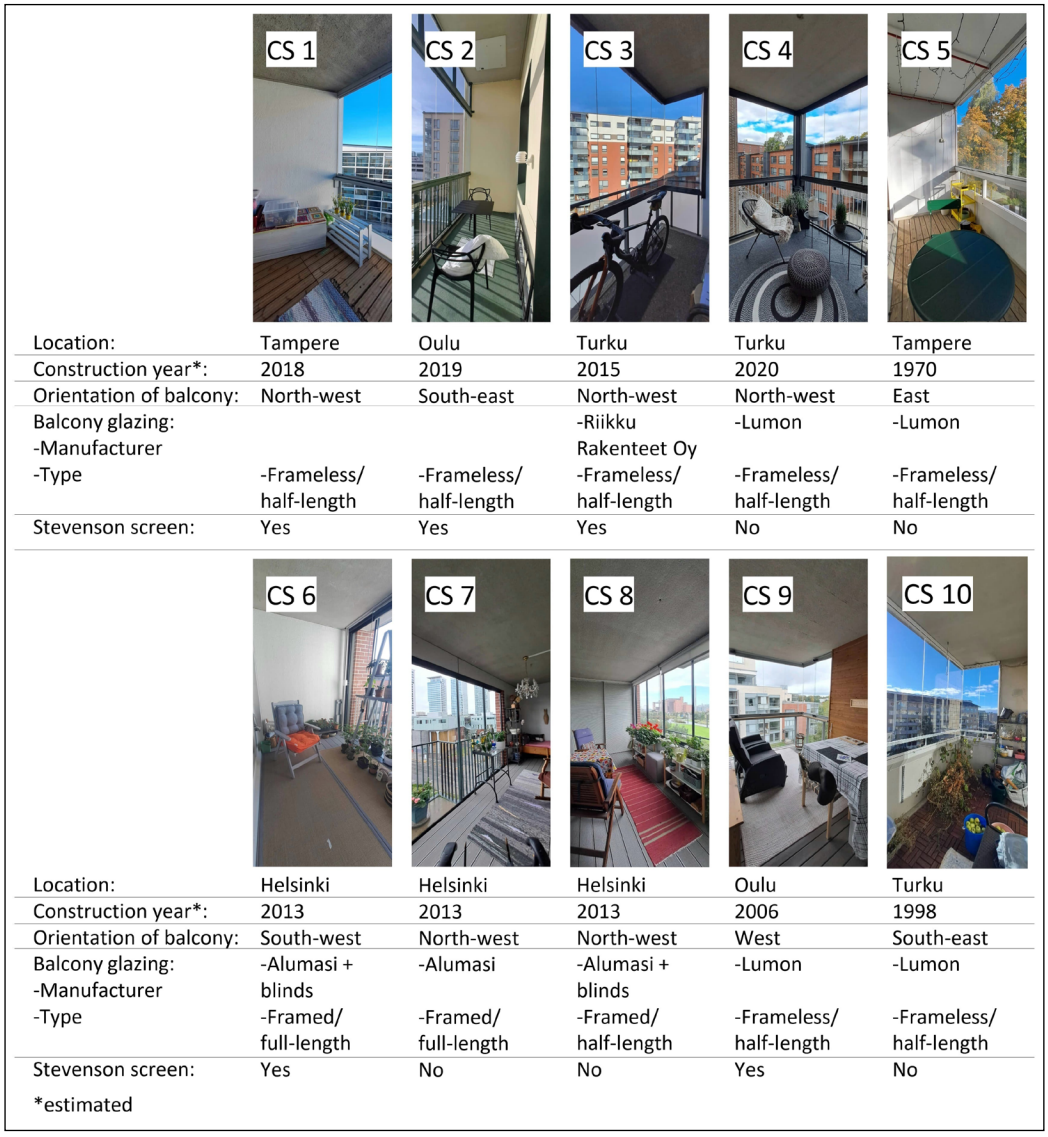
A monitoring campaign was held for one full year (approximately December 2024–December 2025, with slight variation across cases). For the purpose of this paper, analysis was restricted to summertime (1 June–31 August 2025). Daylighting monitoring results are reported by Jegard *et al.* (2026). Apartments partially unoccupied during the monitoring campaign were included in the dataset because they are part of realistic observable uses and this enabled reflection on prior research (see Section 1) that highlighted that apartments have increased overheating risk with limited opportunities for purge ventilation (Elsayed *et al*. 2024; Kravchenko *et al*. 2026), but this risk is reduced with fully opening balcony windows, which are also modelling assumptions for energy regulation compliance (Liljeström & Hurme 2012).

2.2.1 *In-situ* temperature measurements

Each case study was equipped with temperature loggers (Figure 3) continuously measuring the glazed balcony temperature and interior apartment spaces at 1-hour intervals. Balconies were equipped with weatherproof loggers (HOBO MX2301A; accuracy ±0.25°C from –40 to 0°C and ±0.2°C from 0 to 70°C) and placed in Stevenson screens for shading where needed (Figure 3), mounted on rainwater downpipes or placed on walls. In the apartments, a minimum of two sensors (with the exception of CS8) were placed on walls in the main area adjacent to the balcony (models HOBO MX2301A as before or HOBO MX1104 with accuracy ±0.20°C from 0 to 50°C). Logger type was based on availability; where multiple sensors were used, cross-comparison was undertaken and the minimums reported. Typically, monitoring was done away from localised heat sources and from windows to avoid direct solar exposure consistent with SFS-EN ISO 7726:2025:En (ISO n.d.)

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requirements. All sensors were placed at a height of 1.4 m, with exception only when this height was not achievable (Figure 4 shows sensor placement and height for all case studies). Although all balconies had temperature sensors, two fell down and one malfunctioned (CS1, CS2 and CS9), so the data were excluded.



	CS 1	CS 2	CS 3	CS 4	CS 5
Location:	Tampere	Oulu	Turku	Turku	Tampere
Construction year*:	2018	2019	2015	2020	1970
Orientation of balcony:	North-west	South-east	North-west	North-west	East
Balcony glazing: -Manufacturer			-Riikku Rakenteet Oy	-Lumon	-Lumon
-Type	-Frameless/ half-length	-Frameless/ half-length	-Frameless/ half-length	-Frameless/ half-length	-Frameless/ half-length
Stevenson screen:	Yes	Yes	Yes	No	No

	CS 6	CS 7	CS 8	CS 9	CS 10
Location:	Helsinki	Helsinki	Helsinki	Oulu	Turku
Construction year*:	2013	2013	2013	2006	1998
Orientation of balcony:	South-west	North-west	North-west	West	South-east
Balcony glazing: -Manufacturer	-Alumasi + blinds	-Alumasi	-Alumasi + blinds	-Lumon	-Lumon
-Type	-Framed/ full-length	-Framed/ full-length	-Framed/ half-length	-Frameless/ half-length	-Frameless/ half-length
Stevenson screen:	Yes	No	No	Yes	No

*estimated

Figure 1: Case study inventory and photographs.

Source: Adapted from Jegard *et al.* (2026).

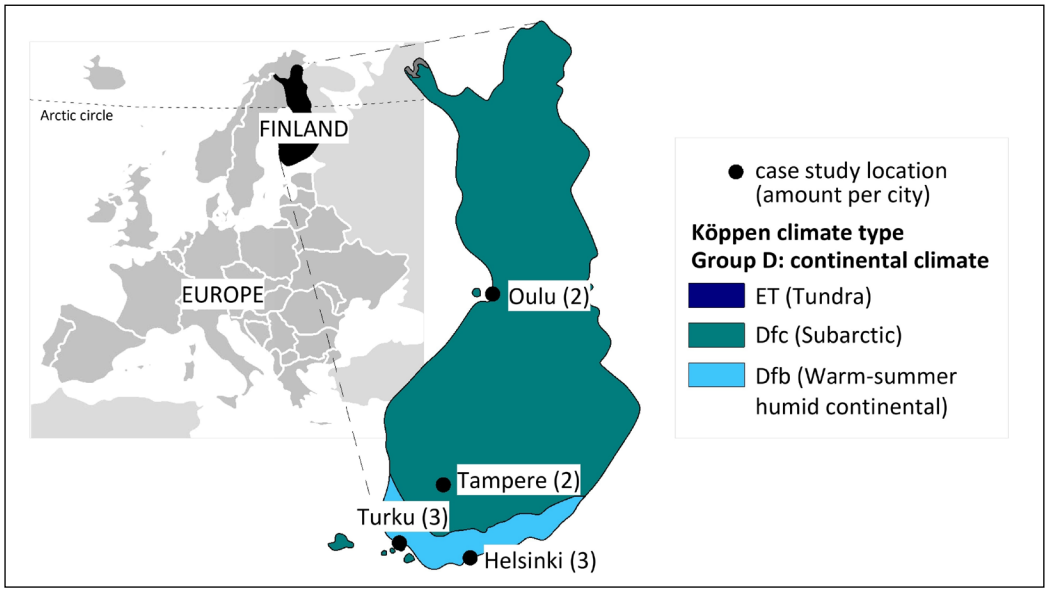


Figure 2: Map of Finland showing the case study sites.

Source: Adapted from Jegard *et al.* (2026).



Figure 3: Sensors (left) and Stevenson screens (right).



Figure 4: Sensor placement shown for each apartment.

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2.2.2 Diaries and semi-structured interviews

Participants were asked to keep a 'balcony-use diary' where residents noted any relevant information. Suggested prompts included glazing opening (*e.g.* open/closed, how many parts, for how long, *etc.*); what activity was performed on the balcony; and other (shading, balcony door left open, *etc.*). While not a complete dataset, the collected data of five of the 10 participants (CS4–CS8) (see Appendix C in the supplemental data online) nevertheless provided meaningful insights into how balcony glazing influenced balcony use.

Participant semi-structured interviews were undertaken and commonly used to further contextualise monitoring data and to understand occupants' thermal comfort and behaviour in post-occupancy evaluations (Elsayed *et al.* 2023). Interviews were framed about balcony use across seasons and impacts, including aspects related to visual and thermal comfort and privacy. Interviews were recorded, transcribed and translated; questions and excerpts are presented in Appendix C in the supplemental data online. Additional clarifications were requested by email during data analysis (*e.g.* gaps in diaries or out-of-period interviews).

2.3 MIXED-METHOD DATA INTEGRATION

An explanatory sequential mixed-method approach was used to integrate quantitative and qualitative evidence. Temperature and degree-hour analyses enabled systematic comparison across case studies, while balcony-use diaries and semi-structured interviews contextualised the quantitative findings through occupants' experiences and behaviour. This integrated analysis helped explain case-specific variations and provided a detailed, more comprehensive understanding of overheating in Finnish apartments with glazed balconies.

3. RESULTS AND DISCUSSION

3.1 OVERHEATING PREVALENCE IN THE STUDIED SAMPLE

An overview of overheating conditions across case studies is presented in Figure 5 (for case-specific results, see Appendix A in the supplemental data online). Following the Ministry of the Environment, Department of the Built Environment (2017), degree-hours above 27 and 32°C were

							Average apartment		Individual room degree-hours (Kh) >				Balcony			
Location	Average T outside [°C]	Max T outside [°C]	Number of hot days /Number pf very hot days	Case study (CS)	Max T apartment [°C]	Indoor overheating* [yes/no]	Degree-hours (Kh) > 27°c	Number of days above comfort range**	Living room #1	Living room #2	Bedroom #1	Bedroom #2	Max T [°C]	degree-hours (Kh) > 27°c	degree-hours (Kh) > 32°c	Average T difference balcony/outside [°C]
Tampere	16.3	30.8	15/2	CS1	27.8	no	1	23	0	x	5		x	x	x	x
				CS5	30.1	yes	775	56	742	811	x	x	35.6	1209	123	4.5
Oulu	15.5	32.3	18	CS2	30.5	yes	10	63	278	x	494	386	x	x	x	x
				CS9	29.0	yes	429	64	503	476	330	x	37.3	971	138	5.7
Turku	16.9	30.9	14/2	CS3	28.8	yes	6	62	380	323	560	x	34.3	345	25	3.9
				CS4	29.1	no	40	26	58	26	x	x	34.8	240	8	3.4
				CS10	31.4	yes	788	91	1035	x	569	x	x	x	x	x
Helsinki	17.1	28.4	7/2	CS6	28.0	no	27	47	9	63	x	x	35.2	214	9	3.7
				CS7	26.5	no	0	81	112	101	x	x	37.8	1062	152	5.7
				CS8	27.9	no	23	37	23	x	x	x	32.9	298	2	5.2
													average			4.60

*as defined in Energy and Performance of Buildings, 2017
** as defined per Indoor climate and ventilation in buildings 2010
T=temperature
: below threshold to compliant
: slight excendance to significant exceedance

Figure 5: Overview of the overheating conditions across the case studies.

calculated for each room and balcony, and this highlighted that half of case studies experienced summertime overheating (CS2, CS3, CS5, CS9 and CS10). Although none of the apartments exceeded the maximum indoor temperature limit of 32°C specified for residential buildings, three apartments surpassed the 30°C for elderly care homes (CS2, CS5 and CS10) (Ministry of Social Affairs and Health 2015), suggesting that these indoor temperature may not be safe for some occupants.

Outdoor conditions varied across the four locations (see Appendix B in the supplemental data online). Oulu experienced the highest number of hot days (n = 18) and highest maximum temperature (32.3°C) compared with seven hot days and a maximum of 28.4°C in Helsinki. Tampere and Turku showed intermediate conditions with 15 and 14 hot days, respectively, and maximum temperatures of approximately 31°C. These differences are broadly reflected in the apartment overheating results; apartments in Helsinki did not experience overheating compared with apartments in Oulu. One of two apartments in Tampere experienced overheating and two of three in Turku. However, outdoor conditions alone did not explain these variations, indicating the influence of design constraints and occupant behaviour, further discussed below.

As expected, glazed balconies were consistently warmer than outdoors, averaging 4.6°C higher during the monitoring period, consistent with previous findings (Hilliaho *et al.* 2016). All seven monitored balconies reached at least 32°C, with temperatures reaching 37°C in CS7 and CS9 (above the 30 and 32°C health-related threshold), and all exceeded 150°C h above 27°C. Because balconies are not indoor spaces, these thresholds provide reference rather than compliance criteria. Nevertheless, the consistently high temperatures indicate substantial summertime heat exposure and potential constraints on balcony usability (Ebi *et al.* 2021; Jegard *et al.* 2024).

3.2 DESIGN CONSTRAINTS AND OCCUPANT BEHAVIOUR

Comparison across the cases suggests that overheating should be interpreted in relation to a combination of variables rather than any single apartment or balcony characteristic. The following discussion therefore examines contrasting outcomes and eight main contributing factors: (1) construction year; (2) solar exposure; (3) window glazing ratios; (4) shading strategies; (5) purge ventilation and Finnish window design; (6) occupant behaviour; (7) balcony-glazing design and use; and (8) active cooling systems. Results are synthesised in Figure 6.

			Apartment design						Balcony design		
Location	Case study (CS)	Indoor overheating* [yes/no]	Orientation	Size (m2)	Construction year	Purge ventilation capacity (beyond balcony door)	Window integrated blinds	External shading obstructions	Shading	Structural airtighness	Occupant behaviour
Tampere	CS1	no	North-west	41	2018	limited	yes	yes	no	no	Daily ventilation
	CS5	yes	East	54	1970	limited	yes	no	no	no	Absent june-july: glazing closed
Oulu	CS2	yes	South-east	98	2019	ok	yes	no	no	no	Daily ventilation
	CS9	yes	West	78	2006	limited	yes	no	no	no	Not lived in continuously
Turku	CS3	yes	North-west	49	2015	limited	yes	no	no	no	Fear of pet falling: 1 mesh panel for ventilation
	CS4	no	North-west	43	2020	no	yes	yes	no	no	Daily ventilation
	CS10	yes	South-east	80	1998	limited	no	no	no	no	Noise restricts window opening
Helsinki	CS6	no	South-west	60	2013	ok	yes	no	yes	yes	2 balony pabes open all summer
	CS7	no	North-west	74	2013	ok	yes	no	no	yes	2 balcony panes open occasionnally
	CS8	no	North-west	45	2013	no	yes	no	yes	yes	No possibility to ventilate outside balcony

strong association with overheating
limited association with overheating
no association with overheating or associated with reduced overheating risk

Figure 6: Heat map classification based on evidence from the literature and study findings.

3.2.1 Construction year

Three of the five overheating cases (CS5, CS9 and CS10) were built before 2012. Notably, these cases also exhibited the most severe overheating outcomes, indicating that older apartments are more susceptible to overheating due to reduced fabric performance, as also observed by Elsayed *et al.* (2023) in Finnish apartments without balconies. However, overheating was also observed in newer buildings, highlighting that the problem is not confined to the older building stock. These findings are consistent with existing research showing that some recently constructed apartments fail to meet overheating performance requirements (Farahani *et al.* 2024b).

3.2.2 Solar exposure

Intense solar exposure emerged as a recurring characteristic of apartments affected by overheating, consistent with previous findings (Kravchenko *et al.* 2026). CS10 represented the most severe overheating case in the sample. The apartment, including its balcony, faced south-east and was unobstructed, resulting in intense solar exposure. Indoor temperatures remained above the thermal comfort range throughout summer (CS10) (see Appendix A in the supplemental data online), with a maximum recorded indoor temperature of 31.4°C, 1035°C h above 27°C in the living room and 569°C h above 27°C in the bedroom (Figure 5). Residents confirmed this experience stating that 'the apartment was way too hot in the summer'. A likely contributing factor was the absence of integrated window blinds, a condition unique to this case study and identified as one of the most effective passive cooling measures after natural ventilation (Sukanen *et al.* 2023). Similarly, CS5 experienced severe overheating despite its east-facing orientation (Figure 7), which is less commonly associated with excessive solar gains (Grudzińska 2021). The apartment overlooks a parking lot providing no shading. During the interview, the resident described the apartment as being particularly uncomfortable in the morning. The maximum recorded temperature in the living space (behind the glazed balcony) was 30.1°C, with 742°C h above 27°C (Figure 5). CS9 showed a comparable pattern but faces west and is unobstructed, leading to high solar gains (see also Kravchenko *et al.* 2026). The maximum temperature reached 29°C, with 476°C h above 27°C in the living space and 330°C h above 27°C in the bedroom behind the balcony (Figure 5). Average indoor temperatures remained above the thermal comfort range for most of June and through July until mid-August (CS9) (see Appendix A online), indicating persistent overheating.

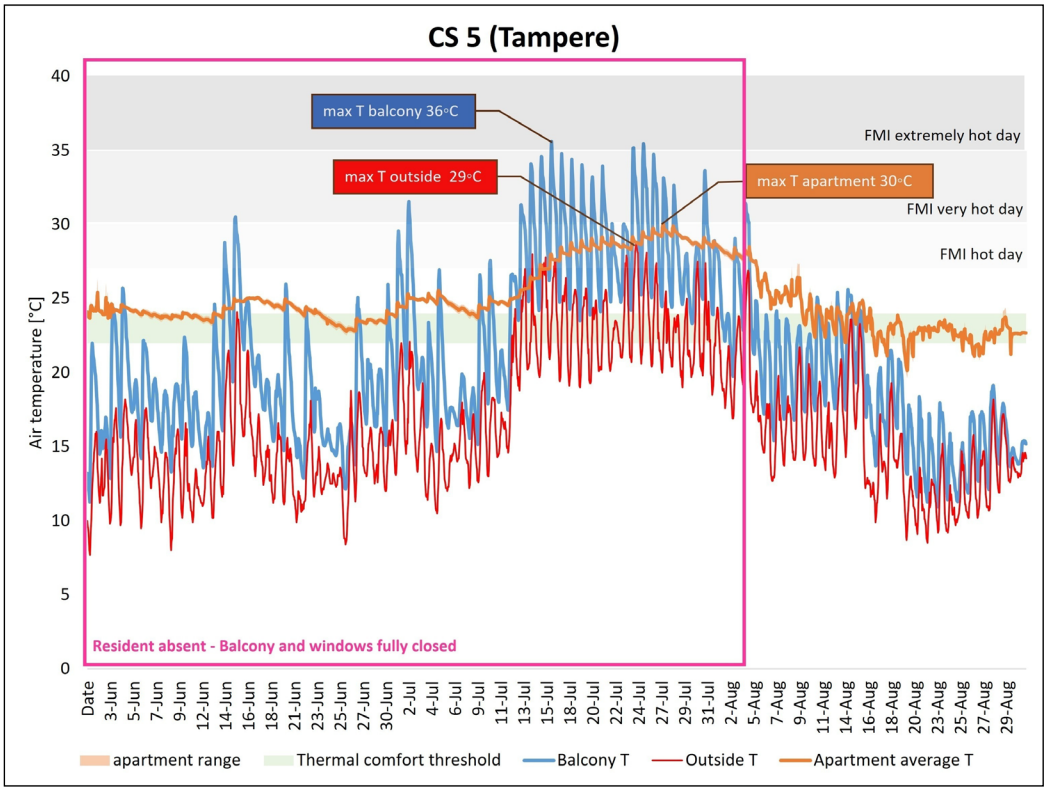


Figure 7: Temperature summary for CS5.

Additional design characteristics in CS2 further illustrate the influence of solar gains. Although it faced three directions, its strong south-facing exposure subjected the apartment to high solar radiation which, while beneficial in winter, can exacerbate overheating in summer (as also found by Jegard *et al.* 2026; and Kravchenko *et al.* 2026).

3.2.3 Apartment window-glazing ratio

Connected to solar exposure, CS2 is the only case with a ceiling height of 3.6 m and proportionally large windows, including a balcony with a 3.8 m-tall glazed facade, resulting in a high window-to-wall ratio, which Bhattacharjee *et al.* (2023) identified as another key contributor factor to excess heat accumulation. Residents reported in the interview that the apartment became uncomfortably hot during summer, particularly when outdoor temperatures exceeded 25°C.

Similarly, in CS3, higher temperatures in the bedroom compared with the living room can be explained by a combination of the glazed balcony shading the living room but not the bedroom and a higher bedroom glazing ratio relative to the room size, similar to Bhattacharjee *et al.*'s (2023) findings.

3.2.4 Shading strategies

In contrast, the cases that did not experience overheating generally benefited from effective shading strategies, including integrated window blinds combined with external obstructions (CS1 and CS4) or balcony shading (CS6 and CS8). CS1 featured a north-west-oriented balcony, while its east-facing windows were largely shaded by a neighbouring building. As the blinds were typically being closed for privacy (at the expense of daylight access and views), direct solar gains were further reduced, likely contributing to the absence of overheating (Kravchenko *et al.* 2026). The balcony received only limited solar exposure (only a few hours of evening sun), which may have further reduced indoor temperatures, consistent with Hilliaho *et al.* (2016). Similarly, this combination of orientation and external shading obstructions likely reduced solar heat gains in CS4, which is a north-facing apartment with a north-west corner balcony located in front of the bedroom. On the west side, the balcony was shaded by a neighbouring six-storey building. CS8 was the only studio apartment among the case studies with its single orientation facing north-west with no additional external windows. The balcony extended across the width of the apartment, likely preventing overheating (Chan 2015), though in a previous study the balcony shading in this same apartment was associated with reduced daylighting (Jegard *et al.* 2026).

3.2.5 Purge ventilation and Finnish window design

In most case studies (with the exception of CS2, CS6 and CS7), balcony doors served as the only large opening for purge ventilation of the whole apartment, a limitation identified as a contributing factor to overheating in prior research (Elsayed *et al.* 2024; Jiang *et al.* 2023). Other rooms only had a small section of the window that was operable (see the example in Figure 8), limiting ventilation. As noted by CS5, a resident:

> I have to use my balcony [door] for ventilation because the windows don't really open much. I'm glad to have the balcony even if it's just as a way to ventilate the apartment.

A typical window in Finland includes two sections: an openable section and a non-openable section; each made of two window parts (usually one single-glazed and one double-glazed connected to open together). This prevents full window opening, and when combined with fall-prevention requirements the openable section is typically small, thereby restricting ventilation airflow (Figure 8; the window is located to the right of the balcony door). There are no regulated minimum dimensions for the openable parts because manual airing via windows is treated as a supplementary practice, with current regulatory focus away from summertime overheating but on year-round healthy indoor air quality, provided by mechanical systems. However, usually a balcony door meets the criteria of one larger facade opening as a secondary escape route in apartments, thereby allowing purge ventilation. As seen in all 10 cases studied, effective purge ventilation may be jeopardised and adds another layer of occupant behaviour dependency if this opening leads to

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a glazed balcony. Regardless, the hot and very hot day monitoring results suggest that to achieve thermal comfort additional passive measures may be needed (Sukanen *et al.* 2023), and possibly even supported with mechanical cooling, as suggested by Kravchenko *et al.* (2026) and Tognon *et al.* (2026).



Figure 8: Typical configuration in a Finnish apartment: a balcony door from the living room or bedroom opens onto the glazed balcony.

Note: Additional windows from other rooms (either facing the glazed balcony or directly outdoors) include only a small operable section for ventilation (approximately 20% of the total window area).

CS2 was the only apartment with a second, unglazed living room balcony, while CS6 and CS7 had dual-aspect layouts effective for cross-ventilation (Jiang *et al.* 2023), but these opportunities for cross-ventilation did not seem fully utilised. For example, residents reported primarily ventilating through the balcony door, but did not mention using the other openings, possibly due to furniture placement and furnishability constraints limiting their practical usability.

3.2.6 Balcony-glazing design

The balconies in CS6–CS8, all located within the same building, featured a different glazing system than the other case studies, which used the more common Finnish balcony-glazing system. While other cases used frameless retractable glazing with ventilation gaps and full opening capacity, these balconies used a framed sliding system (see Figure 1 for manufacturer details). High balcony temperatures were observed on these balconies, despite some movable solar shading provided by residents in CS6 and CS8, and the highest temperature of 37.8°C recorded for CS7, suggesting some impact from the shading, as reported by Sukanen *et al.* (2023). CS7 and CS8 also showed the largest temperature differences relative to outdoors. In this case, framed glazing (together with prolonged resident absence for CS7) may have contributed to these extreme temperatures due to reduced structural airtightness, a key factor for glazed-balcony thermal performance, as found by Hilliaho *et al.* (2016). Differences in structural airtightness between glazing systems are rarely reported in the literature, making comparisons across studies difficult and potentially obscuring an important source of variation in overheating variables.

3.2.7 Occupant behaviour

Findings suggest that the extent to which the potential of overheating mitigation measures translated into reduced summertime temperatures depended on occupants' actual behaviour and operation of the balcony glazing, balcony doors, shading devices and windows.

While fully opening the balcony glazing can reduce indoor overheating (Kravchenko *et al.* 2026), this was not realised in the monitored cases where none of the residents reported doing so, and is consistent with findings from Hilliaho *et al.* (2016). One partial explanation appears to be periods of some occupant absence during which the glazing (together with balcony door and windows) remained fully closed. This occurred in CS5, where the resident was absent during June and July and the maximum balcony temperature recorded reached 35.6°C (Figure 5). Similarly, in CS9, balcony temperatures were exceptionally high (CS9) (see Appendix A in the supplemental data online) including during periods of moderate outdoor temperatures (Figure 5), despite residents

reporting partial opening of the glazing. In this case, the balcony configuration may also have limited effectiveness, with hot air becoming trapped within the deep structure (*e.g.* 3.8 m depth, of which only 1.2-m sections were operable in addition to the front side; for the floorplan, see Figure 4). The role of balcony-glazing operation as a potential contributing factor is discussed further below.

Conversely, the effective use of available ventilation pathways appeared to contribute to moderating indoor temperatures and the effectiveness of night-cooling to lower indoor temperatures aligns with previous studies (Elsayed *et al.* 2024; Sukanen *et al.* 2023). In CS1, the resident left the balcony door open most nights together with one balcony-glazing pane. Similarly, when present, the CS5 resident kept the balcony door open together with at least one balcony-glazing pane. While outdoor temperatures were lower at the time, the effectiveness of night-cooling is still reflected in the greater day–night temperature fluctuations observed in August (Figure 7). In CS4, the resident kept the balcony door open daily and opened one to six balcony-glazing panes for several hours, as documented in the diary, thereby enhancing natural ventilation, a key factor found to influence indoor thermal conditions (Sukanen *et al.* 2023). Despite high temperatures recorded on the balcony with a maximum of 34.8°C in CS4 (Figure 5) (see Appendix A in the supplemental data online), indoor room temperatures in both case studies generally remained within the thermal comfort range, exceeding it only on hot days, although the defined overheating threshold was not reached (Figure 5). On such days, both residents reported keeping glazing, blinds and curtains closed during the day. Nevertheless, the CS4 resident described the apartment as uncomfortably hot during the interview and expressed regret about not having air-conditioning. These findings align with current evidence suggesting that during peak heat events, a combination of passive measures may be needed (which often rely on occupant behaviour), possibly supplemented by mechanical cooling (Kravchenko *et al.* 2026; Sukanen *et al.* 2023; Tognon *et al.* 2026).

3.2.8 Balcony-glazing usability

Across the case studies, usability emerged as a critical factor in determining whether balcony glazing functioned as an effective adaptive feature (Jegard *et al.* 2024; Peters & Halleran 2020). Limitations in the use or operation of the balcony glazing reduced its intended benefits and, in some cases, may have contributed to overheating. The following section discusses specific balconies, their glazing and user engagement in more detail.

In CS9, the glazed balcony is in front of the main bedroom, with half of its depth recessed into the building and the other extending outward. It is seen by residents as a functional extension of the indoor living area. However, when opened, the balcony-glazing panes occupy approximately one-third of the balcony width (Figure 9), obstructing the space and requiring furniture rearrangement, making full opening impractical and likely not anticipated in the initial design.



Figure 9: CS9 with its balcony glazing open.

In the case of CS3, the resident is a pet-owner of a cat, and while the balcony door was occasionally kept open to ventilate the apartment, simultaneous opening of the balcony glazing and balcony door was avoided due to safety concerns for the cat, a behavioural challenge noted by Jegard *et al.* (2024). During the warm season, the resident replaced a glass pane with a metal wire shelf panel (Figure 10) as a practical solution to enable ventilation while preventing the pet from falling from the balcony. This allowed ventilation while maintaining safety, although the remaining glazing remained fixed. As a result, two seasonal configurations were used: during the cold period, the glazing remained fully closed; and during the warm period, one pane was replaced with the mesh panel. While this offers a practical solution, restricting additional openings remain a significant limitation for overheating mitigation. As the resident stated:

> If it wasn't for the cat; it would be more open all summer then it wouldn't be so hot.



Figure 10: Hardware store metal wire shelf panel repurposed as a ventilation panel in place of glazing, preventing the cat jumping or falling (CS3).

Moreover, during the data-collection period, glazing systems were repeatedly opened and closed across cases for measurement purposes. However, frameless systems were found to be difficult to manoeuvre and perceived as fragile, potentially discouraging their use. By contrast, the sliding system in CS6–CS8 was easier to operate and more robust than the frameless retractable system. This residents of CS6 and CS8 installed balcony-mounted roll-down blinds (independent of glazing) (Figure 11), enabled by the sliding glazing system which does not rotate inwards. Because this blind type can shade large areas with minimal effort, they may encourage more frequent user engagement than segmented pane-mounted systems (commonly available in Finland, although not present in any of the case studies) that require multiple individual adjustments. They also allow shading and ventilation simultaneously, whereas pane-mounted systems often require occupants to choose between the two.



Figure 11: Interior roll-down blinds and sliding glazing panes (that do no rotate inward) (CS7).

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3.2.9 Active cooling systems

The three case studies located in Helsinki (CS6–CS8), where no internal room overheating was recorded, were all situated within the same building completed in 2013, featuring a heat-recovery system that pre-cooled incoming air by up to 2°C. While distinguished from the other cases, valuable insights were gained as this feature likely reduced overheating risk. For CS6 and CS8, indoor temperatures remained within the thermal comfort range for most of the period, exceeding it only during an extended warm period from mid-July to mid-August (CS6) (see Appendix A in the supplemental data online). During interviews, residents reported discomfort only when outdoor temperatures exceeded 27–28°C. For CS7, indoor temperatures remained above the thermal comfort range from early June to mid-August. Residents declared being absent for most of the summer, keeping the windows fully closed. This highlights that, in addition to a heat-recovery system providing some cooling, maintaining thermal comfort also relied on natural ventilation strategies that require active occupant involvement (Sukanen *et al.* 2023).

None of the case studies incorporated external shutters, operable awnings or facade-mounted shading devices which are reported to be more effective than integrated blinds in lowering overheating risk (Sukanen *et al.* 2023). In warmer climates, balconies are often valued for their overhang effect, which ran reduce solar gains to the facade and adjacent indoor spaces (Chan 2015). However, although further research is needed, the present findings suggest that the addition of balcony glazing may reduce solar gains, but may also partially negate the balcony's shading benefit by increasing heat accumulation within the balcony itself if the balcony glazing is not opened. This is particularly relevant in the Finnish context where manual window opening for ventilation remains relatively uncommon, both culturally and due to building systems not designed to support it (Sukanen *et al.* 2023; Thomson *et al.* 2019). Consequently, the proven effectiveness of reducing overheating through natural ventilation in Finnish apartments (Kravchenko *et al.* 2026; Sukanen *et al.* 2023; Velashjerdi Farahani *et al.* 2024) remains underutilised, representing a significant missed opportunity.

As balcony glazing is increasingly adopted in new and retrofitted residential buildings internationally (Coelho Pagel *et al.* 2019; Ribeiro *et al.* 2020), careful consideration of solar control and ventilation strategies, but also the balcony design and its use, are essential to avoid inadvertently increasing overheating risk under a warming climate.

As has been highlighted in some of the studied cases, apartment overheating risk can be exacerbated by its adjacent glazed balconies and their use. If this trend is found in a larger representative sample in the Finnish housing stock, Finnish apartment design risks becoming reliant on mechanical cooling systems to ensure summertime occupant thermal comfort, leading to increased energy use and potentially increased carbon emissions and further exacerbating outdoor temperatures.

4. CONCLUSIONS

Understanding and addressing overheating in residential buildings is increasingly urgent in Finland, where particularly *in-situ* monitoring studies remain limited. The impact of Finland's typical glazed balconies is poorly characterised, though the few studies have found they are linked to intensified summertime overheating in indoor spaces. Given the increasing global application of glazed balconies, the findings from the established Finnish context of glazed balconies have broader relevance, especially for warmer climates where the risk of overheating may be even more pronounced. Through a field study of 10 apartments in Finland, this paper provided insights on indoor thermal conditions and that of its glazed balconies. *In-situ* temperature measurements, balcony-use diaries and semi-structured interviews were undertaken to evaluate overheating risk during the summer of 2025 and to investigate how balcony design and occupant behaviour affected overheating outcomes.

Findings highlighted that half of the case studies experienced overheating, including three apartments built before 2012, as well as two newer ones, indicating that overheating also occurred under current building practices. Without passive-mitigation practices and occupant

control, maintaining comfortable indoor temperatures is unlikely even during less warm outdoor conditions.

It was found that rooms directly behind balconies—mostly living rooms—typically performed slightly better, explained by a combination of smaller glazing ratios relative to room size, balcony shading and access to a balcony door to ventilate more intensively. However, the latter was occupant dependant, and it was observed that resident glazing-opening actions were generally conservative (not fully open for extended periods), significantly limiting ventilation potential. This was identified as a reason why balcony temperatures consistently reached uncomfortable or even dangerous temperatures in all studied cases. Like other studies (*e.g.* Elsayed *et al.* 2024), apartment purge ventilation was found to be crucial in overheating risk mitigation. However, no resident kept the balcony glazing fully open, contrary to energy calculations assumptions (Liljeström & Hurme 2012), affecting also indoor apartment temperatures, if the balcony is the main ventilation path.

This study emphasised that balcony and glazing designs often obstructed effective and intuitive use; *e.g.* occupants' unwillingness to open the glazing can be attributed to several factors: from lack of knowledge (Hilliaho *et al.* 2016), or ability (Sukanen *et al.* 2023), to inconvenience or fear of pets falling (Jegard *et al.* 2024). As such, it was found that glazed balconies themselves became uncomfortably, or even dangerously, hot for extended periods, regardless of reasonable mitigation practices, ultimately limiting year-round usability. However, the impact of glazed balconies on indoor apartment overheating (Bhattacharjee *et al.* 2023; Jegard *et al.* 2024; Kravchenko *et al.* 2026; Ribeiro *et al.* 2020) was found to be more complex and dependent on many variables in this study, such as: (1) construction year; (2) solar exposure; (3) window glazing ratios; (4) shading strategies; (5) purge ventilation and Finnish window design; (6) occupant behaviour; (7) balcony-glazing design and use; and (8) active cooling systems.

This highlighted an urgent need to better consider balcony-glazing design and its use.

4.1 POLICY AND DESIGN IMPLICATIONS

A key lesson from this Finnish study, a context with a long history of glazed balcony implementation, is that as glazed balconies are increasingly adopted in other countries as a generalisable solution for thermal renovation in Central Europe, maintaining adequate opportunities and easy occupant control for purge ventilation from internal spaces to outside but also from balcony to outside is a critical design consideration to mitigate overheating risks. Without these considerations, apartments may increasingly rely on active cooling, further increasing energy use and exacerbating climate change. This highlights that designers, developers, and also industry should urgently review and develop balcony and balcony-glazing designs to ensure they perform optimally in all aspects.

Although preliminary, the findings helped to inform a set of design recommendations to minimise overheating risk in glazed balconies and apartment design across contexts, which designers and manufacturers should consider—as set out below.

At the block or apartment scale:

- *Limit solar overexposure without compromising daylight*

  Use of environmental shading strategies including orientation, surrounding buildings, vegetation and use of external shutters, operable awnings or facade-shading devices.

- *Provide effective purge ventilation pathways for the apartment in addition to the balcony door*

  Window systems outside of the glazed balcony space must be improved to support large and safe openings that enable effective natural ventilation and unobstructed use of spaces when open.

Concerning the balcony and glazing systems:

- *Fundamentally improve air permeability regardless of glazing operability*

  As an outside space, balconies should remain fully permeable to air while still providing protection from the elements. A seasonal approach with minimal intervention should be considered, *i.e.* a summer mode that maximises ventilation and a winter mode that increases enclosure to retain solar heat gains. Instead of full glazing, the facade or railing system could incorporate perforated or ventilated elements with gaps.

- *Provide more robust balcony-glazing solutions with proven user operability that support pet-safe ventilation, shading, furniture placement and everyday unobstructed usability*

  While some systems may offer greater theoretical flexibility, such as fully retractable glazing, this flexibility is not always realised in practice, as the open panes can obstruct balcony use and may therefore remain closed.

Moreover, addressing non-design factors playing a critical role in policy formulation or building-permit evaluation is recommended. Climate data need to be updated to consider the changing climate and realistic future scenarios. Glazed balconies must be integrated into dynamic simulations and calculations considering the worst-case scenario as found in this study to consider suboptimal conditions and occupant behaviour (*i.e.* 'glazing fully closed' during summertime, as for apartment windows). Conversely, balcony glazing should systematically be drawn and evaluated with 'glazing fully open' as the default state during design (potentially during building permit process), ensuring space usability in this condition. Considering increased window operability and a minimum requirement for operable windows in each room is also essential.

Finally, consideration should also be given to minimise the risk of suboptimal occupant behaviour through public information campaigns and explicit guidance, *e.g.* providing recommendations on how to use balcony glazing and windows during warm periods and general advice on how to keep the apartment cool.

4.2 LIMITATIONS AND FURTHER RESEARCH

Due to the exploratory case-study nature of the research and the limited number of monitored apartments, this study was never intended to be statistically representative and the findings should be interpreted as in-depth insights into the studied cases from which initial trends and lessons can be highlighted that can inform future studies.

Some key study limitations related to monitoring that affect the thermal performance of the cases include: (1) sensor placement (*e.g.* temporary sunlight exposure; resident interference without the researchers' knowledge); (2) glazing operation frequency was documented to some extend but not comprehensively; (3) unknown or different construction and ventilation systems than retrieved data; (4) external temperature data from local weather stations may not perfectly represent local case study microclimatic conditions; and (5) the exclusion of floor height and glazing properties in the analysis.

Also excluded from this study were thermal comfort studies and apartment and balcony simulations that would have supported a more comprehensive sensitivity analysis; this is highlighted for further research. Larger datasets are needed to understand the impact of detailed balcony-glazing design and residents' operation on indoor overheating. Also highlighted for further research are field studies with reference apartments without a balcony to better isolate and quantify the influence of balconies on overheating risk; and extended monitoring with controlled conditions during heatwaves.

To reduce balcony temperatures and associated indoor overheating risk, more research is required on the proven effectiveness of fully opening the balcony glazing and its specification and resident usability of these different balcony-glazing systems (including older systems that have not been used or maintained properly) by various types of users (older people and others with limited mobility, *etc.*).

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AI DECLARATION

In line with the journal's ethical guidelines, Microsoft Copilot was used to refine language and clarify phrasing, without influencing the scientific content.

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L.J. conducted the literature review, data collection, analysis, draft and completion of the paper; S.P. and R.C.R. contributed equally to revisions and finalisation.

COMPETING INTERESTS

The authors have no competing interests to declare. S.P. is an editorial board member of this journal but was not involved in the review process or editorial decisions for the manuscript.

DATA ACCESSIBILITY

Supporting data for this study's findings are available from the authors upon reasonable request.

ETHICAL CONSENT

Each participant read a privacy notice detailing the research project and provided informed consent before taking part in the study. Semi-structured interviews were conducted on a voluntary basis, and participants were informed that they could decline to answer or withdraw at any time. Ethical review was not required for this study under the applicable regulations.

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SUPPLEMENTAL DATA

Supplemental data (Appendices A–C) for this article can be accessed at: https://doi.org/10.5334/bc.881.s1

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