EFFECTS OF ADDED GLAZING ON BALCONY INDOOR TEMPERATURES: FIELD MEASUREMENTS

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ABSTRACT

In this study the temperatures on 22 balconies (17 glazed) and adjacent flats were monitored with an aim to determine the key factors affecting the ability of a glazed balcony to warm up and remain warm without a heater. Considered were glazed balconies in different locations, the amount of glazing and building heat loss, the tightness of balcony vertical structures, and balcony ability to capture solar radiation.

Temperature monitoring showed that over a year the air temperature of both glazed and unglazed balconies remained almost without an exception above the outdoor air temperature. On average, the temperatures of unglazed balconies were 2.0 °C and those of glazed balconies 5.0 °C higher than the outdoor air temperature. The three key factors affecting the glazed balcony temperatures seemed to be the level of air leakage in the balcony vertical structures, the balcony's ability to capture solar radiation, and the heat gain from an adjacent flat, in that order. The air tightness of the glazing was the most crucial factor, since it affected the results all the year round. Solar radiation was important from spring to autumn and heat gain in midwinter.

Keywords: balcony glazing; balcony temperatures; field monitoring; temperature monitoring; prefabricated building

Highlights

- Field monitoring was conducted on 22 balconies and in adjacent flats
- Temperature conditions were measured at 1-hour intervals
- A glazed balcony was 5.0 °C and an unglazed one 2.0 °C warmer than the outdoor air
- Main contributors were air tightness, solar absorption, and building heat losses

1 INTRODUCTION

For centuries, large glazed spaces have been architecturally and structurally interesting building details [1, 2, 3]. Their attraction lies in large spaces, novel architectural solutions, and interesting details. However, these spaces have not usually been built solely for architectural reasons, but functional requirements have also been set for them as they have served as hospital waiting areas, reception areas in office buildings, etc. The design of such spaces is based on required indoor air conditions, such as minimum acceptable indoor air temperature, desired average temperature, and maximum acceptable temperature. They determine the design solution, which takes into account issues such as heat losses in the building and the space, storage of solar radiation, solar protection, and minimisation of cooling and heating needs, if the required indoor conditions cannot be realized without an external energy source. [4]

In Finland, glazed spaces are not usually big and impressive structures but quite simple and rather small spaces, such as glazed balconies. The glazing system consists of 5 - 6 opening balcony glass panes, characterized by transparent 6-mm float glass panes (U=5.8 W/m2K, g=0.82) and non-insulated aluminum profiles. Between the panes have usually 2 – 3-mm air gaps [5], allowing sufficient natural ventilation in the balcony and making continuous heating of the balcony uneconomical [6]. Because many Finns are not aware of the energy saving and overheating impacts of balcony glazing, some residents keep their balcony glazing partly open throughout the winter, reducing thus energy savings, and fully closed during summer, causing thereby overheating problems [7, 8]. This is partly due to a lack of broader study of glazed balcony temperature behavior in northern climate conditions and lacking information about the key factors affecting the energy and indoor climate design of a glazed space. The need for such information has also been emphasized in other studies [4, 9].

This paper presents the results of a study conducted by measuring temperatures on 22 balconies (17 glazed) and adjacent flats in Tampere, Finland, to determine the effect of building conduction losses, tightness of balcony vertical structures, ability to capture solar radiation, and the amount of glazing and locations on the balcony indoor climate. The study sought to find the key factors affecting the ability of glazed balconies to warm up in northern climate conditions and thereby to improve glazed balcony temperature behavior for future design.

2 BACKGROUND

According to the literature, glazed space air temperatures have been measured to evaluate, e.g., thermal comfort and operative temperatures on many occasions and almost all over the world. Studies have usually focused on either a clearly different climate [10, 11, 12], another continent [13, 14, 15], or central Europe [16, 17], where the climate conditions differ from those in Finland. Thus their perspective has been different (e.g., emphasis on overheating rather than on energy saving). Their measurements have focused on atrium [10, 13], sunspace [12, 15, 18] or some solar space [11], though some balcony glazing studies have also been made [16, 17, 19]. Older measurements have focused on indoor climate behavior [12, 16] and later ones, either partially [15] or wholly [12, 18], on the validation of simulation programs. The only extensive field monitoring of glazed balconies is over ten years old, conducted under the International Energy Agency (IEA) Solar Heating and Cooling (SHC) program Task 20 "Solar energy in building renovation". Its results are available, e.g., in [9, 20, 21]. Rather than by extensive field measurements, the sensitivity of glazed space characteristics to space temperatures has been mainly analyzed by computer simulation [22, 23]. Glazing has generally been single glazing [17, 24] and/or double glazing [6, 23, 25] with sliding [19, 26] or non-sliding panes [12], and as a rule with vertical frames [6, 19, 23, 25]. Previous studies have rarely focused on the most commonly used frameless single glazing in Finland with a sliding and pane-by-pane opening glazing system, such as that in [24] . A special feature of this glazing are its 2-3-mm air gaps between the panes, which makes it a significantly un-tighter solution than that in previous studies.

Some studies in Finland and the neighboring countries have monitored balcony temperatures [4, 8, 19, 24, 27]. In most of them, either the number of measured balconies has been small [4, 19, 24] and/or their research perspective has been other than to improve the thermal behavior of a glazed balcony [19, 24]. The first such study was [8], on whose basis this paper has been written. Some studies have focused on the potential of balcony glazing for energy savings [4, 8, 19, 27], a topic also discussed in [7, 28], though without temperature measurements.

In terms of measurement technicalities, the previous studies differ very little. Usually monitored have been the temperatures of the sunspace, the adjacent living space, and the outside air (dry bulb and relative humidity) while at the same time using factory-calibrated data loggers [11, 13, 15, 16, 17], some temperature sensors [15], and/or thermocouples (shielded or unshielded) [10, 12, 13, 18]. Temperatures have usually been recorded at 10-min [15], 15-min [11, 14, 16, 17], 20-min [10], or 1-hour intervals, and measurements have lasted from a few days to several years [24]. The most common temperature recording interval has been 10 or 15 minutes, but one monitoring study has established that a logging interval of one hour would be sufficient [16]. Of particular importance has also been to use the same measuring intervals with individual loggers [16] and to start temperature recording simultaneously for easier later comparison of the results.

The results of the previous studies clearly show that the temperatures of a glazed space, such as sunspaces [11, 15, 29] and glazed balconies [8, 24, 27] are higher than the outdoor air temperature. They also show that to maximize the temperature difference between a glazed space and the outdoor air, space type and size must be optimized along with the thermal insulation capacity and air-tightness of the structures. As to the balcony type, a recessed glazed balcony is superior to a protruding balcony, because it has a small exterior glazed area and a large exterior wall area, through this balcony receives transferred heat from the adjacent flat [16, 27]. Increasing the length of a balcony also increases transmission losses from the adjacent flat. In general, a long and narrow balcony is recommended for maximizing energy savings and natural light [30].

The location affects the energy saving effect and the indoor climate of a glazed space. The basic principle is that the more southern and milder the climate, the higher the yearly mean temperature and the bigger the percentage of energy savings. This is because of the increased amount of energy absorbed by the space due to the increased intensity of solar radiation [31]. The highest energy savings are possible in a sunny and cold climate [20], such as that of the southern European Alps. Orientation, external obstructions, and solar shading also affect the solar radiation stored, because they limit the amount of radiation entering the space. It is important that the space be oriented towards the equator (+/-30º), though it has been observed that orientation is not the major contributor to the energy savings of a glazed balcony [26]. It is also proved that added glazing area can increase the amount of solar energy absorbed and lead to the overheating of the balcony or the adjacent rooms [6], even in northern climates [22] in the absence of shading.

The material properties of the glazed space and the building external wall affect the indoor temperature and energy savings of the glazed space. According to [23], e.g., the thermal conductivity of the wall strongly affects the heat flux through the wall, but its density and heat capacitance (C) have only a small effect [23], albeit heat capacitance affects temperature variations and the thermal comfort of the space [4]. By contrast, the absorption coefficients of the surfaces and the ability of the space to store solar radiation have a strong impact on the interior temperatures of the glazed space and the energy savings [4].

The air-tightness of the envelope structures of glazed spaces has a further marked impact on their temperatures. Ventilation with outdoor air removes a fraction of the energy absorbed and consequently lowers the temperature of the sunspace [31]. The air exchange rate of un-tight glazed spaces varies daily and greatly depends on the temperature difference between the glazed space and the outdoor air and the wind conditions [4]. The building's ventilation solution also affects the end result. In terms of the heating energy savings of the building, it is advisable to integrate the glazed space with mechanical exhaust ventilation and thus use the glazed balcony as a supply air pre-heater [20]. The overheat of the glazed space could thus warm up the adjacent flat in summer time, if the supply air terminals between the glazed balcony and the flat are not easily closable [19]. Excessive indoor temperatures could be prevented by using an appropriate solar shading solution with the glazing [22] and by increasing airing by opening the balcony glazing [32].

As mentioned above, most glazed space studies have focused on glazed spaces other than glazed balconies and with glazing solutions different from the typical Finnish one. In addition, the climate conditions in those studies have differed from the northern European climate, and their sensitivity analysis has been founded on computer models instead of field monitoring.

3 RESEARCH MATERIALS AND METHODS

The research material consists of climate and weather information on Tampere, a description of the studied buildings and balconies, and a monitoring set up for 22 balconies and their adjoining flats.

3.1 Climate and weather

The city of Tampere (61°29′53″N, 23°45′39″E) is located about 200 km north of the Finland`s southern coastal line. Its winter is cold and summer mild (Köppen-Geiger Dfc) [33]. The annual average temperature of the city is 4.4 °C (36.4 °F), and in a normal year, it has 4424 heating degree-days (HDD17) [34].

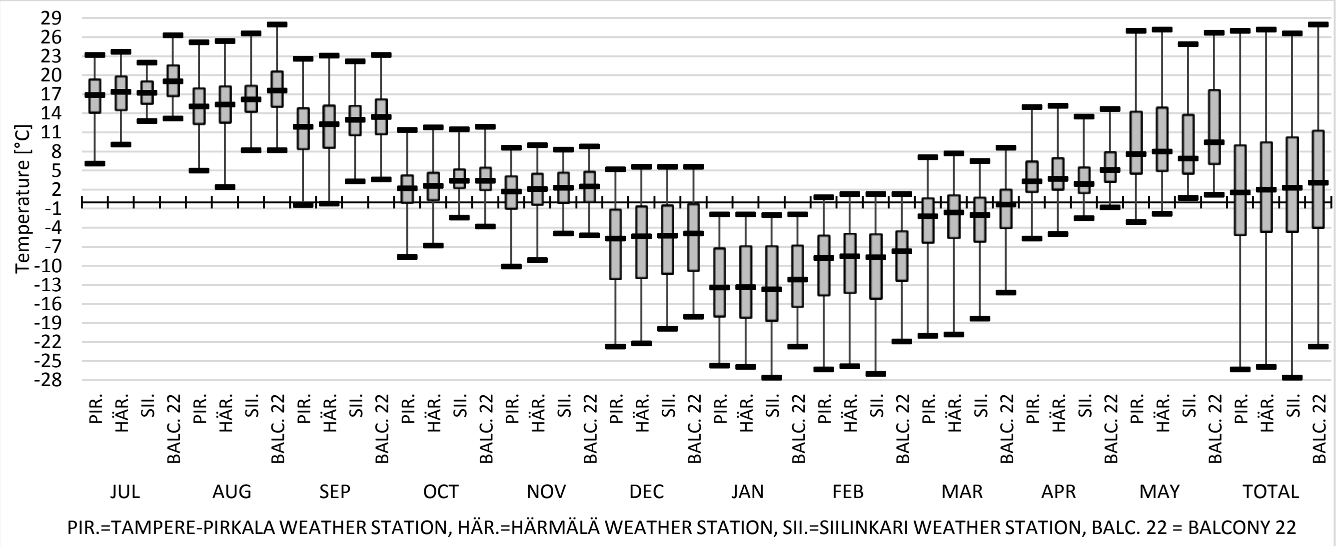

Figure 2. Monthly mean temperatures at Siilinkari, Härmälä, and Tampere-Pirkkala weather stations (station locations shown in Figure 1).

The Finnish Meteorological Institute measured the outside temperature at the measurement time in three different locations of Tampere region (Figure 1). The stablest temperature among the stations was monitored at Tampere–Pirkkala airport (Figure 2) and chosen for the reference outdoor temperature in this study. The station’s average temperature was 1.5 ° C with a range of -26.3 °C (on 20th February 2010 at 8 AM) to 27.0 °C (on 16th May 2010 at 3 PM). In the measurement period, the warmest month was July and the coldest January.

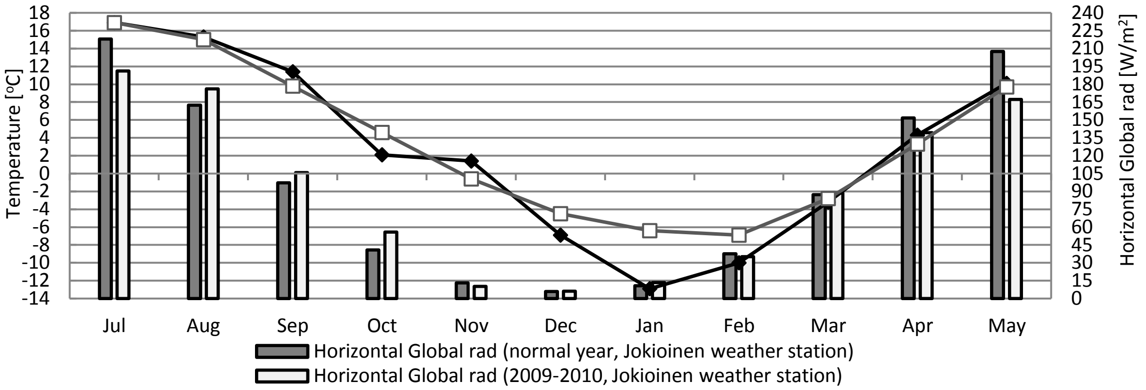

Figure 3. Monthly average temperatures and horizontal global radiation during the field measurement period compared to a normal year.

Comparison of the measurement period and normal year outdoor temperatures [34] at Tampere-Pirkkala as well as the measurement period and normal year global solar radiation level at Jokioinen (nearest, about 100 km from Tampere) reveals that the only significant deviation from the long-term average is the unusually cold winter in the middle of measurement period (Figure 3). The deviations between the July and May radiation values were caused by different measurement times: the normal yearly values covered whole months and the measurement period values half the respective months (the measurement period was from 17th July 2009 to 17th May 2010). Thus the values are not directly comparable.

3.2 Studied buildings and balconies

Eleven blocks of flats in four different urban areas in the city of Tampere were chosen for the study and specified from oldest to newest by individual letter codes (Figure 4). The oldest building was from 1966 (Building A) and the most recent from 2006 (Building K). Most buildings are of typical 1970s prefabricated element-based construction. Four pre-1978 buildings did not originally include balconies for all flats, but balconies were later added to two of them (buildings C and D). In their external wall, window, door, and balcony structures, the 1970s buildings B - F were similar at the time of their completion. However, with the exception of building E, their windows doors, and balcony railings in buildings B, C and D have since been renovated.

Figure 4. Balconies in the studied blocks of flats, showing well the decade of their construction. The buildings are identified by a letter code A - K (see also Table 1).

Test site acquisition

The site was acquired in co-operation with the staff of Lumon Oy, a balcony glazing company, and VVO-Yhtymät Oyj, a real estate company. Test sites for the study were selected from among the real estate company's rental flats, because they were near enough for regular follow-up. Almost all the balconies in the chosen blocks of flats were also partly glazed, allowing thus temperature measurement of glazed and unglazed balconies in the same building. From among the tenants who consented, flats suited for the study were chosen based on the building's age, structural solutions, and facade orientation. Additionally, some balconies were acquired through other networks (researcher's own flat etc.). Five of the blocks of flats are located in Hervanta, two in Härmälä, three in Lielahti, and one in Hatanpää (Figure 1).

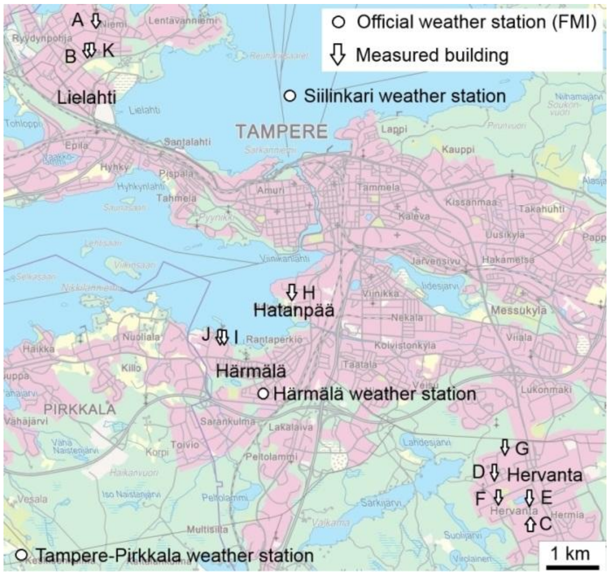

Figure 1. Measured buildings are located in three suburban areas in Tampere. The weather stations (three) of the Finnish Meteorological Institute (FMI) are shown in dots. The Tampere-Pirkkala airport weather station is located in the bottom left corner.

Representation methods of balconies

The balconies studied are described in numerical code from coldest to warmest and specified by rectangles and circles for unglazed and glazed balconies, respectively (Figure 5). Numbers 1 - 17 are glazed and 18 - 22 unglazed balconies, which means, that all the glazed balconies were warmer than the unglazed ones. Also shown are building ages and façade orientations, balcony glazing use characteristics (openness grade of glazing), and measured period mean temperatures. The openness grades were as follows: balcony glazing fully closed (closed), one glass pane 2.5 cm open (ventilation position), and one glass pane fully open (one pane open). Balconies without information on the openness grade are unglazed.

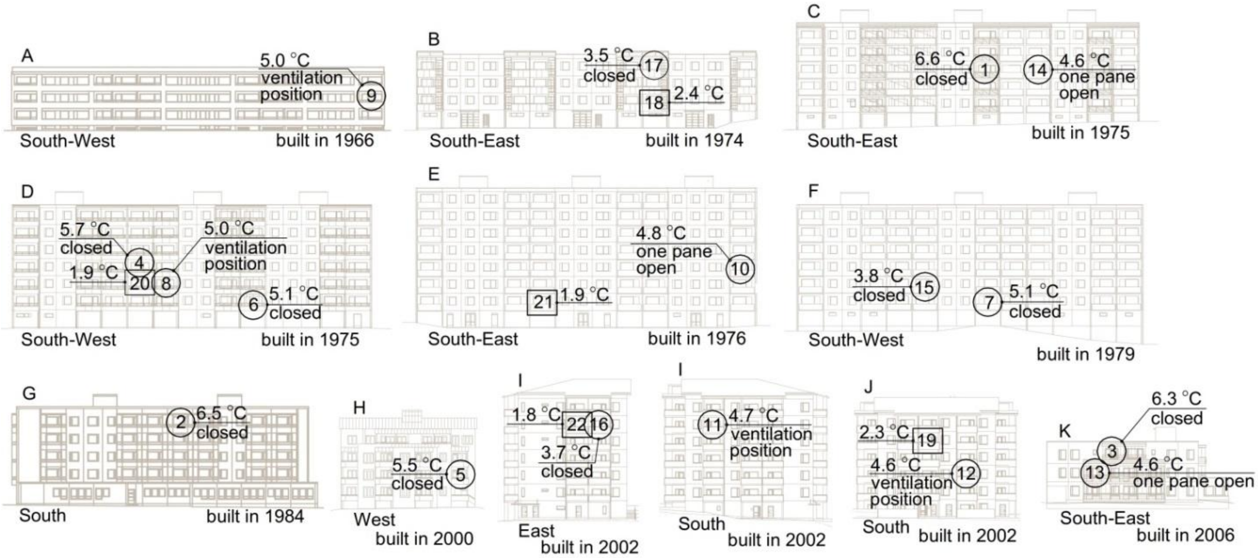

Figure 5. Studied block of flats from oldest to newest, identified by a letter code A - K. Balconies are numbered from warmest to coldest. Numbers 1 - 17 are glazed balconies and 18 - 22 unglazed ones.

Evaluation of balcony properties

Solar energy absorption on balconies, heat transfer by conduction from an adjacent flat to the balcony, and unintended ventilation from balcony to outside were estimated for each building on a scale of very low to very high (Table 1). Heat losses were estimated by inspecting structural and architectural drawings and solar energy absorption with the help of architectural drawings and by visual observation of the building sites. Solar absorption considered external obstructions and balcony orientation. The air leakage of the balcony vertical structures, designated as “tightness level” in this paper, was estimated by measuring the air gaps on site and by inspecting the structural drawings. Tightness was chosen instead of leakage because “very high” would then in all instances represent the best condition and “very low” the poorest. The leakage level of a glazed space could perhaps be better indicated by using fan pressurization equipment [4], but those measurements are hampered by intensive labor demands and difficulty to produce enough pressure difference between leaky glazing structures. Hence these tests were excluded in this study.

Table 1. The building-specific information on the studied buildings.

Building code	Balcony codes	Location	Building type, construction year, external wall structure and U-value	Balcony type, dimensions (Number of glazed sides informed in parentheses)	U-values of windows and doors	Balcony material (parapet material informed in parentheses)	Heat transfer by conduction (ΣU*A) from adjacent flat to balcony [W/K]	Solar absoption level of balconies (External obstruction informed in parentheses)	Overall tightness of the balcony* (after user effect)
A	**9**	Lielahti	in-situ frame, band façade, 1966, brick U=0.47	Recessed, w=3.8m, d=1.5m, h=2.6m, (1)	U=1.8 (windows), U=1.4 (doors)	Concrete balcony, (hardboard parapet)	Very high, 15.9	Typical (adjacent building)	High (typical)
B	**17, 18**	Lielahti	precast concrete, 1974, concrete sandwich panel, U=0.4	Protruding, w=4.0m, d=1.9m, h=3.1 or 2.6m (1)	U=1.2 (windows), U=1.2 (doors)	concrete balcony (extended 0.5m), (hardboard parapet)	Typical, 9.5	Very high (no external obstruction)	Very low
C	**1, 14**	Hervanta	precast concrete, 1975, concrete sandwich panel, U=0.4	Protruding, w=4.0m, d=1.5m, h=2.6m (both 1 and 2)	U=1.2 (windows), U=1.2 (doors)	concrete balcony, (30 % glass, 70% concrete parapet)	Low, 7.4	Very high (no external obstruction)	Very high (low)
D	**4, 6, 8, 20**	Hervanta	precast concrete, 1975, concrete sandwich panel, U=0.4	Protruding, w=4.0m, d=1.5m, h=2.6m (both 1 and 2)	U=1.4 (windows), U=1.2 (doors)	concrete balcony, (hardboard parapet)	Typical, 9.5	High (building ≈50 m in front)	High (typical)
E	**10, 21**	Hervanta	precast concrete, 1976, concrete sandwich panel, U=0.4	Protruding, w=4.0m, d=1.5m, h=2.6m (1)	U=2.1 (windows), U=2.0 (doors)	concrete balcony, (concrete parapet)	High, 12.7	Low (medium dense forest in front)	Very high (low)
F	**7, 15**	Hervanta	precast concrete, 1979, concrete sandwich panel, U=0.29	Protruding, w=4.0m, d=1.5m, h=2.6m (1)	U=1.2 (windows), U=1.2 (doors)	concrete balcony, (concrete parapet)	Low, 7.7	Very low (dense forest in front)	Very high
G	**2**	Hervanta	precast concrete, 1984, concrete sandwich panel, U=0.29	Protruding, w=3.9m, d=2.2m, h=2.6m (1)	U=1.8 (windows), U=2.0 (doors)	concrete balcony, (concrete parapet)	Typical, 10.3	Very high (no external obstruction)	Very high
H	**5**	Hatanpää	precast concrete, 2002, concrete sandwich panel, U=0.27	Protruding, w=2.8m, d=2.4m, h=3.0m (2)	U=1.4 (windows), U=1.4 (doors)	concrete balcony, (concrete parapet)	Low, 8.0	Very high (no external obstruction)	Very high
I	**11, 16, 22**	Härmälä	precast concrete, 2002, concrete sandwich panel, U=0.27	Protruding, w=3.6m, d=2.4m, h=2.8m (2 and 3)	U=1.4 (Windows), U=1.4 (doors)	concrete balcony, (sheet metal parapet)	Low, 7.8	Typical (buildings adjacent and ahead)	Typical (low)
J	**12, 19**	Härmälä	precast concrete, 2002, concrete sandwich panel, U=0.27	Protruding, w=3.6m, d=2.4m, h=2.8m (3)	U=1.4 (windows), U=1.4 (doors)	concrete balcony, (sheet metal parapet)	Low, 7.8	High (adjacent buildings)	Typical (low)
K	**3, 13**	Lielahti	precast concrete, 2006, concrete sandwich panel, U=0.24	Protruding, w=4.3m, d=2.0m, h=2.7m (2)	U=1.2 (windows), U=1.2 (doors)	concrete balcony, (glass parapet)	Very low, 6.3	Very high (no external obstruction)	Very high (low)

*** In Finland, all balcony glazing structures are leaky structures because of 2–3-mm air gaps between the glass panes, yet the air outflow can range, according to our estimation, from 1l/s to 40l/s because of different overall glazed balcony solutions (the main things are the tightness of the balcony vertical structures and balcony heat gains from solar radiation and transfer from the adjacent flat). This effect was assessed at this point. In some flats, residents left their balcony glazing periodically partly open or even for the entire measurement period. This effect on overall balcony tightness is given in parentheses.**

3.3 Field measurements

In these blocks of flats, data loggers were installed on ceilings in 17 glazed and 5 non-glazed balconies and in the adjoining flats for about 10 months from 17th July 2009 to 17th May 2010. Monitored were air temperature and relative humidity on the balconies and in the adjacent flats. Data were recorded at 1-hour intervals with factory-calibrated Comark Diligence EV (N2003 and N2013) data loggers, whose accuracy (Table 2) was confirmed before measurements with TUT calibration equipment. The precision of the devices was T= ±0.5 °C and RH = ±3 % RH.

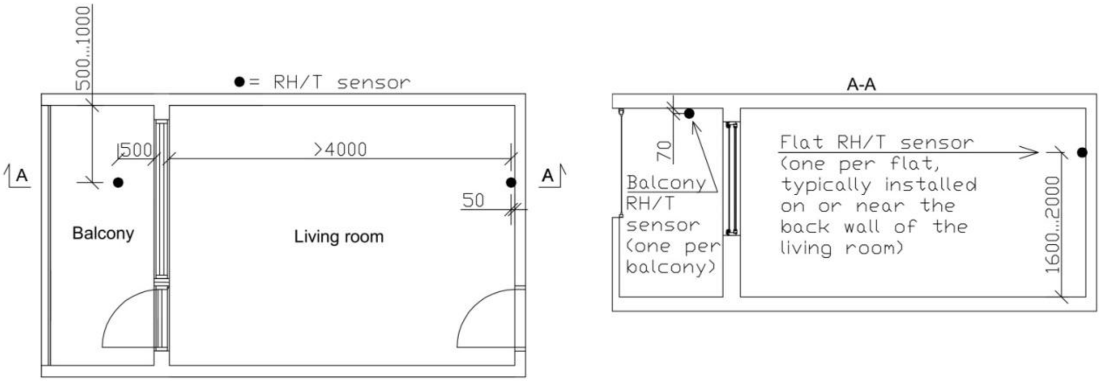

Figure 6. Arrangement of monitoring in a balcony and flat.

Data loggers were installed at circa 2 meters from the floor and at least 4 meters from the external walls. External loggers were installed on balcony ceilings, away from sunshine, and at least 0.5 meters from external walls (the most common installation arrangement is shown in Figure 6). In logger installation, mechanical attachment was avoided.

Table 2. Measurement range, display resolution, and accuracy of the used Comark Diligence EV (N2003 and N2013) data loggers.

	Measurement range	**Display resolution**	**Accuracy -25°C to +50°C**
Temperature	-20°C to +60°C	0.1°	±0.5°
	Measurement range	**Display resolution**	**Accuracy -20°C to +80°C**
Humidity	0- 97 %	0.1% RH	±3 RH

Measurements of indoor, outdoor, and balcony temperatures enabled determination of the actual temperatures and heat loss reduction (Equation 1) in the building section adjacent to the balcony as a whole (including balcony back wall, windows, and door) after glazing installation. The results are reliable, if the measuring devices are accurate enough and calibrated, and if measurements are properly taken.

$$Heat\ loss\ reduction = 1 - \frac{T_{FLAT} - T_{BALCONY}}{T_{FLAT} - T_{OUTDOOR}} \qquad (1)$$

4 RESULTS AND DISCUSSION

4.1 Balcony temperatures

Temperatures of unglazed balconies

In general, the surrounding buildings, trees and the balcony vertical structures form a micro-climate inside the balconies, a phenomenon that can be observed from the slightly higher measured temperature values in the balconies than those in the open terrain. The phenomenon is the most obvious in the minimum temperatures, but also the mean and maximum temperatures differ somewhat from the outdoor air temperatures (Figure 7a). On average, the temperatures of the five unglazed balconies differed 2 °C from the outdoor air temperature measured at the Tampere-Pirkkala airport and ranged from 1.8 °C to 2.4 ° C, depending on the balcony (Table 3).

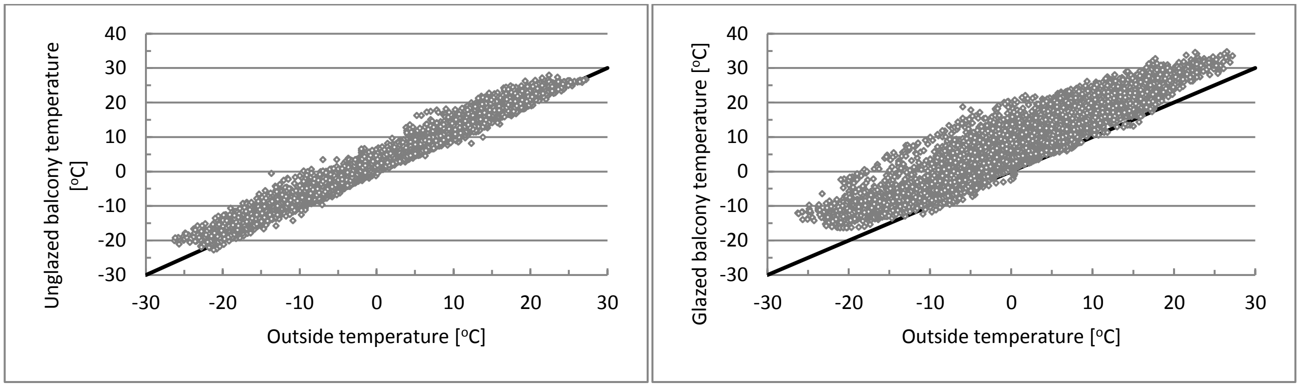

Figure 7a and 7b. Temperatures of the coldest unglazed balcony (code 22, left) and of the warmest glazed balcony (code 1, right) in relation to the outdoor temperature measured at the Tampere-Pirkkala weather station.

Analysis of the monthly level (Figure 8) shows that there is considerable deviation between the warmest and the coldest unglazed balconies and between unglazed balconies and the outdoor air. Differences between the median and maximum temperatures on unglazed balconies and the outside temperature stand out in autumn and spring, but minimum temperature differences are more consistent. The temperature difference between unglazed balconies (balconies 22 and 18) shows deviations that are smoother than those between unglazed balconies and the outside and mostly follow the same trend throughout the year. The only significant deviation between the balconies can be seen in the maximum temperatures in spring and autumn.

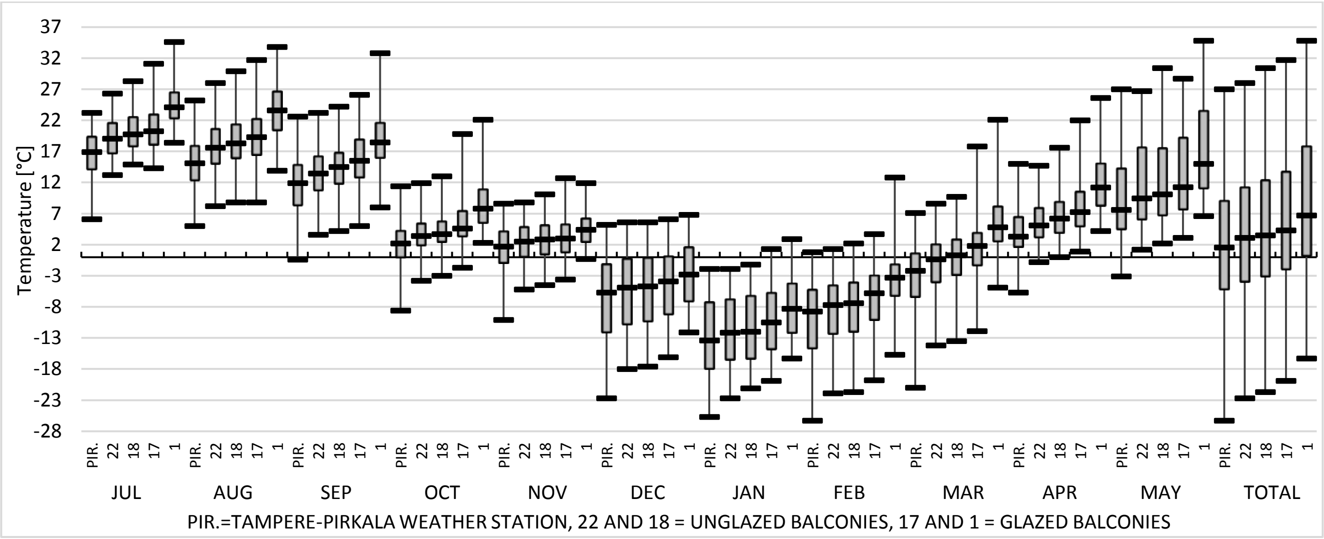

Figure 8. Monthly and total temperature behavior of the coldest and the warmest unglazed and glazed balconies and that at the Tampere-Pirkkala weather station.

A daily temperature review of the balconies confirms the same trend as the monthly level study (Figure 9). Day temperatures, divided into a six-hour average, show clearly that unglazed balconies do not cool as much as the outside air during a cold winter night. Similarly, solar radiation in spring warms up balconies with the intensity of warming depending significantly on balcony orientation and external obstructions. Balconies facing south (balcony 19) warm up most, and those facing east (balcony 22) the least.

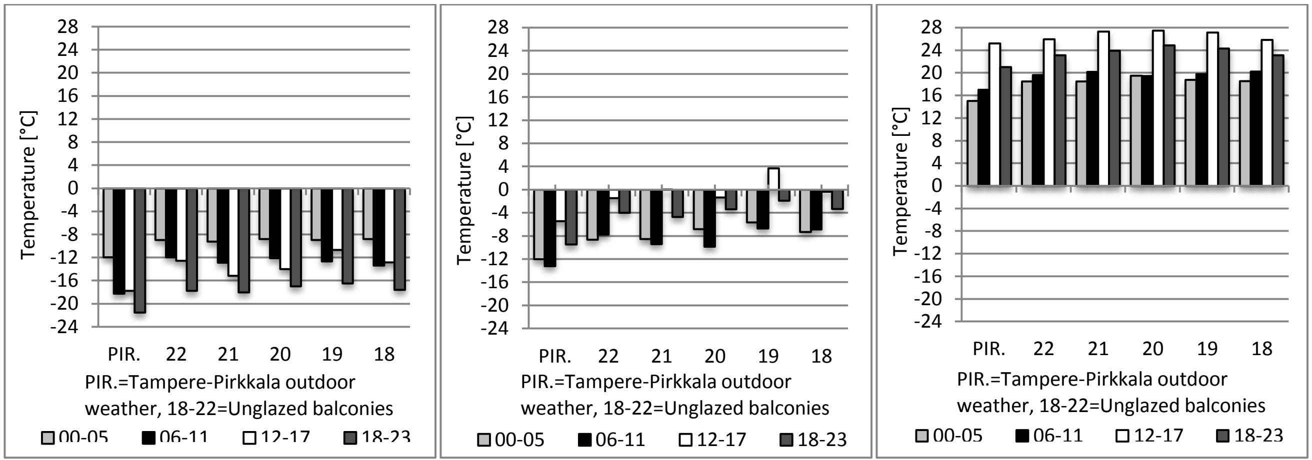

Figure 9. One cold winter day (26th January), an early spring day (15th Mars), and a late spring day (16th May) and Tampere-Pirkkala outdoor weather divided into six-hour periods.

Temperatures of glazed balconies

On average, the temperatures of 17 glazed balconies differed 5.0 °C from the outdoor temperature and ranged from 3.5 °C to 6.6 °C, depending on the balcony. The importance of glazing (all 17 pc) for balcony indoor temperatures varied seasonally. Glazing had the highest effect in March, when the average temperature difference of the 17 glazed balconies was 6.6 °C compared to the outdoor air and the lowest in November with a 2.8 °C temperature difference. Calculated seasonally, the average temperature differences between the glazed balconies and the outdoor air were 4.2 °C in autumn (Sep - Dec) and 5.8 °C in spring (Mar - May). A difference of more than one and a half degrees between the autumn and spring values was caused by solar radiation, since it affected temperatures more in spring than in autumn. Annually, the warmest was an extended balcony (balcony 1) glazed on two sides in a block of flats built in 1975 (Building C), whose solar absorption was very high, air tightness very high, and heat loss low (Table 3). In contrast, the coldest was an extended balcony (balcony 17) glazed on one side in a building one year older (Building B), whose heat loss was low, solar energy absorption very high, and air tightness very low. This shows that balcony air tightness seems to be the most critical factor for balcony indoor temperatures.

Monthly analysis showed marked differences in the individual behavior of glazed balconies. Balcony 1 warmed up significantly from solar radiation and showed good ability to store solar energy in its structures. Consequently, the results differed clearly from the coldest glazed balcony (balcony 17). However, also the coldest glazed balcony performed better than unglazed balconies, and occasionally their temperatures clearly differed from those of unglazed ones, as can be inferred from the high maximum temperatures of balcony 17 in October and March. Those monthly deviations are interesting because balconies 17 and 18 were located in the same building and on top of each other. Thus both balconies received the same amount of solar radiation, yet they differed greatly in their temperature behavior.

Table 3. Balconies ranked from warmest to coldest based on their mean air temperatures over the whole measurement period.

Balcony number	Building code	Construction year	Mean temperature [°C]	Maximum temperature [°C]	Minimum temperature [°C]	Temperature difference to outside air* [°C]	Adjacent flat temperature [°C]	Heat loss reduction [%], calculated according to equation 1.	Heat transfer by conduction (ΣU*A) from adjacent flat to balcony [W/K]	Solar absorption level of balconies (reason)	Overall tightness of the balcony vertical structures	The number of the glazed sides of the balconies
Unglazed balconies												
1.	C	1975	8.1	34.8	-16.3	6.6	23.7	29.8	Low, 7.4	Very high (no external obstruction)	Very high	**2**
2.	G	1984	8.0	36.9	-13.3	6.5	23.1	30.1	Typical, 10.3	Very high (no external obstruction)	Very high	**1**
3.	K	2006	7.9	39.0	-16.7	6.3	23.1	29.4	Very low, 6.3	Very high (no external obstruction)	Very high	**2**
4.	D	1975	7.3	33.6	-14.6	5.7	22.7	27.1	Typical, 9.5	High (building ≈50 m in front)	High	**1**
5.	H	2000	7.0	33.4	-16.1	5.5	23.5	25.1	Low, 8.0	Very high (no external obstruction)	Very high	**2**
6.	D	1975	6.7	35.6	-15.7	5.1	23.6	23.2	Typical, 9.5	High (building ≈50 m in front)	High	**1**
7.	F	1979	6.6	29.6	-15.8	5.1	21.5	25.4	Low, 7.7	Very low (dense forest in front)	Very high	**1**
8.	D	1975	6.5	36.1	-17.3	5.0	23.5	22.8	Typical, 9.5	High (building ≈50 m in front)	Typical	**2**
9.	A	1966	6.5	34.6	-14.9	5.0	23.0	23.3	Very high, 15.9	Typical (adjacent building)	Typical	**1**
10.	E	1976	6.3	29.1	-15.4	4.8	21.7	23.6	High, 12.7	Low (medium dense forest in front)	Low	**1**
11.	I	2002	6.2	35.6	-17.2	4.7	24.9	20.1	Low, 7.8	Typical (buildings adjacent and ahead)	Low	**3**
12.	J	2002	6.2	37.0	-18.1	4.6	24.2	20.4	Low, 7.8	High (adjacent buildings)	Low	**3**
13.	K	2006	6.1	31.3	-16.3	4.6	23.9	20.5	Very low, 6.3	Very high (no external obstruction)	Low	**2**
14.	C	1975	6.1	33.4	-16.7	4.6	23.3	21.0	Low, 7.4	Very high (no external obstruction)	Low	**1**
15.	F	1979	5.3	30.9	-16.5	3.8	23.6	17.1	Low, 7.7	Very low (dense forest in front)	Very high	**1**
16.	I	2002	5.2	32.4	-18.1	3.7	23.6	16.6	Low, 7.8	Typical (buildings adjacent and ahead)	Typical	**2**
17.	B	1974	5.1	31.7	-19.9	3.5	22.6	16.8	Typical, 9.5	Very high (no external obstruction)	Very low	**1**
Unglazed balconies												
18.	B	1974	3.9	30.4	-21.7	2.4	23.4	11.0	Typical, 9.5	Very high (no external obstruction)		
19.	J	2002	3.8	29.4	-21.7	2.3	23.9	10.1	Low, 7.8	High (adjacent buildings)		
20.	D	1975	3.4	30.8	-21.7	1.9	23.2	8.7	Typical, 9.5	High (building ≈50 m in front)		
21.	E	1976	3.4	29.5	-22.2	1.9	23.3	8.7	High, 12.7	Low (medium dense forest in front)		
22.	I	2002	3.3	28.0	-22.7	1.8	25.1	7.5	Low, 7.8	Typical (buildings adjacent and ahead)		
Outdoor air (Tampere - Pirkkala airport weather station)												
			1.5	27.0	-26.3							

* Temperature difference has been calculated by deducting Tampere-Pirkkala average outdoor air temperature (1.5 °C) from average balcony temperature over the whole period. For example, balcony 1 temperature difference is 8.1-1.5=6.6 °C.

Characteristically, glazed balconies seemed to undergo strong fluctuation in their temperature and the outdoor air. Typically, temperature differences were greatest in spring and autumn and lowest in mid-winter. The largest differences between the balconies and the outdoor air were caused by solar radiation. Another factor was airing flats through the balcony door, though only one tenant did it systematically and for long periods during the year (Balcony 7). Overall, these temperature differences ranged from -5.8 °C to 29.6 °C during the measurement period. The highest below air temperature value was measured on balcony 7, a brief -5.8 °C below the outdoor temperature due to a rapid increase in the outdoor temperature, to which the concrete glazed balcony reacted with a short delay. The greatest difference was measured during solar radiation, which rapidly warmed up balcony 3 and caused a 29.6 °C temperature difference between the space and the outdoors air. However, this phenomenon had only a slight impact on the indoor air temperatures of the adjacent flat, because it was momentary and abated quickly as the sun went down.

Comparison of glazed and unglazed balconies

In comparison of the balconies, glazed balconies were almost without exception warmer than unglazed balconies (Figure 10). On average, their temperature difference was 3.0 °C, which was slightly more than the average difference between glazed and unglazed balconies in the same buildings. Only in July, August, and September was the unglazed balcony 18 with very high solar absorption (Table 1) warmer than the glazed balcony 15 with a dense forest in front of it. In addition, in October, the unglazed balcony 19 was warmer than the glazed balcony 16 on the east side of the adjacent building. However, the difference between the two was slight: 0.2 ° C in July and 0.3 ° C in the other months.

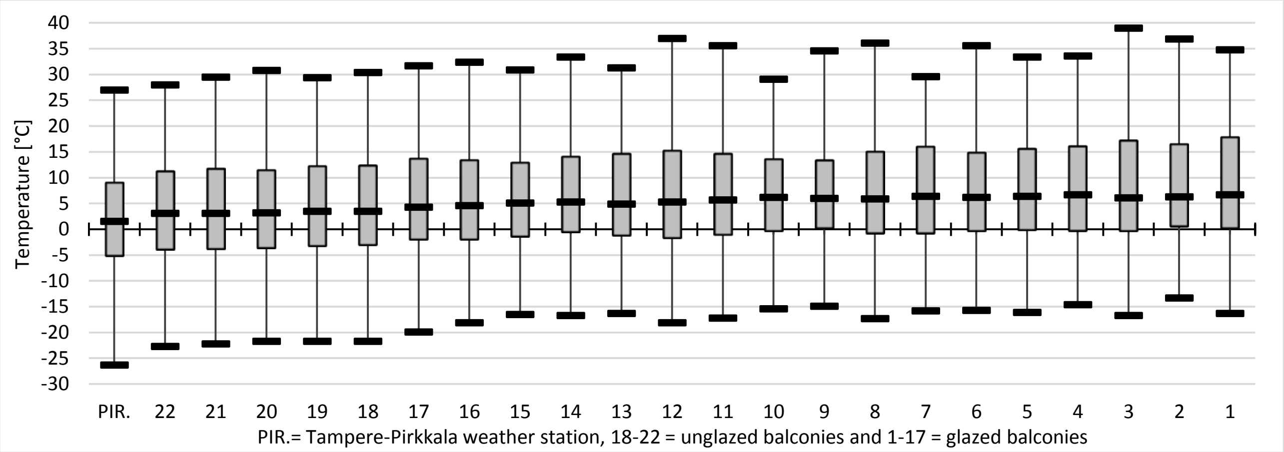

Figure 10. Overall behavior of outdoor air temperatures in unglazed and glazed balconies during the measurement period.

Comparison of glazed and unglazed balcony scatter diagram (Figure 7) reveals three important observations. First, the set of points is clearly widely spread out, which shows that occasional deviations relative to the ambient air are clearly higher in glazed balcony than unglazed balcony temperatures. Second, the set of points in the glazed balcony scatter diagram are more apparent in the black line (denoting outdoor temperature); i.e., balcony temperatures are clearly separate from the outdoor temperature and yet, almost without exception, higher. Momentarily, balcony temperatures are also below the outside temperature, but such moments are limited to a range of -13 °C and 18 °C. Third, the set of plots is most clearly detached from the outdoor temperature at its lowest and highest end of the temperature range, which indicates that glazing has the most significant effect during cold (outside temperature <13 °C) and warm days (ambient temperature >18 °C).

4.2 Factors affecting balcony inside temperatures

Heat loss reduction

Results show that the glazed balcony temperatures cannot be evaluated based on the buildings' age, as is evident from the mean ages of the different heat loss reduction groups (Table 4). Because the average age of all the groups ranges from 1985 to 1987, each group includes both new and old buildings. Furthermore, comparison of the results in terms of heat transfer by conduction (∑U*A) from the adjacent flat (column 9 in Table 4) shows that conduction loss is not a good indication of glazed balcony performance, because it contains only one balcony heat balance component. This can be seen, e.g., by comparing conduction loss reductions with total heat loss reductions. Conduction loss was the lowest in the group whose total change in heat loss (> 25%) was the highest. In contrast, the total heat loss reduction calculated with equation 1 gives a good picture of the actual temperature behavior of the balconies.

Table 4. Balcony mean air temperatures and the temperature difference between balconies and outdoor air in terms of balcony conduction loss reduction.

Balcony number	Construction year	Mean temperature [°C]	Maximum temperature [°C]	Minimum temperature [°C]	Temperature difference to outside air* [°C]	Adjacent flat temperature [°C]	Heat loss reduction [%], calculated according to equation 1.	Heat transfer by conduction (∑U*A) from adjacent flat to balcony [W/K]	Number of measured balconies
Outdoor air (Tampere - Pirkkala airport weather station)									
		1.5	27.0	-26.3					
Heat loss reduction <15 % (Unglazed balconies)									
20	1986	3.6 ± 0.3	29.6 ± 1.1	-22.0 ± 0.4	2.1 ± 0.3	23.8 ± 0.8	9.2 ± 1.4	9.5 ± 2.0	5
Heat loss reduction 15-20 % (glazed balconies)									
16	1985	5.2 ± 0.1	31.7 ± 0.8	-18.2 ± 1.7	3.7 ± 0.1	23.3 ± 0.6	16.8 ± 0.2	8.3 ± 1.0	3
Heat loss reduction 20-25 % (glazed balconies)									
10	1985	6.3 ± 0.2	34.1 ± 2.7	-16.5 ± 1.1	4.8 ± 0.2	23.5 ± 0.9	21.9 ± 1.5	9.6 ± 3.2	8
Heat loss reduction > 25 % (glazed balconies)									
4	1987	7.5 ± 0.6	34.6 ± 3.2	-15.5 ± 1.3	6.0 ± 0.6	22.9 ± 0.8	27.8 ± 2.3	8.2 ± 1.5	6

Heat transfer by conduction from building to balcony has a significant impact on the temperatures of glazed balconies during the coldest months of the year (Dec, Jan, and Feb). Because solar radiation is hardly available in the Tampere region in this period, glazed balconies are heated mostly via heat losses from the building. The balconies with most their wall within the building's "warm" enclosure structures (e.g., integrated balconies) seem to perform better than the protruding ones. The reason is higher heat transfer from the adjacent flat (on three sides of the balcony) and higher overall balcony tightness (one glazed side) than in protruding balconies with two or three glazed sides. However, if the solution is not tight enough, a good overall solution cannot be reached. For example, the integrated balcony (Balcony 9) shows the highest heat losses in January, but it is not the best balcony in this period because of poor tightness. A better solution, for example, is balcony 2 with typical heat loss but very high tightness.

Location (microclimate)

Measurements made by the Finnish Meteorological Institute (Section 3.1) showed that small local differences occurred in the outside temperatures during the measurement period, even though the measuring stations sought to eliminate the effect of micro-climatic factors. A strengthening of these effects can easily be inferred from comparing the results on the balconies with the Tampere–Pirkkala temperature information (Table 5).

Table 5. Balcony mean air temperatures and the temperature difference between the balconies and outdoor air in terms of building locations in Tampere suburban areas.

	Balcony number	Construction year	Mean temperature [°C]	Maximum temperature [°C]	Minimum temperature [°C]	Temperature difference to outside air* [°C]	Adjacent flat temperature [°C]	Heat loss reduction [%], calculated according to equation 1.	Heat transfer by conduction (∑U*A) from adjacent flat to balcony [W/K]	Number of measured balconies
Outdoor air (Tampere - Pirkkala airport weather station)										
			1.5	27.0	-26.3					
Hervanta										
Unglazed	21	1976	3.4 ± 0.0	30.2 ± 0.9	-22.0 ± 0.4	1.9 ± 0.0	23.3 ± 0.1	8.7 ± 0.0	11.1 ± 2.3	**2**
Glazed	7	1977	6.8 ± 0.9	33.3 ± 2.9	-15.7 ± 1.2	5.3 ± 0.9	23.0 ± 0.8	24.4 ± 4.2	9.1 ± 1.8	**9**
Härmälä										
Unglazed	21	2002	3.5 ± 0.4	28.7 ± 1.0	-22.2 ± 0.7	2.0 ± 0.4	24.5 ± 0.8	8.8 ± 1.9	7.8 ± 0.0	**2**
Glazed	13	2002	5.9 ± 0.6	35.0 ± 2.4	-17.8 ± 0.5	4.3 ± 0.6	24.2 ± 0.7	19.0 ± 2.1	7.8 ± 0.0	**3**

Lielahti										
Unglazed	18	1974	3.9	30.4	-21.7	2.4	23.4	11.0	9.5	**1**
Glazed	11	1988	6.4 ± 1.2	34.2 ± 3.6	-17.0 ± 2.1	4.9 ± 1.2	23.2 ± 0.5	22.5 ± 5.3	9.5 ± 4.5	**4**
Hatanpää										
Glazed	5	2000	7.0	33.4	-16.1	5.5	23.5	25.1	8.0	**1**

The coldest unglazed balcony was located in Härmälä (Balcony 22), the two next coldest in Hervanta (Balcony 20 and 21), the fourth coldest in Härmälä (Balcony 19), and the warmest in Lielahti. Interestingly, the temperature differed by 0.5 °C between the two unglazed balconies in Härmälä 15-20 metres apart from each other. The warmer balcony (Balcony 19) was 2.3 °C warmer than the outside and the colder one (balcony 22) 1.8 °C. Both balconies were open on two sides but oriented differently, which may explain the difference. The colder balcony was at a windy spot facing east and the warmer one in a sheltered area facing south. In addition, their solar absorption levels differed greatly. Balcony 22 showed typical solar energy absorption and balcony 19 a high level. Interestingly, the temperature difference between the two balconies was greater than that between the coldest (Hervanta) and the warmest (Lielahti) area (0.4 °C) (Table 5). It seems that the temperature differences between these unglazed balconies stemmed mostly from their different capabilities to absorb and store outside heat and from air circulation around them (cooling effect of wind). In some locations, more attention seems to have been paid to microclimate design, which resulted in a slight difference in unglazed balcony temperatures, though geographically the areas are less than 20 km apart with little effect on results in that respect.

Solar absorption (orientation and external obstacles)

On average, the impact on balcony temperatures of the difference between the best (very high) and the weakest (very low) solar absorption level was about 1.0 °C (Table 6). All the balconies with high or very high solar absorption warmed up strongly or very strongly in spring with the sun shining on them. The solar absorption levels of the three warmest balconies were also very high (Table 3). The warmest glazed balcony (Balcony 1) was in a block of flats in Hervanta with its indoor temperatures 6.6 °C higher than the outside because of very high solar absorption and structural tightness (Table 1). The second best balcony (Balcony 2) was also in Hervanta and the third best (Balcony 3) in Härmälä. Their temperature differences were 6.5°C and 6.3°C, respectively, above the outside air. However, balconies 11 and 7 deviated from the general pattern. Balcony 11 with three glazed sides received solar radiation clearly more than its classification indicates (typical solar absorption) (Figure 11). In contrast, the warming effect on balcony 7 was unlikely due to solar radiation but to extended flat ventilation through the open balcony door (Figure 12).

Table 6. Balcony mean air temperatures and the temperature difference between the balconies and outdoor air in terms of the number of external obstacles.

Balcony number	**Construction year**	**Mean temperature [°C]**	**Maximum temperature [°C]**	**Minimum temperature [°C]**	**Temperature difference to outside air* [°C]**	**Adjacent flat temperature [°C]**	**Heat loss reduction [%], calculated according to equation 1.**	**Heat transfer by conduction (ΣU*A) from adjacent flat to balcony [W/K]**	**Number of measured balconies**
Outdoor air (Tampere - Pirkkala airport weather station)									
		1.5	27.0	-26.3					
Unglazed balconies									
20	1986	3.6 ± 0.3	29.6 ± 1.1	-22.0 ± 0.4	2.0 ± 0.3	23.8 ± 0.8	9.2 ± 1.4	9.5 ± 2.0	5
Very low solar absorption level of balconies									
11	1979	5.9 ± 0.9	30.3 ± 0.9	-16.2 ± 0.5	4.4 ± 0.9	22.6 ± 1.5	21.2 ± 5.9	7.7 ± 0.0	2
Low solar absorption level of balconies									
10	1976	6.3	29.1	-15.4	4.8	21.7	23.6	12.7	1

Typical solar absorption level of balconies									
12	1990	6.0 ± 0.7	34.2 ± 1.6	16.7 ± 1.7	4.5 ± 0.7	23.8 ± 1.0	20.0 ± 3.4	10.5 ± 4.7	3
High solar absorption level of balconies									
8	1982	6.7 ± 0.4	35.6 ± 1.4	-16.4 ± 1.6	5.1 ± 0.5	23.5 ± 0.6	23.4 ± 2.8	9.1 ± 0.9	4
Very high solar absorption level of balconies									
8	1989	6.9 ± 1.2	34.4 ± 2.8	-16.5 ± 1.9	5.4 ± 1.2	23.3 ± 0.4	24.6 ± 5.3	7.9 ± 1.5	7

In addition to external obstruction, the balconies' orientation seemed to affect their ability to capture solar radiation. However, the orientation effect could not be analyzed in detail because the sample size was not sufficient for all orientations. In addition, the reliability of the analysis would have undermined external obstruction, which is also affected by the availability of solar energy. However, based on the research, southward orientation seems recommended. Furthermore, a deviation of ±45 ° from the South seems not to result in significantly reduced solar radiation. Of the five most energy-saving, glazed balconies, two were south-east oriented and the remaining three west, south-west, and south oriented (Table 3). Because there was almost no shading in front of those balconies, they received solar radiation also in winter. As mentioned above, the west-facing balcony had two open sides with one on the south side; consequently, it received more solar radiation than the south-facing balconies with one open side.

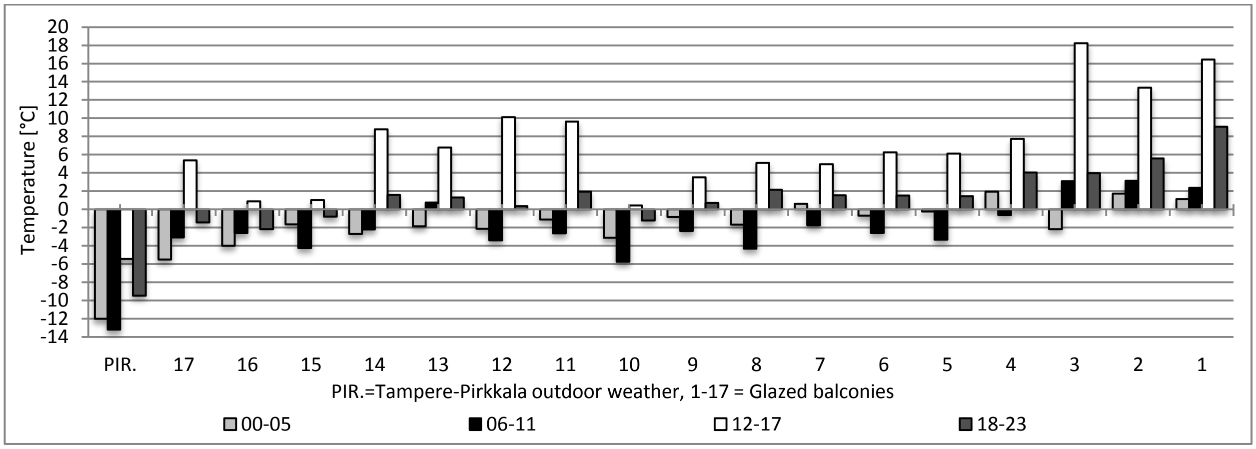

Figure 11. One early spring day (15th March) and outdoor weather at Tampere-Pirkkala divided into six-hour periods.

As a whole, solar absorption seems a more critical factor than heat loss from building to balcony or the building's location. The three annually warmest balconies (Balcony 1, 2 and 3) were far from the warmest in November and December, but without exception they were the warmest in spring and autumn. Solar radiation seems to start affecting monthly temperatures as early as in January. In February, the second coldest month of the year, heat losses from buildings to balconies affect the results greatly, but low heat loss can be compensated for by the spring sun, whose effect is also significant.

Amount of glazing

Increasing the amount of glazing by replacing a 180-mm thick balcony side wall element ($U = 3.5\ W / m^2K$) with balcony glazing ($U = 5.7\ W / m^2K$) increased slightly conduction heat losses from balcony to outside air. Increased glazing affected also the air tightness of the balcony, because a part of a tight wall structure was replaced with a leaky glazing structure, which increased unintended ventilation on the glazed balcony. On the other hand, increased glazing increased the balcony's solar absorption, thus compensating for conduction heat losses and increasing unintended ventilation. The effect of these factors is discussed in this section.

Table 7. Balcony mean air temperatures and the temperature difference between the balconies and outdoor air in terms of the number of balcony glazed sides.

Balcony number	Construction year	Mean temperature [°C]	Maximum temperature [°C]	Minimum temperature [°C]	Temperature difference to outside air* [°C]	Adjacent flat temperature [°C]	Heat loss reduction [%], calculated according to equation 1.	Heat transfer by conduction (ΣU*A) from adjacent flat to balcony [W/K]	Number of measured balconies
Outdoor air (Tampere - Pirkkala airport weather station)									
		1.5	27.0	-26.3					
Unglazed balconies									
20	1986	3.6 ± 0.3	29.6 ± 1.1	-22.0 ± 0.4	2.0 ± 0.3	23.8 ± 0.8	9.2 ± 1.4	9.5 ± 2.0	5
Glazed balconies, one glazed side									
9	1976	6.4 ± 0.9	32.8 ± 2.7	-15.9 ± 1.8	4.9 ± 0.9	22.8 ± 0.8	23.1 ± 4.3	10.0 ± 2.7	9
Glazed balconies, two glazed side									
8	1994	6.8 ± 1.1	34.5 ± 2.8	-16.8 ± 0.8	5.3 ± 1.1	23.6 ± 0.3	24.0 ± 5.1	7.6 ± 1.2	6
Glazed balconies, three glazed side									
12	2002	6.2 ± 0.1	36.3 ± 1.0	-17.7 ± 0.6	4.7 ± 0.1	24.6 ± 0.5	20.3 ± 0.2	7.8 ± 0.0	2

Table 7 shows that balconies with two or more open side capture a lot of solar radiation (from two or three directions), though they are also untighter than the balconies with one open side (untighness is directly proportional to the amount of glazing). In general, this means that temperature fluctuations become greater with an increased amount of glazing. On average, the solar energy absorption of balconies with one glazed side was typical, those with two glazed sides very high, and those with three glazed sides high (Table 3). Similarly, the air tightness of the balconies was high, high, and low, respectively. The optimal solution for the indoor air temperature mean seems to be balconies glazed on two sides because of their high solar absorption and tightness (Table 7). In contrast, the coldest temperatures were recorded for balconies with three glazed sides, low tightness, and high solar energy absorption, which means that increased unintended ventilation lowered the results more than increased solar energy absorption could compensate for. On average, the temperature difference between the balconies with two and three open sides was 0.6 °C.

Tightness of balcony vertical structures

The average temperature difference between the balconies with very high tightness and those with very low tightness is 2.1 °C (Table 8), i.e., clearly more than in any other review in section 4.2. Furthermore, the difference between balconies with very high and low tightness was significant (1.0 °C). This clearly shows the importance of tightness for the final result. Table 8 also reveals that the maximum temperature of the balconies with very high tightness is lower than that of balconies with typical or high tightness. At the same time, heat transfer by conduction from flat to balconies is the lowest for balconies with very high tightness (7.9 W/K), but the change in their total heat losses (26.1%) is the highest. These findings indicate that tightness is the most important factor in terms of balcony indoor temperatures. The effect of tightness bears also on balcony minimum temperatures, which have increased with improved tightness. The balconies with high tightness show an average minimum temperature of -15.2 °C and those with very high tightness an average minimum temperature of -15.8 °C. This result have seen even if the balconies with high tightness receive more heat from the adjacent apartment (heat transfer through enclosed structures) during the winter season than those with very high tightness.

Table 8. Balcony mean air temperatures and the temperature difference between the balconies and the outdoor in terms of structural air tightness.

Balcony number	Construction year	Mean temperature [°C]	Maximum temperature [°C]	Minimum temperature [°C]	Temperature difference to outside air* [°C]	Adjacent flat temperature [°C]	Heat loss reduction [%], calculated according to equation 1.	Heat transfer by conduction (ΣU*A) from adjacent flat to balcony [W/K]	Number of measured balconies
Outdoor air (Tampere - Pirkkala airport weather station)									
		1.5	27.0	-26.3					
Unglazed balconies									
20	1986	3.6 ± 0.3	29.6 ± 1.1	-22.0 ± 0.4	2.0 ± 0.3	23.8 ± 0.8	9.2 ± 1.4	9.5 ± 2.0	5
Very low overall tightness of the balcony vertical structures									
17	1974	5.1	31.7	-19.9	3.5	22.6	16.8	9.5	1
Low overall tightness of the balcony vertical structures									
12	1992	6.2 ± 0.1	33.3 ± 3.2	-16.7 ± 1.0	4.7 ± 0.1	23.6 ± 1.2	21.1 ± 1.4	8.4 ± 2.5	5
Typical overall tightness of the balcony vertical structures									
11	1981	6.1 ± 0.8	34.4 ± 1.9	-16.8 ± 1.7	4.6 ± 0.8	23.4 ± 0.3	20.9 ± 3.8	11.1 ± 4.3	3
High overall tightness of the balcony vertical structures									
5	1975	7.0 ± 0.4	34.6 ± 1.4	-15.2 ± 0.8	5.4 ± 0.4	23.2 ± 0.6	25.1 ± 2.8	9.5 ± 0.0	2
Very high overall tightness of the balcony vertical structures									
6	1987	7.2 ± 1.1	34.1 ± 3.6	-15.8 ± 1.3	5.6 ± 1.1	23.1 ± 0.8	26.1 ± 5.0	7.9 ± 1.3	6

The importance of tight structures is also confirmed in Table 3. The air leakage of glazed balcony 17 (the coldest) was the highest in the group, and the five coldest balconies included three leakiest glazed balconies. However, the air tightness of two of those balconies was very high (Balcony 14 and 13), but for some reason the tenant had left the glazing open for the entire measurement period, thus contributing to a low total tightness. The effect of increased air circulation to the balcony temperatures was particularly evident in buildings C and D. For example, in building C, the glazing on balcony 1 was kept closed whereas that on balcony 14 was partly open for the whole measurement period, resulting in a 2.0 °C temperature difference (6.6 °C and 4.6 °C, respectively) between the balconies, though they were almost adjacent to each other. Similarly, in building K, the average temperatures were 6.3 °C with the balcony closed and 4.6 °C with the balcony partly open (one pane open). Resident activity was also instrumental in another context. For example, balcony 7 warmed effectively when its door was left open for long periods during the measurement period (Figure 12), yielding a significant difference in the average temperature of the balconies in the same building (1.3 °C between balconies 7 and 15).

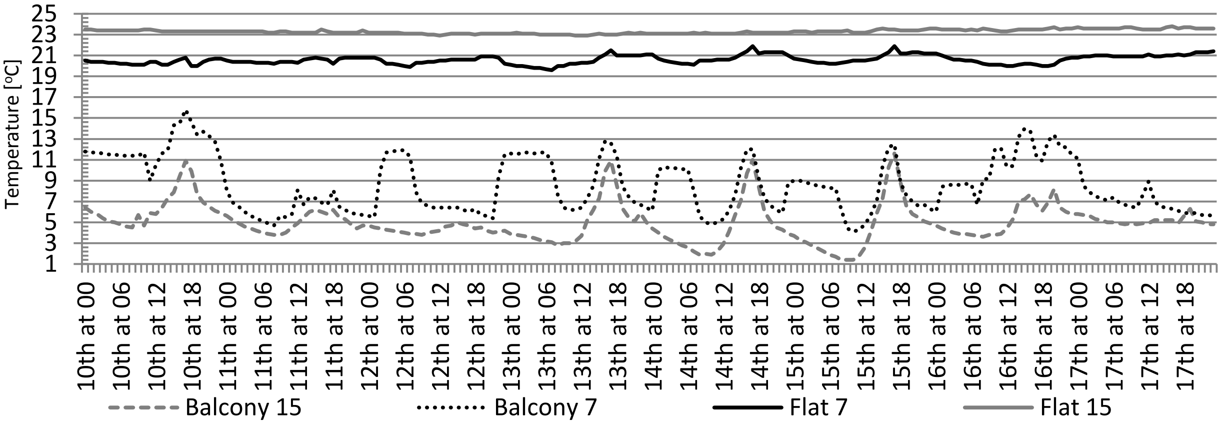

Figure 12. Temperatures of balcony 15 and 7 and of adjacent apartments from 10 to 17 October, 2009. The figure shows how the resident of flat 7 ventilated the flat by keeping the balcony door open, especially at night.

4.3 Possible uncertainties

The measurement data used, like large field data in general, included several possible sources of error, which may have affected the results and led to misinterpretations of the results. Such sources of error comprise the following:

- Different placements of the measurement devices (The devices were not all identically positioned, because the new mechanical attachment was avoided).
- Wrong information about buildings, balconies, and balcony glazing structural properties (buildings are not necessarily built according to blueprints).
- A lack of knowledge of tenant activities in flats and balconies (most important).
- Inaccuracy of the building's external shading and balcony tightness (evaluated by measuring air gaps on site, inspecting structural drawings, and visually observing on-site).
- Uncertainty caused by the cooling effect of air entering a flat through a glazed balcony (if the inlet was inside a glazed balcony). The effect of an air inlet on temperature drop is typically in the range of 1 – 3°C, depending on the volume of the balcony in relation to that of the flat [9].
- Temperature stratification on the balcony and its variation depending on the case.

It is impossible to assess afterwards the impact of the above errors. The only option then is to make the sample size as large as possible to minimize the effect of various errors. In some cases, though the sample size was not sufficient enough to generalize about the results, it yet produced valuable, practical information about glazed balcony temperature behavior and provided valuable comparison material for computational analysis.

5 CONCLUSION

Measurements showed that the temperature of both glazed and unglazed balconies is above the outdoor temperature almost throughout the year. On average, the temperature of the unglazed balcony was 2.0°C and that of the glazed balcony 5.0°C higher than outdoors. The differences in temperature between the balconies and the outdoor air varied depending on the time of day and the season. As outdoor temperatures decreased, the difference in temperature between the glazed balcony and the outdoor air increased, and vice versa. The greatest temperature difference between the glazed balcony and the outside air was measured during solar radiation, which warmed up the glazed space very rapidly and caused the greatest temperature difference between the space and the outdoor air (29.6 °C). The three key factors affecting the indoor temperatures of the glazed balconies seemed to be structural air tightness, absorption of solar radiation, and heat losses from building to balcony, in that order. Air tightness was the most crucial factor since it affected the results all year round. Solar radiation was significant only in spring, summer, and autumn because of Finland´s high latitudinal location. Heat loss from building to balcony, in turn, was relevant in mid-winter when the difference in temperature between the building and the outdoors could be as high as 60 °C. In mid-winter, glazing a balcony as opposed to an unglazed balcony brings the benefit of being able to store the heat loss from the building inside the balcony.

6 ACKNOWLEDGEMENT

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Tables with Captions

Table 1. The building-specific information on the studied buildings.

Building code	Balcony codes	Location	Building type, construction year, external wall structure and U-value	Balcony type, dimensions (Number of glazed sides informed in parentheses)	U-values of windows and doors	Balcony material (parapet material informed in parentheses)	Heat transfer by conduction (ΣU*A) from adjacent flat to balcony [W/K]	Solar absoption level of balconies (External obstruction informed in parentheses)	Overall tightness of the balcony* (after user effect)
A	**9**	Lielahti	in-situ frame, band façade, 1966, brick U=0.47	Recessed, w=3.8m, d=1.5m, h=2.6m, (1)	U=1.8 (windows), U=1.4 (doors)	Concrete balcony, (hardboard parapet)	Very high, 15.9	Typical (adjacent building)	High (typical)
B	**17, 18**	Lielahti	precast concrete, 1974, concrete sandwich panel, U=0.4	Protruding, w=4.0m, d=1.9m, h=3.1 or 2.6m (1)	U=1.2 (windows), U=1.2 (doors)	concrete balcony (extended 0.5m), (hardboard parapet)	Typical, 9.5	Very high (no external obstruction)	Very low
C	**1, 14**	Hervanta	precast concrete, 1975, concrete sandwich panel, U=0.4	Protruding, w=4.0m, d=1.5m, h=2.6m (both 1 and 2)	U=1.2 (windows), U=1.2 (doors)	concrete balcony, (30 % glass, 70% concrete parapet)	Low, 7.4	Very high (no external obstruction)	Very high (low)
D	**4, 6, 8, 20**	Hervanta	precast concrete, 1975, concrete sandwich panel, U=0.4	Protruding, w=4.0m, d=1.5m, h=2.6m (both 1 and 2)	U=1.4 (windows), U=1.2 (doors)	concrete balcony, (hardboard parapet)	Typical, 9.5	High (building ≈50 m in front)	High (typical)
E	**10, 21**	Hervanta	precast concrete, 1976, concrete sandwich panel, U=0.4	Protruding, w=4.0m, d=1.5m, h=2.6m (1)	U=2.1 (windows), U=2.0 (doors)	concrete balcony, (concrete parapet)	High, 12.7	Low (medium dense forest in front)	Very high (low)
F	**7, 15**	Hervanta	precast concrete, 1979, concrete sandwich panel, U=0.29	Protruding, w=4.0m, d=1.5m, h=2.6m (1)	U=1.2 (windows), U=1.2 (doors)	concrete balcony, (concrete parapet)	Low, 7.7	Very low (dense forest in front)	Very high
G	**2**	Hervanta	precast concrete, 1984, concrete sandwich panel, U=0.29	Protruding, w=3.9m, d=2.2m, h=2.6m (1)	U=1.8 (windows), U=2.0 (doors)	concrete balcony, (concrete parapet)	Typical, 10.3	Very high (no external obstruction)	Very high
H	**5**	Hatanpää	precast concrete, 2002, concrete sandwich panel, U=0.27	Protruding, w=2.8m, d=2.4m, h=3.0m (2)	U=1.4 (windows), U=1.4 (doors)	concrete balcony, (concrete parapet)	Low, 8.0	Very high (no external obstruction)	Very high
I	**11, 16, 22**	Härmälä	precast concrete, 2002, concrete sandwich panel, U=0.27	Protruding, w=3.6m, d=2.4m, h=2.8m (2 and 3)	U=1.4 (Windows), U=1.4 (doors)	concrete balcony, (sheet metal parapet)	Low, 7.8	Typical (buildings adjacent and ahead)	Typical (low)
J	**12, 19**	Härmälä	precast concrete, 2002, concrete sandwich panel, U=0.27	Protruding, w=3.6m, d=2.4m, h=2.8m (3)	U=1.4 (windows), U=1.4 (doors)	concrete balcony, (sheet metal parapet)	Low, 7.8	High (adjacent buildings)	Typical (low)
K	**3, 13**	Lielahti	precast concrete, 2006, concrete sandwich panel, U=0.24	Protruding, w=4.3m, d=2.0m, h=2.7m (2)	U=1.2 (windows), U=1.2 (doors)	concrete balcony, (glass parapet)	Very low, 6.3	Very high (no external obstruction)	Very high (low)

*** In Finland, all balcony glazing structures are leaky structures because of 2–3-mm air gaps between the glass panes, yet the air outflow can range, according to our estimation, from 1l/s to 40l/s because of different overall glazed balcony solutions (the main things are the tightness of the balcony vertical structures and balcony heat gains from solar radiation and transfer from the adjacent flat). This effect was assessed at this point. In some flats, residents left their balcony glazing periodically partly open or even for the entire measurement period. This effect on overall balcony tightness is given in parentheses.**

Table 2. Measurement range, display resolution, and accuracy of the used Comark Diligence EV (N2003 and N2013) data loggers.

	Measurement range	**Display resolution**	**Accuracy -25°C to +50°C**
Temperature	-20°C to +60°C	0.1°	±0.5°
	Measurement range	**Display resolution**	**Accuracy -20°C to +80°C**
Humidity	0- 97 %	0.1% RH	±3 RH

Table 3. Balconies ranked from warmest to coldest based on their mean air temperatures over the whole measurement period.

Balcony number	Building code	Construction year	Mean temperature [°C]	Maximum temperature [°C]	Minimum temperature [°C]	Temperature difference to outside air* [°C]	Adjacent flat temperature [°C]	Heat loss reduction [%], calculated according to equation 1.	Heat transfer by conduction (ΣU*A) from adjacent flat to balcony [W/K]	Solar absorption level of balconies (reason)	Overall tightness of the balcony vertical structures	The number of the glazed sides of the balconies
Unglazed balconies												
1.	C	1975	8.1	34.8	-16.3	6.6	23.7	29.8	Low, 7.4	Very high (no external obstruction)	Very high	**2**
2.	G	1984	8.0	36.9	-13.3	6.5	23.1	30.1	Typical, 10.3	Very high (no external obstruction)	Very high	**1**
3.	K	2006	7.9	39.0	-16.7	6.3	23.1	29.4	Very low, 6.3	Very high (no external obstruction)	Very high	**2**
4.	D	1975	7.3	33.6	-14.6	5.7	22.7	27.1	Typical, 9.5	High (building ≈50 m in front)	High	**1**
5.	H	2000	7.0	33.4	-16.1	5.5	23.5	25.1	Low, 8.0	Very high (no external obstruction)	Very high	**2**
6.	D	1975	6.7	35.6	-15.7	5.1	23.6	23.2	Typical, 9.5	High (building ≈50 m in front)	High	**1**
7.	F	1979	6.6	29.6	-15.8	5.1	21.5	25.4	Low, 7.7	Very low (dense forest in front)	Very high	**1**
8.	D	1975	6.5	36.1	-17.3	5.0	23.5	22.8	Typical, 9.5	High (building ≈50 m in front)	Typical	**2**
9.	A	1966	6.5	34.6	-14.9	5.0	23.0	23.3	Very high, 15.9	Typical (adjacent building)	Typical	**1**
10.	E	1976	6.3	29.1	-15.4	4.8	21.7	23.6	High, 12.7	Low (medium dense forest in front)	Low	**1**
11.	I	2002	6.2	35.6	-17.2	4.7	24.9	20.1	Low, 7.8	Typical (buildings adjacent and ahead)	Low	**3**
12.	J	2002	6.2	37.0	-18.1	4.6	24.2	20.4	Low, 7.8	High (adjacent buildings)	Low	**3**
13.	K	2006	6.1	31.3	-16.3	4.6	23.9	20.5	Very low, 6.3	Very high (no external obstruction)	Low	**2**
14.	C	1975	6.1	33.4	-16.7	4.6	23.3	21.0	Low, 7.4	Very high (no external obstruction)	Low	**1**
15.	F	1979	5.3	30.9	-16.5	3.8	23.6	17.1	Low, 7.7	Very low (dense forest in front)	Very high	**1**
16.	I	2002	5.2	32.4	-18.1	3.7	23.6	16.6	Low, 7.8	Typical (buildings adjacent and ahead)	Typical	**2**
17.	B	1974	5.1	31.7	-19.9	3.5	22.6	16.8	Typical, 9.5	Very high (no external obstruction)	Very low	**1**
Unglazed balconies												
18.	B	1974	3.9	30.4	-21.7	2.4	23.4	11.0	Typical, 9.5	Very high (no external obstruction)		
19.	J	2002	3.8	29.4	-21.7	2.3	23.9	10.1	Low, 7.8	High (adjacent buildings)		
20.	D	1975	3.4	30.8	-21.7	1.9	23.2	8.7	Typical, 9.5	High (building ≈50 m in front)		
21.	E	1976	3.4	29.5	-22.2	1.9	23.3	8.7	High, 12.7	Low (medium dense forest in front)		
22.	I	2002	3.3	28.0	-22.7	1.8	25.1	7.5	Low, 7.8	Typical (buildings adjacent and ahead)		
Outdoor air (Tampere - Pirkkala airport weather station)												
			1.5	27.0	-26.3							

* Temperature difference has been calculated by deducting Tampere-Pirkkala average outdoor air temperature (1.5 °C) from average balcony temperature over the whole period. For example, balcony 1 temperature difference is 8.1-1.5=6.6 °C.

Table 4. Balcony mean air temperatures and the temperature difference between balconies and outdoor air in terms of balcony conduction loss reduction.

Balcony number	Construction year	Mean temperature [°C]	Maximum temperature [°C]	Minimum temperature [°C]	Temperature difference to outside air* [°C]	Adjacent flat temperature [°C]	Heat loss reduction [%], calculated according to equation 1.	Heat transfer by conduction (ΣU*A) from adjacent flat to balcony [W/K]	Number of measured balconies
Outdoor air (Tampere - Pirkkala airport weather station)									
		1.5	27.0	-26.3					
Heat loss reduction <15 % (Unglazed balconies)									
20	1986	3.6 ± 0.3	29.6 ± 1.1	-22.0 ± 0.4	2.1 ± 0.3	23.8 ± 0.8	9.2 ± 1.4	9.5 ± 2.0	5
Heat loss reduction 15-20 % (glazed balconies)									
16	1985	5.2 ± 0.1	31.7 ± 0.8	-18.2 ± 1.7	3.7 ± 0.1	23.3 ± 0.6	16.8 ± 0.2	8.3 ± 1.0	3

Heat loss reduction 20-25 % (glazed balconies)									
10	1985	6.3 ± 0.2	34.1 ± 2.7	-16.5 ± 1.1	4.8 ± 0.2	23.5 ± 0.9	21.9 ± 1.5	9.6 ± 3.2	8
Heat loss reduction > 25 % (glazed balconies)									
4	1987	7.5 ± 0.6	34.6 ± 3.2	-15.5 ± 1.3	6.0 ± 0.6	22.9 ± 0.8	27.8 ± 2.3	8.2 ± 1.5	6

Table 5. Balcony mean air temperatures and the temperature difference between the balconies and outdoor air in terms of building locations in Tampere suburban areas.

	Balcony number	Construction year	Mean temperature [°C]	Maximum temperature [°C]	Minimum temperature [°C]	Temperature difference to outside air* [°C]	Adjacent flat temperature [°C]	Heat loss reduction [%], calculated according to equation 1.	Heat transfer by conduction (∑U*A) from adjacent flat to balcony [W/K]	Number of measured balconies
Outdoor air (Tampere - Pirkkala airport weather station)										
			1.5	27.0	-26.3					
Hervanta										
Unglazed	21	1976	3.4 ± 0.0	30.2 ± 0.9	-22.0 ± 0.4	1.9 ± 0.0	23.3 ± 0.1	8.7 ± 0.0	11.1 ± 2.3	**2**
Glazed	7	1977	6.8 ± 0.9	33.3 ± 2.9	-15.7 ± 1.2	5.3 ± 0.9	23.0 ± 0.8	24.4 ± 4.2	9.1 ± 1.8	**9**
Härmälä										
Unglazed	21	2002	3.5 ± 0.4	28.7 ± 1.0	-22.2 ± 0.7	2.0 ± 0.4	24.5 ± 0.8	8.8 ± 1.9	7.8 ± 0.0	**2**
Glazed	13	2002	5.9 ± 0.6	35.0 ± 2.4	-17.8 ± 0.5	4.3 ± 0.6	24.2 ± 0.7	19.0 ± 2.1	7.8 ± 0.0	**3**
Lielahti										
Unglazed	18	1974	3.9	30.4	-21.7	2.4	23.4	11.0	9.5	**1**
Glazed	11	1988	6.4 ± 1.2	34.2 ± 3.6	-17.0 ± 2.1	4.9 ± 1.2	23.2 ± 0.5	22.5 ± 5.3	9.5 ± 4.5	**4**
Hatanpää										
Glazed	5	2000	7.0	33.4	-16.1	5.5	23.5	25.1	8.0	**1**

Table 6. Balcony mean air temperatures and the temperature difference between the balconies and outdoor air in terms of the number of external obstacles.

Balcony number	Construction year	Mean temperature [°C]	Maximum temperature [°C]	Minimum temperature [°C]	Temperature difference to outside air* [°C]	Adjacent flat temperature [°C]	Heat loss reduction [%], calculated according to equation 1.	Heat transfer by conduction (∑U*A) from adjacent flat to balcony [W/K]	Number of measured balconies
Outdoor air (Tampere - Pirkkala airport weather station)									
		1.5	27.0	-26.3					
Unglazed balconies									
20	1986	3.6 ± 0.3	29.6 ± 1.1	-22.0 ± 0.4	2.0 ± 0.3	23.8 ± 0.8	9.2 ± 1.4	9.5 ± 2.0	5
Very low solar absorption level of balconies									
11	1979	5.9 ± 0.9	30.3 ± 0.9	-16.2 ± 0.5	4.4 ± 0.9	22.6 ± 1.5	21.2 ± 5.9	7.7 ± 0.0	2
Low solar absorption level of balconies									
10	1976	6.3	29.1	-15.4	4.8	21.7	23.6	12.7	1
Typical solar absorption level of balconies									
12	1990	6.0 ± 0.7	34.2 ± 1.6	16.7 ± 1.7	4.5 ± 0.7	23.8 ± 1.0	20.0 ± 3.4	10.5 ± 4.7	3
High solar absorption level of balconies									
8	1982	6.7 ± 0.4	35.6 ± 1.4	-16.4 ± 1.6	5.1 ± 0.5	23.5 ± 0.6	23.4 ± 2.8	9.1 ± 0.9	4
Very high solar absorption level of balconies									
8	1989	6.9 ± 1.2	34.4 ± 2.8	-16.5 ± 1.9	5.4 ± 1.2	23.3 ± 0.4	24.6 ± 5.3	7.9 ± 1.5	7

Table 7. Balcony mean air temperatures and the temperature difference between the balconies and outdoor air in terms of the number of balcony glazed sides.

Balcony number	Construction year	Mean temperature [°C]	Maximum temperature [°C]	Minimum temperature [°C]	Temperature difference to outside air* [°C]	Adjacent flat temperature [°C]	Heat loss reduction [%], calculated according to equation 1.	Heat transfer by conduction (ΣU*A) from adjacent flat to balcony [W/K]	Number of measured balconies
Outdoor air (Tampere - Pirkkala airport weather station)									
		1.5	27.0	-26.3					
Unglazed balconies									
20	1986	3.6 ± 0.3	29.6 ± 1.1	-22.0 ± 0.4	2.0 ± 0.3	23.8 ± 0.8	9.2 ± 1.4	9.5 ± 2.0	5
Glazed balconies, one glazed side									
9	1976	6.4 ± 0.9	32.8 ± 2.7	-15.9 ± 1.8	4.9 ± 0.9	22.8 ± 0.8	23.1 ± 4.3	10.0 ± 2.7	9
Glazed balconies, two glazed side									
8	1994	6.8 ± 1.1	34.5 ± 2.8	-16.8 ± 0.8	5.3 ± 1.1	23.6 ± 0.3	24.0 ± 5.1	7.6 ± 1.2	6
Glazed balconies, three glazed side									
12	2002	6.2 ± 0.1	36.3 ± 1.0	-17.7 ± 0.6	4.7 ± 0.1	24.6 ± 0.5	20.3 ± 0.2	7.8 ± 0.0	2

Table 8. Balcony mean air temperatures and the temperature difference between the balconies and the outdoor in terms of structural air tightness.

Balcony number	Construction year	Mean temperature [°C]	Maximum temperature [°C]	Minimum temperature [°C]	Temperature difference to outside air* [°C]	Adjacent flat temperature [°C]	Heat loss reduction [%], calculated according to equation 1.	Heat transfer by conduction (ΣU*A) from adjacent flat to balcony [W/K]	Number of measured balconies
Outdoor air (Tampere - Pirkkala airport weather station)									
		1.5	27.0	-26.3					
Unglazed balconies									
20	1986	3.6 ± 0.3	29.6 ± 1.1	-22.0 ± 0.4	2.0 ± 0.3	23.8 ± 0.8	9.2 ± 1.4	9.5 ± 2.0	5
Very low overall tightness of the balcony vertical structures									
17	1974	5.1	31.7	-19.9	3.5	22.6	16.8	9.5	1
Low overall tightness of the balcony vertical structures									
12	1992	6.2 ± 0.1	33.3 ± 3.2	-16.7 ± 1.0	4.7 ± 0.1	23.6 ± 1.2	21.1 ± 1.4	8.4 ± 2.5	5
Typical overall tightness of the balcony vertical structures									
11	1981	6.1 ± 0.8	34.4 ± 1.9	-16.8 ± 1.7	4.6 ± 0.8	23.4 ± 0.3	20.9 ± 3.8	11.1 ± 4.3	3
High overall tightness of the balcony vertical structures									
5	1975	7.0 ± 0.4	34.6 ± 1.4	-15.2 ± 0.8	5.4 ± 0.4	23.2 ± 0.6	25.1 ± 2.8	9.5 ± 0.0	2
Very high overall tightness of the balcony vertical structures									
6	1987	7.2 ± 1.1	34.1 ± 3.6	-15.8 ± 1.3	5.6 ± 1.1	23.1 ± 0.8	26.1 ± 5.0	7.9 ± 1.3	6

Figure 1

Click here to download high resolution image

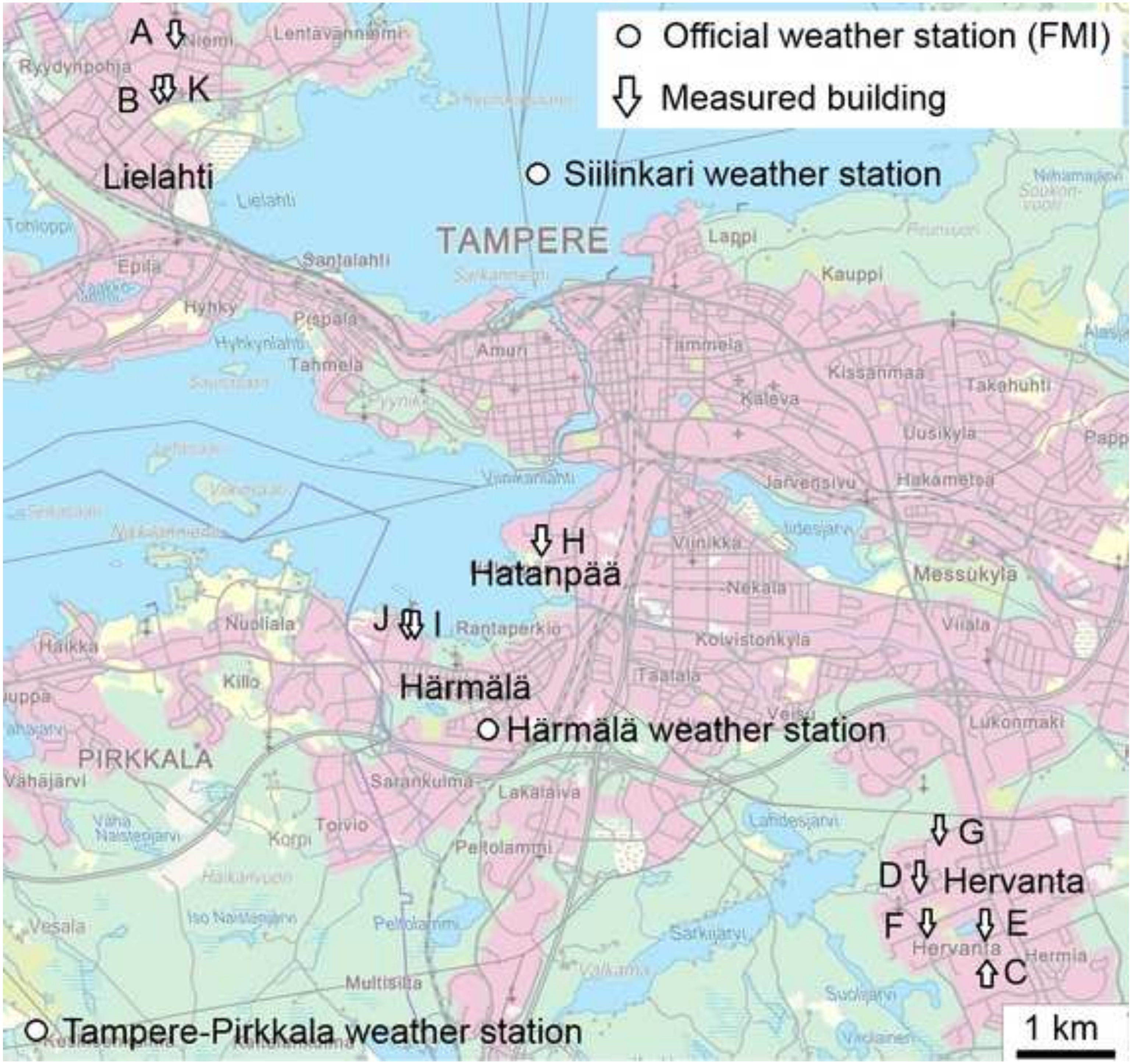
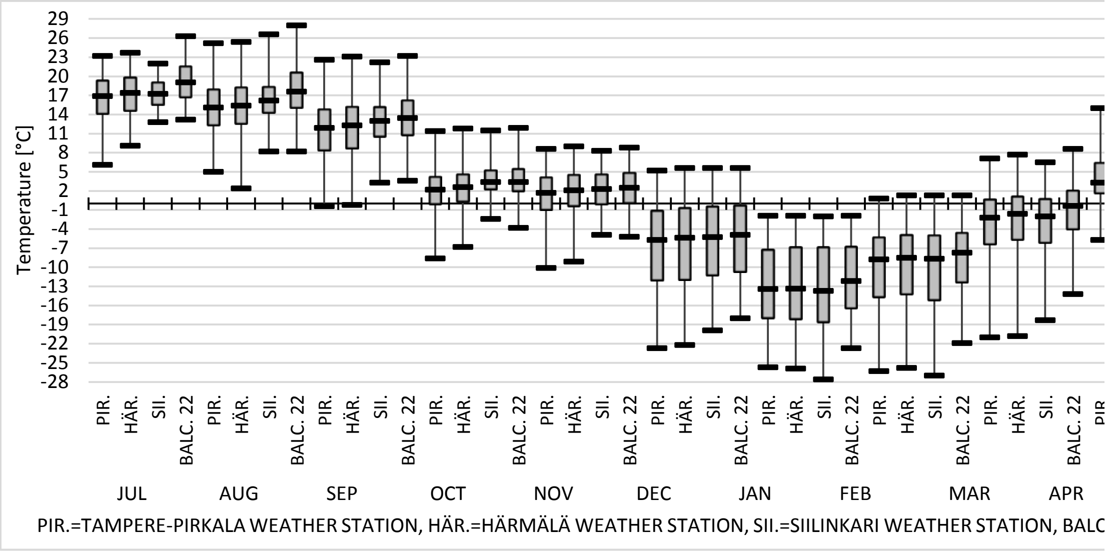


Figure 2



Temperature [°C]
29
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PIR.=TAMPERE-PIRKALA WEATHER STATION, HÄR.=HÄRMÄLÄ WEATHER STATION, SII.=SIILINKARI WEATHER STATION, BALC

Figure 3

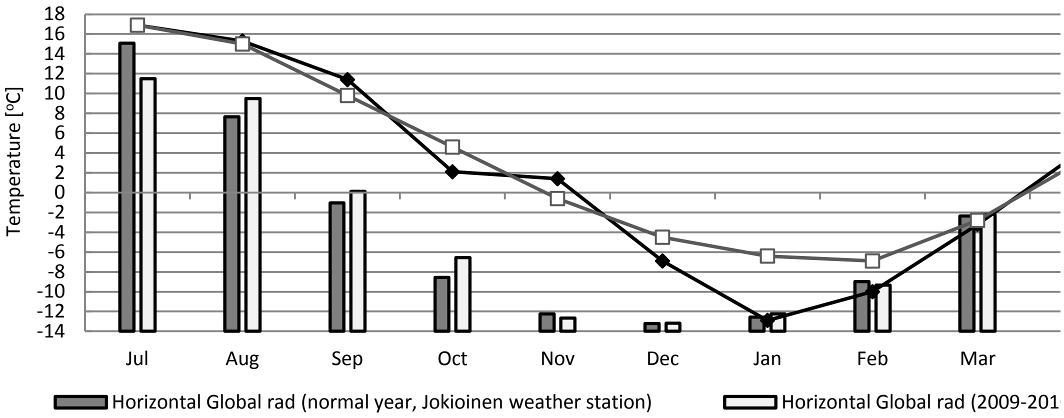

18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
Temperature [°C]
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Horizontal Global rad (normal year, Jokioinen weather station)
Horizontal Global rad (2009-201

Figure 4

Figure 5

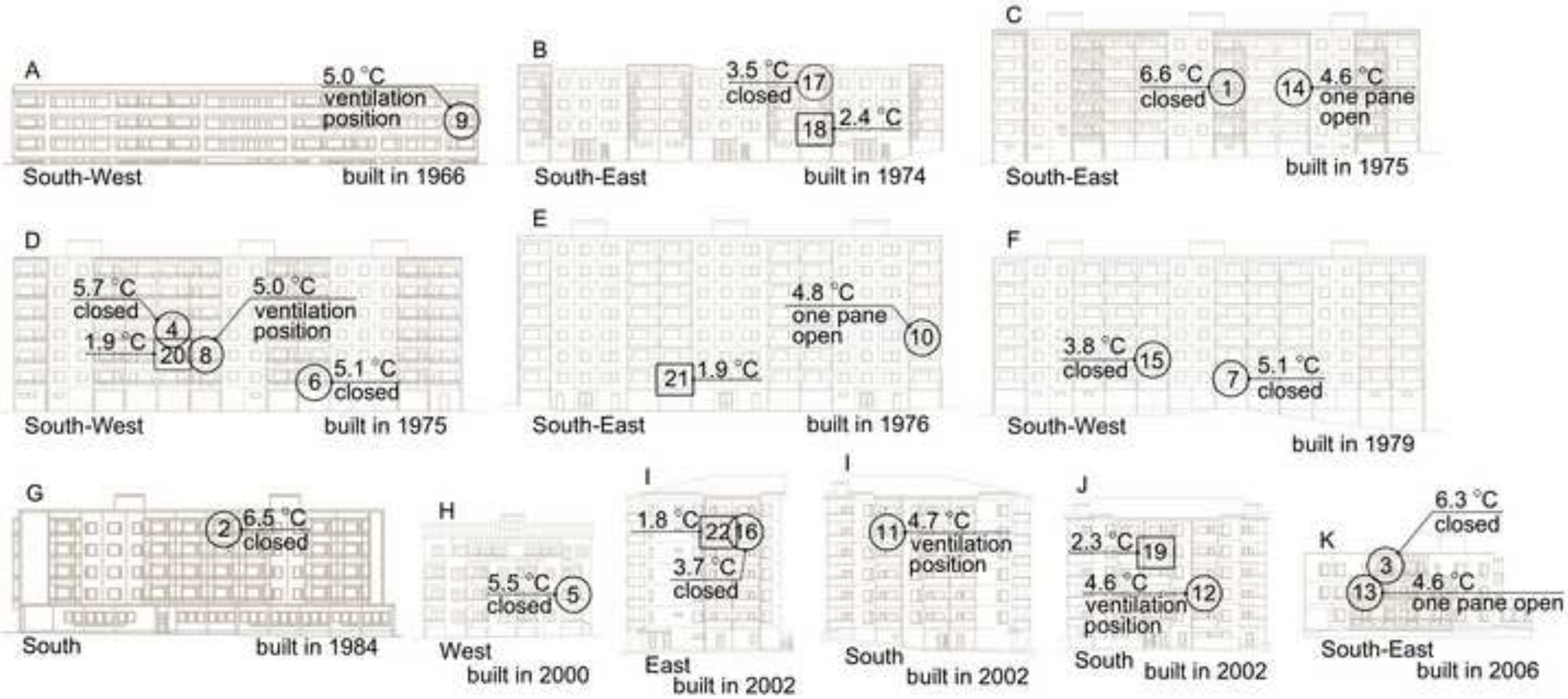

A
5.0 °C ventilation position
9
South-West
built in 1966
B
3.5 °C closed
17
18
2.4 °C
South-East
built in 1974
C
6.6 °C closed
1
14
4.6 °C one pane open
South-East
built in 1975
D
5.7 °C closed
4
5.0 °C ventilation position
1.9 °C
20
8
6
5.1 °C closed
South-West
built in 1975
E
4.8 °C one pane open
10
21
1.9 °C
South-East
built in 1976
F
3.8 °C closed
15
7
5.1 °C closed
South-West
built in 1979
G
2
6.5 °C closed
South
built in 1984
H
5.5 °C closed
5
West
built in 2000
I
1.8 °C
22
16
3.7 °C closed
East
built in 2002
I
11
4.7 °C ventilation position
South
built in 2002
J
2.3 °C
19
4.6 °C ventilation position
12
South
built in 2002
K
6.3 °C closed
3
13
4.6 °C one pane open
South-East
built in 2006

Figure 6

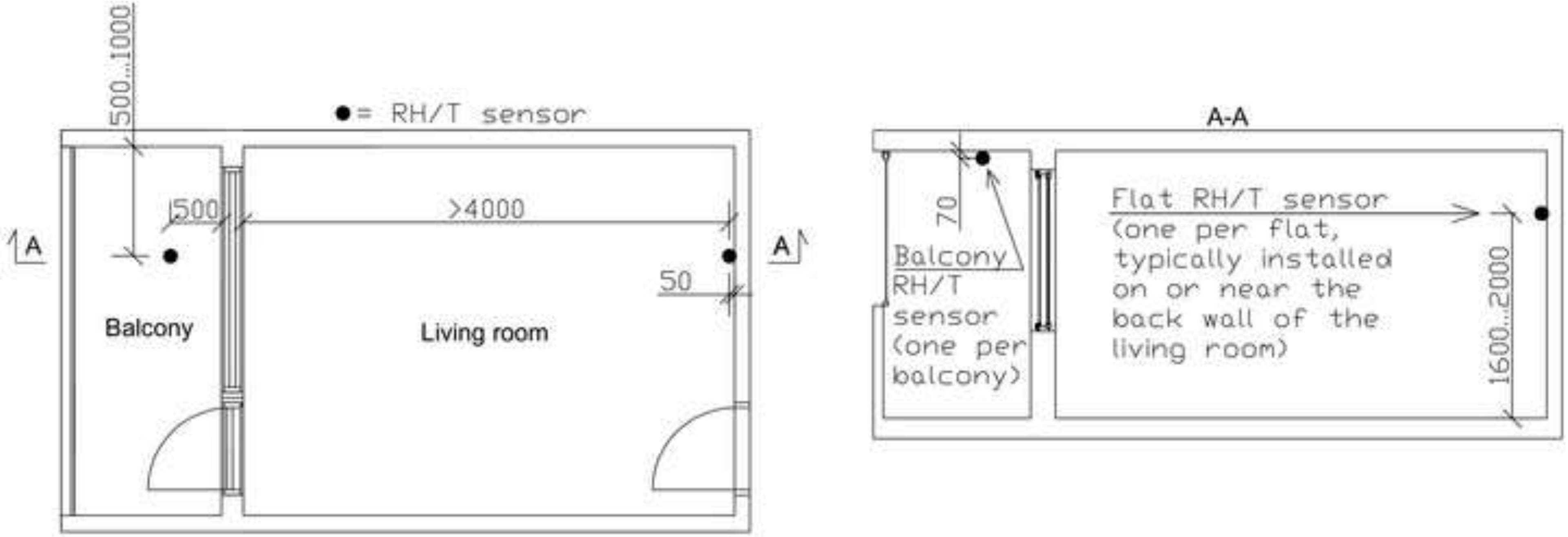

500...1000
● = RH/T sensor
500
>4000
50
A
A
Balcony
Living room
A-A
70
Balcony RH/T sensor (one per balcony)
Flat RH/T sensor (one per flat, typically installed on or near the back wall of the living room)
1600...2000

Figure 7

Figure 8a

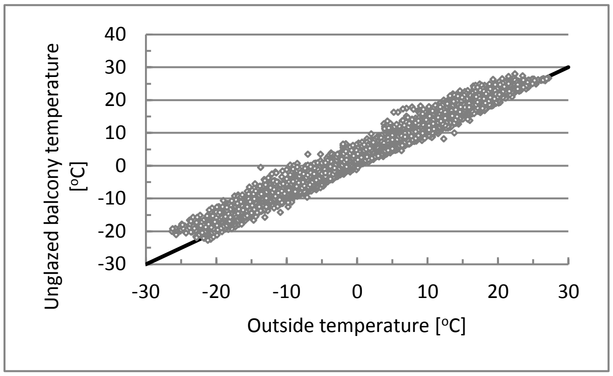


Figure 8b

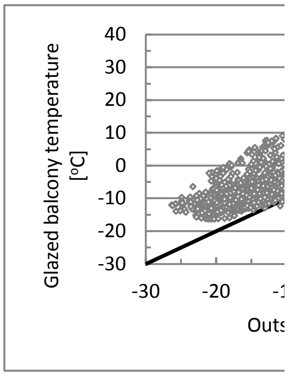


Figure 8

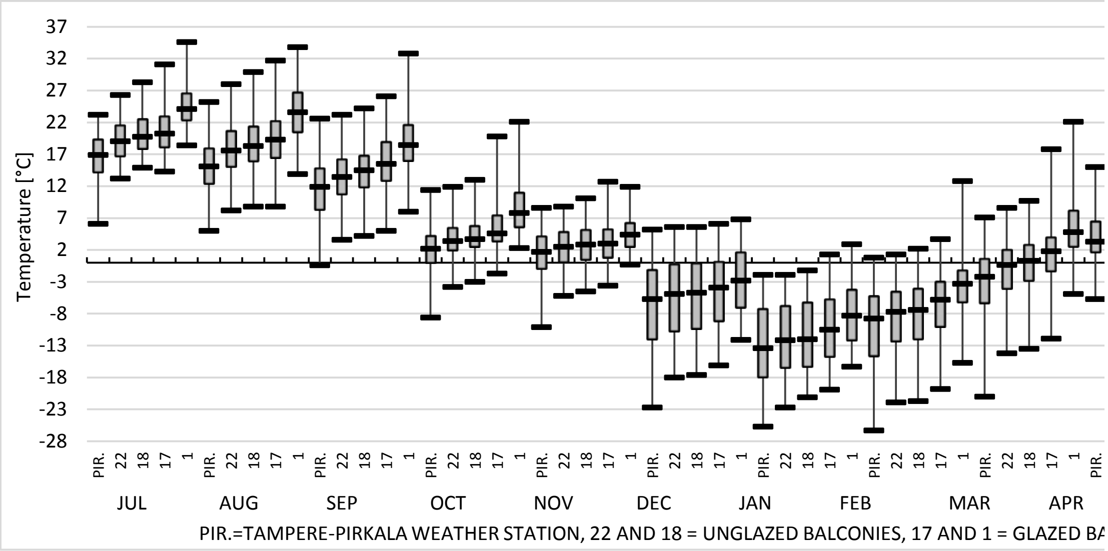

Temperature [°C]
37
32
27
22
17
12
7
2
-3
-8
-13
-18
-23
-28
PIR.
22
18
17
1
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
PIR.=TAMPERE-PIRKALA WEATHER STATION, 22 AND 18 = UNGLAZED BALCONIES, 17 AND 1 = GLAZED BA

Figure 9

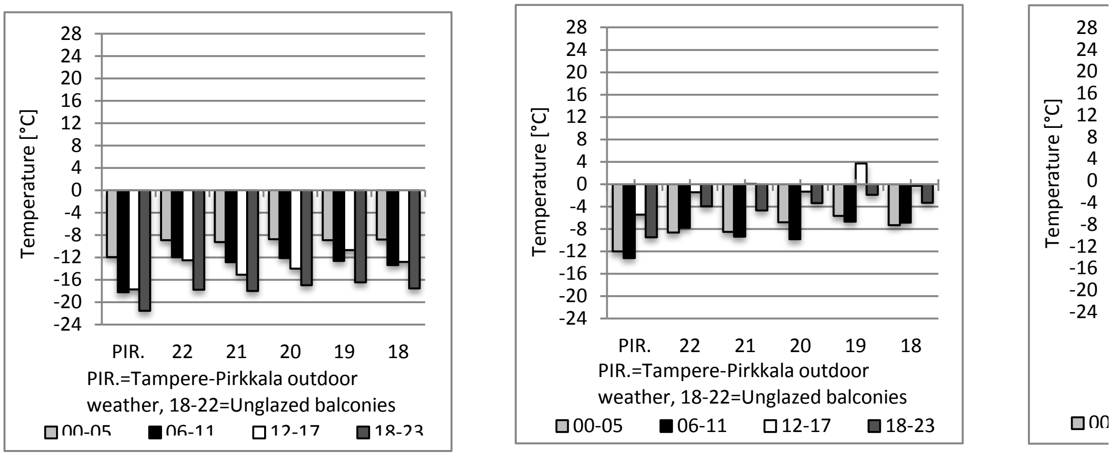
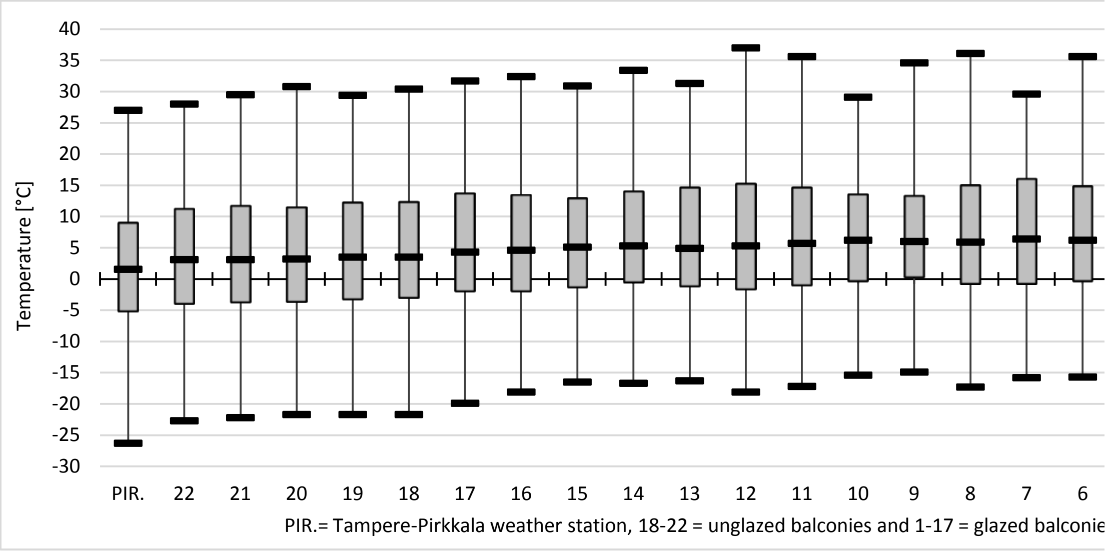

Temperature [°C]
28
24
20
16
12
8
4
0
-4
-8
-12
-16
-20
-24
PIR.
22
21
20
19
18
PIR.=Tampere-Pirkkala outdoor weather, 18-22=Unglazed balconies
▨ 00-05
■ 06-11
☐ 12-17
▨ 18-23
Temperature [°C]
28
24
20
16
12
8
4
0
-4
-8
-12
-16
-20
-24
PIR.
22
21
20
19
18
PIR.=Tampere-Pirkkala outdoor weather, 18-22=Unglazed balconies
▨ 00-05
■ 06-11
☐ 12-17
▨ 18-23
Temperature [°C]
28
24
20
16
12
8
4
0
-4
-8
-12
-16
-20
-24
▨ 00

Figure 10



40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
Temperature [°C]
PIR.
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
PIR.= Tampere-Pirkkala weather station, 18-22 = unglazed balconies and 1-17 = glazed balconie

Figure 11

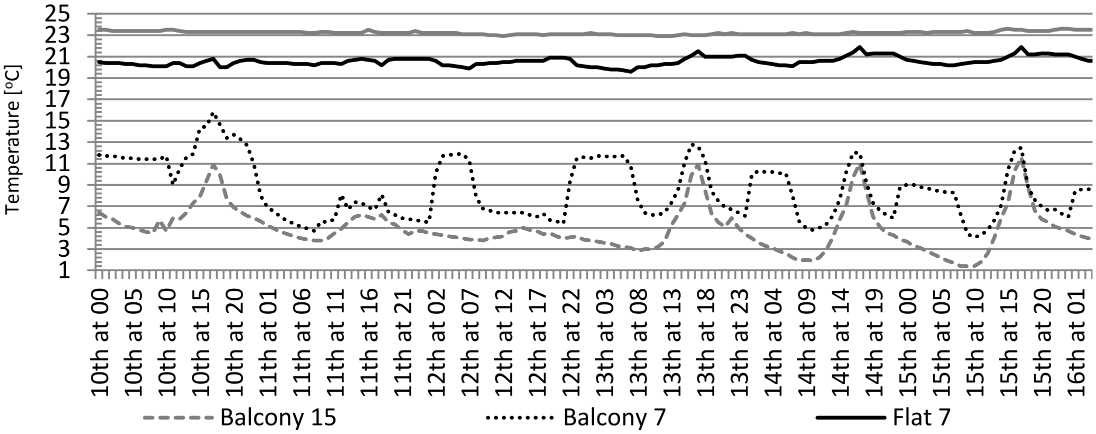
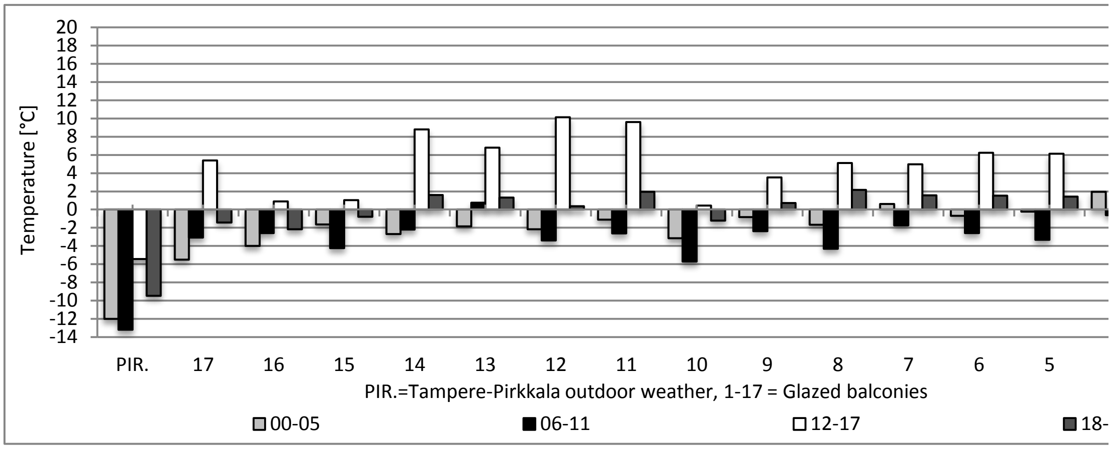

Temperature [ºC]
25
23
21
19
17
15
13
11
9
7
5
3
1
10th at 00
10th at 05
10th at 10
10th at 15
10th at 20
11th at 01
11th at 06
11th at 11
11th at 16
11th at 21
12th at 02
12th at 07
12th at 12
12th at 17
12th at 22
13th at 03
13th at 08
13th at 13
13th at 18
13th at 23
14th at 04
14th at 09
14th at 14
14th at 19
15th at 00
15th at 05
15th at 10
15th at 15
15th at 20
16th at 01
Balcony 15
Balcony 7
Flat 7

Figure 12


Temperature [°C]
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
PIR.
17
16
15
14
13
12
11
10
9
8
7
6
5
PIR.=Tampere-Pirkkala outdoor weather, 1-17 = Glazed balconies
▨ 00-05
■ 06-11
□ 12-17
■ 18-

List of Figure Captions

Figure 1. Measured buildings are located in three suburban areas in Tampere. The weather stations (three) of the Finnish Meteorological Institute (FMI) are shown in dots. The Tampere-Pirkkala airport weather station is located in the bottom left corner.

Figure 2. Monthly mean temperatures at Siilinkari, Härmälä, and Tampere-Pirkkala weather stations (station locations shown in Figure 1).

Figure 3. Monthly average temperatures and horizontal global radiation during the field measurement period compared to a normal year.

Figure 4. Balconies in the studied blocks of flats, showing well the decade of their construction. The buildings are identified by a letter code A - K (see also Table 1).

Figure 5. Studied block of flats from oldest to newest, identified by a letter code A - K. Balconies are numbered from warmest to coldest. Numbers 1 - 17 are glazed balconies and 18 - 22 unglazed ones.

Figure 6. Arrangement of monitoring in a balcony and flat.

Figure 7a and 7b. Temperatures of the coldest unglazed balcony (code 22, left) and of the warmest glazed balcony (code 1, right) in relation to the outdoor temperature measured at the Tampere-Pirkkala weather station.

Figure 8. Monthly and total temperature behavior of the coldest and the warmest unglazed and glazed balconies and that at the Tampere-Pirkkala weather station.

Figure 9. One cold winter day (26th January), an early spring day (15th Mars), and a late spring day (16th May) and Tampere-Pirkkala outdoor weather divided into six-hour periods.

Figure 10. Overall behavior of outdoor air temperatures in unglazed and glazed balconies during the measurement period.

Figure 11. One early spring day (15th March) and outdoor weather at Tampere-Pirkkala divided into six-hour periods.

Figure 12. Temperatures of balcony 15 and 7 and of adjacent apartments from 10 to 17 October, 2009. The figure shows how the resident of flat 7 ventilated the flat by keeping the balcony door open, especially at night.

***Highlights**

Highlights

- Field monitoring was conducted on 22 balconies and in adjacent flats
- Temperature conditions were measured at 1-hour intervals
- A glazed balcony was 5.0 °C and an unglazed one 2.0 °C warmer than the outdoor air
- Main contributors were air tightness, solar absorption, and building heat losses