Exterior Space Retrofitting Planning with Possible Effect on Building Thermal Characteristics

D V Berezin
Institute of Architecture and Construction, South Ural State University, 76, Lenin Avenue, Chelyabinsk 454080, The Russian Federation

E-mail: berezindv@susu.ru

Abstract. The problems of mass housing which was serially designed and produced throughout Eastern European and former Soviet cities in the middle of the 20th century, in regard to its solar-related thermal conditions improvement by refurbishing are raised in the paper. The impact of functional zones’ dimensions (based on the dwellers’ domestic actions) on shading properties of balconies and loggias is analyzed. As a result, the ratios of exterior space area (as a complex of shading elements related to balconies/loggias) to the windows area that reflect the frequency of the indoor air overheating are determined which can serve as a simple evaluative thermal comfort-related tool for projected and existing buildings under a real solar activity between the geographic latitudes 55° – 56°.

1. Introduction
A predominant building type of Chelyabinsk’s dwelling sector – apartment blocks mainly built of mass-produced prefabricated elements on standardized projects in 1960s – 70s – aggregates about a half of the housing stock and seems an increasing problem to the local specialists and government. In view of the fact of accelerated depreciation and inefficiency (in terms of modern energy standards) of the stock the only regional programme to intensify local housing’s energy efficiency [1] was set up in 2009. However, so far there are no obvious results in that part which deals with the housing stock, and specifically building components and materials. Quite limited reported outcomes mainly concern of modernization of central heating grid and some local boiler-houses.

The reasons for evident lack of energy efficiency intervention programmes targeting the building fabric (the situation cannot be compared with large number of successful energy efficiency schemes with government support in England – EEC 1&2, Warm Front, EESoP [2]) and modest achievements of the current one (in terms of the houses’ thermal upgrade) are not a consideration within this study. But it is worth observing that self-dependent thermo-retrofitting is being constantly carried out by apartments’ occupants by means of glazing and fitting shading screens in existing balconies/loggias. On the one hand this modernization is often stimulated by the desire to bring the apartments near to modern image, on the other hand – by the need to improve their thermal properties in order to neutralize the detriment to the residents’ health due to indoor overheating (or overcooling) because of the ability of a glazed balcony to act as a thermal buffer mitigating temperature impact.

As a matter of fact, being minor and uniform parts of the buildings (despite of a façade solar aperture and a number of rooms in a particular flat), balconies still stay neutral as a thermally-related components of design. This underestimation limits their functionality and reduces qualities as to shading and thermal bridging. Whereas potentially they can be important energy-oriented and
comfort-related components of an apartment’s structure which are able to meet many of the challenges of future renovations (for instance, retrofitting of the balconies enables to perform the houses reconstruction without rehousing and concurrently to improve the image of the mass housing environment, rising the housing liquidity and attraction for prospective customers as a result of such measures). Thus, in contemporary practice, there are various approaches to balconies/loggias configuration, area, location about a building surface and function. It can be purposely designed to reduce vulnerability to overheating (up to 42% [3]) or, on the contrary, to maximize passively solar gains in order to reduce the heating load (by up to 46% [4]) that is essentially in cold climatic zones to which the South Ural belongs.

Aiming to explore thermo-related potential of balconies/loggias system (which should be depicted with more generalized and accurate term ‘exterior space’ – ES) to improve living conditions in the prevailing type of apartment block (by the example of the sample building – SB – with architectural features inherent to 40% – 50% of Chelyabinsk housing stock) by means of retrofitting, this study formulates the following tasks: 1) to assess influence of ES extension and degree of enclosure on the indoor discomfort temperatures happening and determine ratios of the ES shading area to the windows area as possible tool of exploratory design and quantitative analysis; 2) to define the retrofitting effect on the heat loss of SB through the thermal envelope as a side consequence of the whole renovation.

2. Methods and data analysis

2.1. Building data interpretation

The building data analyzed – plans, elevations, sections and details – are given by The Head City Design Institute that has been responsible for providing of mass housing development with project documentation since 1935.

Within Chelyabinsk building stock, mass housing of 1960 – 1970 construction years is mostly represented in the form of 3–5-storey blocks, combined into rows, each (so-called ‘section’) with central access from a stairwell to 3 or 4 flats per floor. A typical set of the properties may be interpreted as SB that is under the analysis. This is 4-storey, 2-section building for 32 walkup apartments with 1313 m$^2$ of treated floor area (TFA) and 6049 m$^3$ of outer volume. Its total thermal envelope area (measured outwardly) is 3046 m$^2$, including areas of: floor and walls against ground – 592 m$^2$ (correction temperature factor – $f_T$ – 0.64), walls and roof against outdoor air – 1234 m$^2$, floors against attic and basement – 977 m$^2$ (correction temperature factor – 0.60), front doors – 4 m$^2$, windows – 239 m$^2$ (glazed area – 170 m$^2$). Solar heat gain coefficient (g-value) of the windows is 0.7.

Balconies, which are originally represented in the form of small open spaces (from 1.5 to 2.4 m$^2$ per a flat) attached to living rooms, within SB are reshaped into four types with the following proportions: I – 2.8x1.3 m, II – 5.6x1.3 m, III – 8.4x1.3 m, IV – 14x1.3 m, which are based on typical outdoor kinds of domestic activity – storing, physical training, individual desk-related activity, group leisure and relaxation [5]. The types, in their turn, determine the retrofitting solutions differing from each other in the area of balconies as shading elements and in the windows area that changes when additional entrances appear (so in the second solution of the retrofitting it equals 268 m$^2$ with glazed area 202 m$^2$). The amounts of the areas values of slabs, opaque screens, canopies and cornices are: for current state of SB – 128 m$^2$, for the retrofitting solutions with the only balcony type I and with all types – 293 m$^2$ and – 657 m$^2$ accordingly. Constructively all of the balcony types are supposed to be independent structures with their own bearing posts making walls without penetrations possible to avoid thermal bridges. Being another meaningful aspect, which is in the focus of modernization of conventional buildings’ external areas [6], structural thermal bridges at the slabs-to-wall junctions, in this case, cause approximately 3000 kWh/a (2.3 kWh/m$^2$a) of heat losses through the irregularities.

Although the apartments were used to be quite densely occupied, however, by the moment the real rate is 26 m$^2$ per an occupant on average (it quite correlates with international data on occupancy density [7]); so 50 people is assumed as a number of residents for the SB simulation.
Due to actual absence of insulating layer, the heat-transfer coefficient of the building assembly is quite high. Thus, U-values \((W/(m^2K))\) of the structural components are as follows: masonry external walls – 1.22 (earth-sheltered walls – 1.18); roof – 1.42; concrete floor slab on ground – 3.84; concrete floor slab, adjoining basement – 0.92; concrete floor slab, adjoining attic – 1.02; northern windows – 2.05; eastern/western windows – 2.10; southern windows – 2.04.

As there are evidences that it is room of the top floors that is mostly prone to overheating [8] a corner south-eastern faced apartment of SB is assessed as critical regarding frequency of summertime discomfort temperatures. Its total thermal envelope area is 101.5 m\(^2\), including areas of: exterior walls – 31.8 m\(^2\); southern windows – 6.7 m\(^2\); the only eastern window – 1.7 m\(^2\); walls and floor slabs adjacent to the neighboring property – 100 m\(^2\) (there is no heat flow); surfaces against buffer zones – loft – 61 m\(^2\) (correction temperature factor – 0.27). The treated floor area is 40 m\(^2\) (that is average value for SB apartments), the ceiling height – 2.5 m and the volume – 99 m\(^3\). The U-values and g-value of the apartment fabric and windows are the same as SB.

2.2. Simulation

To predict possible effect of ES as a complex of shading elements on indoor temperature and assess heat loss dependent on the retrofitting solutions, the energy-balancing software – Passive House Planning Package (PHPP 2007) – is used. Being a stationary simulation program it demonstrates the well correlated results with the ones of dynamic simulation and they are proven in practice since preliminary calculations of several hundred buildings in different European settlements accurately coincide with measurements of them [9,10]. Moreover this tool is validated for assessment of existing buildings, including those that with high energy consumption [11]. Making instantaneous calculations PHPP uses input data entered in worksheets each of those deals with particular aspect of a building’s energy performance.

Due to the fact that the study is restricted to ES sunshield, the calculations are focused on respective factors, including windows’ sizes, share of glazing and orientation, dimension of prominent components of the building envelope and numerical values of the shading devices’ influences on the solar gains through the windows. Therefore a few worksheets are only filled in – ‘Climate data’, ‘Areas’, ‘Windows’, ‘Shading’ and a number of subsidiaries. For the rest of the data which are linked with predicting the frequency of overheating events, standard values are assumed by default according to the PHPP manual [12].

The total shading coefficient for the main orientations is the product of five shading factors:

\[
r_{(north, east, south, west)} = r_L \times r_U \times r_H \times r_{SO} \times z
\]

(1)

where \(r_L\) – shading from vertical components of the building envelope (window posts or wall projections); \(r_U\) – shading from horizontal ones (window lintel or balcony slab); \(r_H\) – surrounding objects related shading factor (in this case – the balconies latticed fences); \(r_{SO}\) – a factor of additional shading, for example, from trees; \(z\) – a coefficient taking into account temporal shading in summer. For the purity of the test \(r_{SO}\) and \(z\) factors are considered as optional to activate when frequency of overheating, that is reiteration of the indoor temperature above 25°C, will exceed 10% of the year [12].

The total shading coefficient is automatically transferred to ‘Windows’ worksheet where solar gains are calculated, taking into consideration, besides the total shading coefficient, share of the glazing in the window openings, g-value, glass pollution and not perpendicular solar flux (the last two values are 0.95 and 0.85 respectively, assumed by default). Then based on the critical summer solar gains through the windows, the internal heat gains (Passive House Standard value for residential buildings, occupied 24 hours, is 2.1 \(W/m^2\)), the effective storage capacity (204 Wh/m\(^2\)K – for buildings made of solid components, according to PHPP method), the values of summer heat conductivity and the radiation balance of the opaque, the frequency of overheating event is calculated (the procedure is in ‘Summer’ worksheet). The program forms an annual line of indoor temperatures in a semi-dynamic one-zone model of the building to determine the segment above where the line meets the threshold (25°C) that means a period where indoor temperatures are uncomfortable [13].
The values of conductivity via passive ventilation ($HV,e$) and summer thermal conductivity through the envelope are influential for such a poorly insulated fabric as SB is because of transmission heat from the interior towards outdoor air ($HT,e$) or ground ($HT,g$) during cool nights. PHPP calculates the values by equations, accordingly:

$$HV,e = V \times n \times cL \left( W / K \right)$$  \hspace{1cm} (2)

$$HT,e = \Sigma A \times U \times fTsummer \left( W / K \right)$$  \hspace{1cm} (3)

where $V$ – indoor air volume (TFA by ceiling height) ($m^3$); $n$ – effective air change rate (is obtained from Standard Assessment Procedure, Table P1 [14]) equals 0.8 $h^{-1}$; $cL$ – air specific heat equals 0.33 $Wh/(m^3K)$. $A$ – area of a building component ($m^2$).

The input data on the local solar radiation towards differently oriented surfaces used for all PHPP calculations are obtained from Surface Meteorology and Solar Energy Data Set [15], seen in figure 1.

Special attention is given to the radiation balance of the opaque in terms of determination and taking into the calculations reducing shading factors for the different solutions of ES retrofitting. To determine the annual mean values, the shading factors are graph-analytically found as a share of surface shading by means of formation of solar flux projections onto the opaque at 9 a.m. on 21 December and at 12 on 21 June (respectively, the minimum and maximum heights of the sun). The shading factors (according to azimuths and heights of the sun from [16]) are represented in table 1.

As a side renovating effect calculations of gradual reduction in SB opaque heat loss are being carried out using the equations nearly similar to (2) and (3) ones, but taking into consideration degree-hours – GT (in this case the value is 133, k$Ch$/a):

$$QT = \Sigma A \times U \times fT \times GT \left( kWh / a \right)$$  \hspace{1cm} (4)

$$QT(l) = \Sigma l \times psi \times fT \times GT \left( W / mk \right)$$  \hspace{1cm} (5)

where $QT$ – heat loss through opaque or thermal bridges; $l$ is thermal bridges lengths ($m$); $psi$-value is a measure of heat pass in linear thermal bridges (the total value is 0.42 $W/(mk)$). The thermal bridges calculation by means of equation (5) is important for the case of the existing ES only, whereas concept of the retrofitting implies newly erection of completely thermally separated ones, according to the current practices of low energy construction [17].

3. Conclusions

Although the calculation of the whole building shows that frequency of overheating does not exceed 8% of annual time it is known from the experience that during the hottest period of summer (in July mainly) the temperatures can be uncomfortable, reaching 32°C and lasting for weeks, and it is preferable to have some extra shading. According to the methodology the critical apartment is being
analysed using Passive House Standard. The percent of annual time with temperatures above 25°C (according the PHPP method this must be 10 % or less) turns out to be variable essentially: in the existing SB state – 26 % (2278 hours), in the first and second solutions of the retrofitting – 15 % (1314 hours) and 10 % (876 hours). Such a great exceeding of thermal comfort requirement, when analysing the current state of SB, is a consequence of not only the fabric low thermal resistance to heat flows to and fro all year round (especially that wall insulation alone, on the contrary, can increase indoor temperatures [8]), but also southern, eastern and western orientation of the majority of the living rooms. So it is outer sunshields that play crucial role in overheating decrease by influencing both solar gains through the glazed area and the opaque radiation balance, and the percent within the requirements in the last retrofitting solution proves their effectiveness.

The windows and the outer shading components areas, that underlying the percentage of the overheating frequency found, can be expressed through the ratios (represented in table 1) and then considered as a tool to evaluate inclination for overheating in the building type that is under consideration (similar to relationship between components of building fabric used for researches to estimate the design-related degree of building energy efficiency such as: ratio of building surface to building volume, ratio of total window area to wall/floor area or ratio of roof area to indoor space volume and others [18]). Taking into account the fact that the vast majority of standard housing stock has equal characteristics (as to thermal protection, orientation, windows area per unit and area of outer shading elements) this tool could be quite useful when dealing with refurbishment aiming to normalize thermal conditions in the dwellings under the local climate’s parameters.

### Table 1. Ratios of ES shading area to the windows total area (W) in SB. Shading values for the calculations

| Retrofitting solution | $R_{ES/W}$ | Shading values |
|-----------------------|------------|----------------|
| Before retrofitting   | 0.5        | 0.91           |
| I                     | 1.2        | 0.75           |
| II                    | 2.5        | 0.48           |
| III                   | 2.5        | 0.35           |

Mounting a glass layer to the balconies front proved to have been an effective way to convert them into thermal buffer reducing transmission heat loss by increasing air temperature close to façades and wind protection, which in the past was especially important for buildings with poor insulation and airtightness as SB is [19], see table 2. The measure of mitigation the weather impact on the indoor space by ‘enveloping’ the building ES in covering of glass, can be considered as one more solution of the retrofitting in terms of heat loss through thermal envelope.

The total heat losses value of the opaque – 412850 kWh/a – follows from equation (4); paying attention that for 1070 m² of the vertical building constructions the correction temperature factor – $f_T$ – is 0.57 (as a proportion of the difference of the internal air temperature and the air inside the thermal buffer in a temperature difference of indoor and outdoor air – 29oC/51oC). Additionally, the specific solar gain as a compensation of the heat losses appears to be inactive due to the outer shading area raising. The values even reduce from the current state to the last solution (with the glazed exterior) – from 20 to 18 kWh/(m²a). So it is the thermal buffer that causes essential heat losses reduction (table 2). But apart from providing thermal protection the exterior buffer zone becomes a main superheating factor for the living space, raising the frequency of uncomfortable indoor air temperature up to 26 % of annual time. Nevertheless, the temperature during the peak can be reduced to about 20 – 22oC by means of night ventilation through the windows on opposite sides of the building in the local climate. Furthermore as the calculations in ‘Ventilation’, ‘Summer ventilation’ and ‘Shading’ worksheets (equations (1)-(3)) show that acceptable 4 % of overheating can be resulted from the complex of natural aeration and simple sunshields (blinds, curtains, overhangs) if they are brought together.
Table 2. Specific heat losses in SB.

| Retrofitting solution                                                                 | \( Q_T \), kWh/(m²·a) |
|---------------------------------------------------------------------------------------|-----------------------|
| Before retrofitting                                                                    | 392                   |
| I (thermal bridges are separated)                                                      | 389                   |
| II (thermal bridges are separated but the façades area under glass (at the expense of additional balconies doors appearance) as a weak component of the thermal envelop is extended) | 391                   |
| III with ES as a glazed thermal buffer (90% of the balconies/loggias exterior area covered with glass) | 314                   |

Acknowledgments
The work was supported by Act 211 Government of the Russian Federation, contract №02.A03.21.0011.

References
[1] Regional target program of increase in energy efficiency of the economics of Chelyabinsk Region during 2010–2020 Retrieved from http://gisee.ru/articles/reg_programs/11344/  
[2] Hamilton I G, Shipworth D, Summerfield A J, Steadman P, Oreszczyn T and Lowe R 2014 Building Research & Information 42:3 pp 255–275 DOI: 10.1080/09613218.2014.867643  
[3] Tillson A, Oreszczyn T and Palmer J 2013 Building Research & Information 41:6 pp 652–661 DOI: 10.1080/09613218.2013.808864  
[4] Babae F, Fayaz R and Sarshar M 2016 Architectural Science Review 59:3 pp 239–253 DOI: 10.1080/00038628.2015.1077326  
[5] Neufert P and Neff L 2003 Gekonnt Planen richtig Bauen. Haus, Wohnung, Garten (Wiesbaden: Friedr. Vieweg & Sohn Verlag) pp 106–138  
[6] Richarz C and Schulz C 2013 Energy efficiency refurbishments (Munich: Institut fur Internationale Architektur-Dokumentation) pp 40–41  
[7] Grant N and Clark A 2014 18th International Passive House Conference, Aachen Retrieved from http://www.slideshare.net/econominalnick/internal-heat-gains-and-small-dwellings  
[8] Mavrogianni A, Wilkinson P, Davies M, Biddulph P and Oikonomou E 2012 Building and Environment 55 pp 117–130  
[9] Feist W 2000 Passive house design principles (Darmstadt: Passive House Institute) pp 72–82  
[10] PHPPP – validated and proven in practice. Comparison with measured data Retrieved from http://www.passipedia.org/planning/calculating_energy_efficiency/phpp  
[11] 2016 Implementing deep energy step-by-step retrofits. EuroPHit: Increasing the European potential (Darmstadt: Passive House Institute) p 17  
[12] Feist W, Pfluger R, Kaufmann B, Schnieders J and Kah O 2007 Passive House Planning Package 2007-Requirements for Quality Approved Passive Houses (Darmstadt: Passive House Institute)  
[13] Feist W, 1998 Passive House Summer Climate Study (Darmstadt: Passive House Institute)  
[14] The Government’s standard assessment procedure for energy rating of dwellings 2005 (RdSAP revision 3 Watford: Building Research Establishment) Retrieved from http://projects.bre.co.uk/sap2005/rdsap.html  
[15] Surface Meteorology and Solar Energy Data Set Retrieved from https://eosweb.larc.nasa.gov  
[16] Twarowski M 1970 Slonce w architekturze (Warszawa: Arkady) chapter 17  
[17] Cotterell J and Dadeby A 2012 The Passivhaus. Handbook (London: Green Books)  
[18] Su B 2011 Architectural Science Review 54:4 pp 270–76 DOI: 10.1080/00038628.2011.613638  
[19] Gonzalo R and Vallentin R 2014 Passive House Design (Munich: Institut fur Internationale Architektur-Dokumentation) pp 68–69