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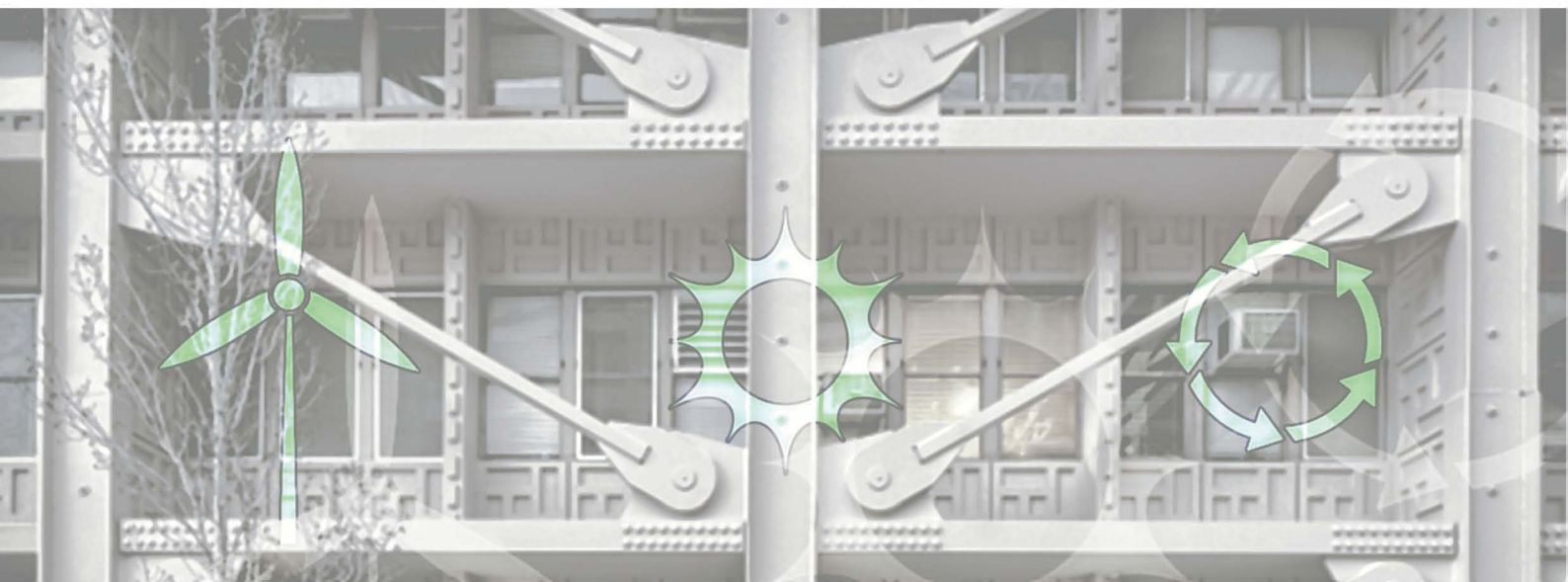
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PROCEEDINGS OF THE

SEISMIC AND ENERGY RENOVATION
FOR SUSTAINABLE CITIES



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Contents

Introduction

1st Session

- 14 TOPIC: Urban vulnerability and sustainable cities
- 15 ASSESSING AND MANAGING SEISMIC RISK IN OLD URBAN CENTRES
José L.P. Aguado, Tiago Miguel Ferreira and Paulo B. Lourenço
- 24 ASSESSING URBAN AND BUILDING VULNERABILITIES CONNECTED TO THE EMERGENCY
MANAGEMENT: AN INTEGRATED METHODOLOGY
Martina Zorzoli, Giovanni Metelli, Michèle Pezzagno, Giovanni Pizzari and Roberto Busi
- 35 COLLECTIVE SOCIALIST HOUSING IN ROMANIA – COMPLEX SOLUTIONS FOR SUSTAINABLE UPGRADE,
BETWEEN/BESIDES ENERGY IMPROVEMENT AND STRUCTURAL SAFETY
Zina Macri
- 44 SUSTAINABLE ENERGY ACTION PLANS: MONITORING THE IMPLEMENTATION OF STRATEGIES FOR
SUSTAINABILITY FOR MUNICIPALITIES IN NORTHERN ITALY
Giuliano Dall'O', Luca Sarto, Alberto Pizzi and Sandro Cristina Reggiani
- 57 A SIMPLIFIED MODEL BASED ON SELF-ORGANIZED CRITICALITY FRAMEWORK FOR THE SEISMIC
ASSESSMENT OF URBAN AREAS
Annalisa Greco, Alessandro Pluchino, Luca Barbarossa, Ivo Calì, Francesco Martinico and Andrea Rapisarda
- 69 A SIMPLIFIED METHODOLOGY TO ASSESS SEISMIC RISK AT DISTRICT AND BUILDING LEVEL
Ivo Calì, Rosa Caponetto, Chiara Ciatto and Daniele La Rosa
- 82 HOSPITAL SAFETY IN SPATIAL AND URBAN PLANNING AND DESIGN–SEISMIC ZONE IN THE
KOLUBARA REGION IN SERBIA
Borjan Brankov, Marina Nenković-Riznić, Mila Pucar and Snežana Petrović
- 92 TOPIC: Resolution of organizational and practical problems
 Economic and financial policies to promote renovation measures
 Strategies for promoting the social sensitivity to prevention actions
- 93 SEISMIC AND ENERGY RENOVATION MEASURES FOR SUSTAINABLE CITIES: A CRITICAL ANALYSIS OF
THE ITALIAN SCENARIO
Paolo La Greca and Giuseppe Margani
- 105 A EUROPEAN PROJECT FOR SAFER AND ENERGY EFFICIENT BUILDINGS: PRO-GET-ONE (PROACTIVE
SYNERGY OF INTEGRATED EFFICIENT TECHNOLOGIES ON BUILDINGS' ENVELOPES)
Annarita Ferrante, Giovanni Mochi, Giorgia Predari, Lorenzo Badini, Anastasia Fotopoulou, Riccardo Gulli and Giovanni Semprini
- 117 RESILIENCE, PREPAREDNESS AND SCENARIO EXERCISES: POTENTIALITIES AND WEAKNESSES OF
DRR EDUCATION STRATEGIES
Mara Benadusi

2nd Session

- 128 TOPIC: Construction techniques of historic and recent buildings
- 129 PROJECTS AND CONSTRUCTION TECHNIQUES IN POST-SEISMIC RECONSTRUCTIONS AT THE
BEGINNING OF THE TWENTIETH CENTURY
Cesira Paolini and Marina Pugnaletto

- 141 THE BUILDING INFORMATION MODELING FOR THE RETROFITTING OF EXISTING BUILDINGS. A CASE STUDY IN THE UNIVERSITY OF CAGLIARI
Giuseppe Desogus, Giuseppe Martino Di Giuda, Giuseppina Monni, Emanuela Quaquero, Antonello Sanna, Lavinia Chiara Tagliabue and Valentina Villa
- 151 ROLE OF SKY GARDENS IN IMPROVING ENERGY PERFORMANCE OF TALL BUILDINGS
Humera Mughal and Rossella Corrao
- 160 THE RESILIENCE OF TRADITIONAL ARCHITECTURE: THE ANTI-SEISMIC CONSTRUCTIVE SYSTEM OF LEFKADA ISLAND
Emilia Garda, Marika Mangosio and Angeliki Vlachou
- 169 OPTIMIZING ENVIRONMENTAL PERFORMANCE OF HISTORICAL BUILDINGS. THE CASE OF HOU JI VILLAGE
Luca Finocchiaro and Fu Xiuzhang
- 181 SEISMIC AND ENERGY REFURBISHMENT OF RESIDENTIAL BUILT HERITAGE IN MEDITERRANEAN CLIMATE
Angelo Salemi, Alessandro Lo Faro, Attilio Mondello, Angela Moschella and Giulia Sanfilippo
- 193 THERMAL AND ECONOMIC GREEN ROOF PERFORMANCE FOR BUILDING RETROFIT
Stefano Cascone, Federico Catania, Antonio Gagliano and Gaetano Sciuto
- 205 SEISMIC AND ENERGY RENOVATION, COMPARISON BETWEEN THE DESIGN APPROACH IN ITALY AND IN ROMANIA
Emil-Sever Georgescu, Mihaela Stela Georgescu, Zina Macri, Edoardo Michele Marino, Giuseppe Margani, Vasile Meita, Radu Pana, Horia Petran, Per Paolo Rossi, Vincenzo Sapienza and Marius Voica
- 221 PRE-MODERN ANTISEISMIC PRESIDIA IN L'AQUILA. WOODEN ELEMENTS AND CONSTRUCTION TECHNIQUES IN HISTORIC BUILDING
Alessandra Bellicoso and Alessandra Tosone
- 233 THE COLLAPSE OF THE TOWER OF VALLADOLID CATHEDRAL AND ITS CONTROVERSIAL RELATIONSHIP WITH THE 1755 LISBON EARTHQUAKE
Angelo Salemi, José Ignacio Sánchez Rivera, Attilio Mondello and Juan Luis Sáiz Virumbrales

3rd Session

- 246 TOPIC: Seismic and energy regeneration strategies at district and urban scale
- 247 THE COMPLEX, MULTICRITERAL RENOVATION OF HOUSING DISTRICTS. INTEGRATED CONCEPT OF PROJECTS FOR HOUSES AND CITY. RESULTS OF "SIR RESEARCH PROJECT" IN ROMANIA
Codruta Iana, Mihaela Stela Georgescu, Cristina Victoria Ochinciuc, Carmen Dumitrescu, Cerasella Craciun, Ana Opris
- 260 PROCEDURES FOR A QUALITATIVE ASSESSMENT OF THE SEISMIC VULNERABILITY OF HISTORICAL CENTERS. THE CASE STUDY OF ACIREALE (CT)
Chiara Circo and Anna Scudero
- 270 A GREEN INFRASTRUCTURE STRATEGY FOR REDUCING SEISMIC VULNERABILITY AND ENHANCING ENERGY EFFICIENCY IN URBAN CONTEXTS
Riccardo Privitera and Daniele La Rosa
- 282 RECOVERING THE ANCIENT HAMLET BY AN INTEGRATED ENERGY AND SEISMIC PLAN ACTION: THE CASE OF BAIA AND LATINA
Marina Fumo, Antonella Violano, Antonio Formisano and Giulia Sibilio
- 294 SEISMIC ASSESSMENT OF TYPICAL MASONRY HISTORICAL RESIDENTIAL BUILDINGS IN CATANIA
Salvatore Caddemi, Ivo Calì, Giuseppe Di Gregorio, Andrea Famà, Annalisa Greco, Grazia Lombardo
- 306 CORRECTIVE REMEDIATION PROPOSALS FOR THE INA CASA DISTRICTS IN MESSINA (1949-1963)
Ornella Fiandaca, Raffaella Lione and Fabio Minutoli
- 319 EXPOSURE AND RISK REDUCTION STRATEGY: THE ROLE OF FUNCTIONAL CHANGE
Roberto De Lotto, Veronica Gazzola and Elisabetta M. Venco

4th Session

- 331 TOPIC: Design, monitoring and management tools
- 332 SUSTAINABLE LOW CO2 EMISSION RETROFIT STRATEGIES OF PUBLIC BUILDING IN MEDITERRANEAN AREA: A CASE STUDY
Manfredi Cannata, Maurizio Detommaso, Gianpiero Evola, Antonio Gagliano, Luigi Marletta, Francesco Nocera
- 341 CRITICAL ISSUES ON INTEGRATED SOLUTIONS FOR SEISMIC AND ENERGY RETROFITTING OF HIGH-RISE BUILDINGS IN REINFORCED CONCRETE WALLS AND PANELS: THE M4 IN TOR BELLA MONACA, ROME
Edoardo Currà, Lorenzo Diana, Emanuele Habib and Salvatore Perno
- 353 MULTICRITERIA ANALYSIS FOR CHOOSING MAINTENANCE STRATEGIES
Maurizio Nicoletta, Claudio Scognamiglio and Alessio Pino
- 365 OPTIMIZATION OF OUTDOOR COMFORT CONDITIONS WITH KINETIC ADAPTIVE SHELTER: THE CASE STUDY OF PIAZZA ARMERINA ARCHAEOLOGICAL SITE
Gianluca Rodonò, Emanuele Naboni, Vincenzo Sapienza, Federico Cucchi and Giacomo Macrelli
- 377 ANALYSIS OF FAILURE IN URBAN ENERGY DISTRIBUTION NETWORKS
Alberto Fichera, Mattia Frasca and Rosaria Volpe
- 389 EARTHQUAKE EARLY WARNING AND STRUCTURAL HEALTH MONITORING IN THE HISTORICAL CITY CENTRE OF CATANIA (ITALY)
Salvatore Scudero, Giovanni Vitale, Luca Greco, Domenico Patanè and Antonino D'Alessandro
- 399 TOPIC: Retrofit optimization through prefabricated systems
- 400 A SMART PREFABRICATION SYSTEM FOR THE INDUSTRIALIZED CONSTRUCTION OF RESILIENT ENERGY-SAVING BUILDINGS
Luis Palmero and Graziella Bernardo
- 410 THE EIGHTEENTH-CENTURY ARCHITECTURES: ANTISEISMIC FRONT SOLUTIONS
Corrado Fianchino and Eleonora Vinci
- 420 PREFABRICATED MODULES FOR HEALTH EMERGENCY
Daniela Besana

5th Session

- 432 TOPIC: Technical solutions, materials and methods for seismic and energy renovation
- 433 TABIÀ RENOVATION FOR ALPINE REGION IN ITALY. TRADITIONAL SOLUTION AND INNOVATIVE TECHNOLOGIES INTEGRATION
Barbara Gherri, Eva Coisson and Fabio Scola
- 444 PRE-STRESSED TRANSLUCENT PANELS MADE OF INNOVATIVE 3D GLASS COMPONENTS DSC-INTEGRATED, FOR SAFETY AND ACTIVE BUILDING FAÇADES
Rossella Corrao
- 453 IMPROVING THE ITALIAN BUILDING STOCK: ENERGY RETROFIT OF A SINGLE-STOREY PUBLIC BUILDING IN SOUTHERN ITALY
Gianpiero Evola, Luigi Marletta, Paolo Girlando and Serena Tamburella
- 465 “SEISMIC AND ENERGY RETROFITTING” OF THE HISTORICAL CENTRES’ BUILDINGS. A CASE STUDY IN ENNA
Tiziana Basirico and Daniele Enea
- 477 STRUCTURE - SPACE – ENVELOPE. BUILDING SOLUTIONS TO MITIGATE URBAN HEAT ISLAND (UHI) EFFECTS
Cristina Victoria Ochinciuc and Mihaela Stela Georgescu
- 485 RENOVATION OF SCHOOL BUILDINGS: ENERGY RETROFIT AND SEISMIC UPGRADE, IN A SCHOOL BUILDING IN MOTTA DI LIVENZA
Tiziano Dalla Mora, Maria Pinamonti, Lorenzo Teso, Giosuè Boscato, Fabio Peron and Piercarlo Romagnoni

- 497 SEISMIC REHABILITATION OF BUILDING STRUCTURES USING ENERGY DISSIPATION DEVICES
Gabriel Danila and Adrian Iordachescu
- 508 MOULD GROWTH RISK EVALUATION OF INTERNAL INSULATION SOLUTIONS IN A HISTORIC BUILDING UNDER TEMPERATE CLIMATES
Andrea Gianangeli, Elisa Di Giuseppe and Marco D'Orazio
- 518 SEISMIC AND ENERGY RENOVATION: AN INNOVATIVE APPROACH TO HISTORIC PRESERVATION
Ivo Caliò, Santi Cascone, Dario Distefano, Antonio Gagliano, Giuseppe Perrica, Gianluca Rodonò and Vincenzo Sapienza
- 530 TECHNICAL SOLUTIONS FOR SEISMIC IMPROVEMENT OF THE MASONRY BUILDINGS: STEEL GRIDS WITH PASSIVE DAMPERS AND RC PANELS WITH FRC DOWELS
Venera Simonovic, Merima Sahinagic-Isovic and Goran Simonovic
- 540 PARTIAL INTERVENTIONS ON THE FACADES IN THE PROCESS OF ENERGY RENOVATION OF RESIDENTIAL BUILDINGS - EXAMPLES FROM THE SERBIAN CONSTRUCTION PRACTICE
Aleksandar Rajčić, Ljiljana Đukanović and Ana Radivojević
- 551 SCHOOL BUILDINGS RECOVERY
Francesca Castagneto

6th Session

- 563 TOPIC: Decision support tools for the selection of the optimal retrofitting scenario
Diagnostic techniques and numerical models to assess seismic vulnerability and energy performance
- 564 TOWARDS THE DEVELOPMENT OF A DECISION SUPPORT SYSTEM (DSS FOR BUILDING RENOVATION: DOMAIN MAPPING MATRIX (DMM FOR SUSTAINABILITY RENOVATION CRITERIA AND RENOVATION APPROACHES
Aliakbar Kamari, Rossella Corrao and Poul Henning Kirkegaard
- 577 ENERGY IN TIME. PARAMETERS OF ENERGETIC ACTUALIZATION OF MATERIALS/COMPONENTS
Caterina Claudia Musarella
- 589 URBAN RESILIENCE AND DISASTER PREVENTIVE PLANNING. MANAGE THE PREPARATION TO OPTIMIZE THE RESPONSE IN HISTORICAL TOWNS
Alessandro D'Amico and Edoardo Currà
- 600 OPTIMAL MEASURES FOR ENERGY RETROFIT ON THE UNIVERSITY BUILDING "EX COTONIFICIO OLCESE" IN VENICE
Davide Balboni, Tiziano Dalla Mora, Alessandro Righi, Fabio Peron and Piercarlo Romagnoni
- 610 ITALIAN SCHOOL BUILDING TOWARD NZEB REQUIREMENTS. THE CASE OF "C. ROSSELLI" HIGH SCHOOL IN CASTELFRANCO VENETO
Giulia Masolo, Tiziano Dalla Mora, Alessandro Righi, Fabio Peron and Piercarlo Romagnoni
- 622 MULTI-CRITERIA METHODOLOGY TO SUPPORT DECISION MAKING CONCERNING OPAQUE ENVELOPE COMPONENTS
Alessandra De Angelis, Rosa Francesca De Masi, Maria Rosaria Pecce, Silvia Ruggiero and Giuseppe Peter Vanoli
- 634 RADIANT PANELS FOR OUTDOOR HEATING: THEORETICAL AND EXPERIMENTAL ANALYSIS FOR THERMAL COMFORT ASSESSMENT
Giorgio Baldinelli, Antonella Rotili and Francesco Bianchi
- 645 TECTONIC SUSTAINABLE BUILDING DESIGN FOR THE DEVELOPMENT OF RENOVATION SCENARIOS – ANALYSIS OF TEN EUROPEAN RENOVATION RESEARCH PROJECTS
Aliakbar Kamari, Rossella Corrao, Steffen Petersen and Poul Henning Kirkegaard

Partial interventions on the facades in the process of energy renovation of residential buildings - examples from the Serbian construction practice

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Abstract

Energy rehabilitation of facades of residential buildings is a process aiming to improve housing comfort and save operational energy. In the case of multi-family housing in Serbia, this procedure often involves partial interventions on the facade, which are mainly due to limited investments and lack of consensus at the building level to implement a comprehensive rehabilitation process.

There are currently several approaches, such as: 1) replacement of facade joinery as a measure taken by tenants most often individually, without synchronization at the building level; 2) thermal insulation of the facade as a technologically more complex measure in which, in certain cases, due to the lack of agreement between all users of the building, certain façade zones remain uninsulated; 3) in rare cases, repair of leaking of flat roofs, with integrated complete or partial thermal insulation.

The paper analyses several situations arising as a result of partial interventions for which, in accordance with EN 10211, a numerical simulation was performed using the T-Studio software. It has been found that the problems caused by a partial insulation of the facade or a partial replacement of facade joinery lead to the occurrence of thermal bridges and increase of the heat flow in certain areas of structures with a reduction in internal contact temperature, which increases the risk of condensation, with consequences in the form of development of mould and of microorganisms, which leads to reduction of life comfort and possible specific diseases of the user. Such negative phenomena occur both, in the apartments whose owners did not participate in the process of energy rehabilitation of facades, and in the contact zones of energy rehabilitated apartments, which, in this way, lose their invested assets and the expected effects of energy savings.

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Keywords: energy renovation; partial interventions; façade envelope; thermal bridges;

1. Introduction

One of the major concerns of the today's society refers to the reduction of energy consumption that can be seen as a vital component of a holistic understanding of sustainability. In such efforts, buildings are recognized as the largest consumers of energy of a society. Hence, increasing their energy efficiency as a way to reduce the need for energy has become an imperative. Following the concept of energy

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performances of buildings which is the basis of modern regulations in the field of thermal protection of buildings [1], Serbia has taken the first steps towards improving energy efficiency of buildings by the adoption of the new energy efficiency regulations, enacted in 2011 [2, 3]. With the new set of regulations, for the first time in Serbia, the issue of energy savings is equally set in front of the newly designed buildings, as well as the existing ones.

Typical structures of the thermal envelope of existing residential buildings in Serbia have thermal properties that are far below those required by modern legislation [4,5]. At the same time, the share of the windows and façade walls in the energy balance is dominant in such buildings. Having this in mind, in the process of energy rehabilitation of multifamily, i.e. collective housing in Serbia, there are several approaches that are present in the practice:

- replacement of facade joinery as a measure taken by the tenants most often individually, i.e. without synchronization at the building level;
- thermal insulation of the façade, which is a technologically more complex measure; consequently, in certain cases, due to the lack of agreement between all users of the building, certain façade zones remain uninsulated;
- in some specific cases that include a problem of leaking of a flat roof - repair of the leaking roofs is integrated with complete or partial thermal insulation.

Such interventions are a result of mainly restrictive and limited investments, combined with a lack of consensus at the building level to implement a comprehensive rehabilitation process. Although, in general, consciousness of tenants regarding the energy efficiency leads towards the success in energy savings [6], since, in the present case, the efforts are usually made by individual tenants, they result with partial interventions on a building envelope. Therefore, the positive effects of the improvement measures might be questioned.

With respect to the mentioned aspects, the paper analyses some cases arising as a result of partial interventions, in the first place those that refer to window replacement and thermal improvement of façade walls as the elements of thermal envelope that most often undergo the energy improvement measures. Selected situations were the subject of a numerical simulation that was performed using the original T-Studio software [7], conducted in accordance with EN 10211 [8]. This software package is designed for two-dimensional calculation of heat balance, using calculation procedure which is based on the finite difference method (FDM).

Nomenclature

Symbols

f_{Rsi} temperature factor

T temperature [°C]

Greek symbols

λ thermal conductivity [W/mK]

φ relative humidity [%]

Subscripts

i internal

e external

si surface internal

se surface external

2. Description and potential side-effects of partial energy improvement measures

2.1. Window replacement

Replacement of facade joinery is a measure that is most cost-effective in terms of saving energy and increasing the comfort in the interior (thermal, acoustic, visual) [5, 9]. This measure is mainly the result of an individual approach and the willingness and financial ability of each of the tenants. Consequently, we are facing a diversity regarding the colour, material, window geometry (division, dimensions) of the facade joinery on existing buildings that shows deviation from the original look. This is especially noticeable and emphasized at the building level in the process of self-initiative, unplanned and unsynchronized glazing process of the loggias and terraces.

It can be said that this phenomenon is that much present that the attention is no longer focused on the consequences (primarily visual), i.e. on the resulting changes of the character of the architectural object and the character of such changes that are permanent or long-lasting. Besides, such changes follow the pattern of the chaotic installation of air-conditioners on the facades. On the other hand, it is often that such interventions are not followed by the simultaneous thermal insulation of the façade walls. Therefore, such contact between the improved, well insulated window and the uninsulated or poorly insulated façade wall represents a thermal bridge that brings a high risk potential for appearance of condensation [10].

2.2. Thermal insulation of façade walls

Thermal insulation of the facade is another frequent measure of energy renovation of the building, but which is technologically more demanding than the replacement of joinery because it requires work from the outside, i.e. the use of the scaffolding.

In addition, the facade wall is in visual sense and by its shape, a more expressive component, and in most cases, its surface area is larger or significantly larger than that of the windows. Therefore, it is logical that in the process of energy rehabilitation the façade is viewed integrally, both from the design and from the energy aspect. However, in a situation when tenants are those who finance the energy renovation of a multifamily building, deviation from a comprehensive facade treatment can be caused by various reasons such as:

- some tenants have no financial opportunity to participate in renovating the facade, and other tenants do not want to compensate this cost, or
- in some cases, certain tenants are *a priori* against any intervention and do not allow any work on the respective facade parts.

Consequently, there are situations with unexpected “architectural results”, as shown on the Figure 1.



Fig. 1. Effects of partial thermal insulation of façade walls – example of a multifamily building from Belgrade

From the technological point of view, partially processed facades bring new, unexpected problems, the solution of which is borne by the extra costs that are most often manifested through sheet metal work to cover the horizontal outflows of thermal insulation, in order to protect them against penetration of atmospheric water and the potential peel off of thermal insulation.

From the energy point of view, there are various new problems, and some of them will be indicated in this paper. The described absence of comprehensive intervention causes the occurrence of thermal bridges and the increase of the heat flow in certain areas of structures, resulting with a reduction in internal contact temperature and the increment of the risk of condensation. Consequently, development of mould and microorganisms might be expected, which leads to the reduction of a living comfort and possible specific diseases of the user. These negative phenomena are certainly expected in those flats whose occupants (owners) did not allow or did not participate in the process of energy rehabilitation of facades, but can be also manifested in neighbouring flats, particularly those above or below the respective.

3. Definition of model and research methodology

3.1. Geometric and material properties of the analysed wall-floor construction connection

As a model which was investigated in this paper, the connection between a 25cm thick solid brick wall and a 20cm reinforced concrete slab was chosen. The wall has 2cm thick mortar render on both sides. The floor construction of the analysed model is a 20cm reinforced concrete slab, plastered on the bottom side with 2cm thick mortar render, and with a 2cm thick parquet floor, placed over the 5cm thick reinforced cement screed. The assumed measure of energy improvement of the facade wall was carried out by adding the layer of thermal insulation and a thin façade rendering as a finishing layer. Thermal properties of assumed structures and elements are given in the Table 1.

Effects of the partial thermal improvement of the façade wall were analysed on two typical models:

- Model 1- simple junction of the façade wall and the floor construction, and
- Model 2 - junction of the façade wall and the floor construction in the contact zone with a facade opening (window) (Figure 2).

Research of the character of the contact at the junction of the wall and the floor structure was analysed through several different scenarios regarding the manner and extent of energy optimization of the wall.

Table 1. Thermal conductivity of the assumed layers of the modelled wall - floor connection

type of structure		layer	λ [W/mK]	thickness [cm]
Façade wall	existing/original layers	internal plaster	0.85	2
		solid brick	0.63	25
		external rendering	0.85	2
	<i>additional layers (optional)</i>	<i>thermal insulation</i>	<i>0.04</i>	<i>10</i>
		<i>facade rendering</i>	<i>0.85</i>	<i>1</i>
Floor construction		plaster	0.85	2
		reinforced concrete slab	2.5	20
		reinforced cement screed	2.33	4
		parquet	0.20	2

3.2. Climate data relevant for the calculation

Presence of thermal bridges could be manifested by the formation of condensation on the analysed contact between the insulated and uninsulated parts of the building fabric. Since this manifestation is potentially possible in the winter period, for the purpose of this study the appropriate climatic data which are in accordance with applicable regulations were set [2]. The external design temperature is defined as -12°C (corresponding to climatic characteristics of Belgrade) with simultaneous relative humidity of 90%. For interior design conditions it is assumed that the temperature of the indoor air was $+20^{\circ}\text{C}$, while the humidity varied.

Although the regulation stipulates that relative humidity of the interior space is 50%, the paper analyzed the cases in which internal relative humidity is higher (55, 60, 65, or 70%). Such situation is realistic and often happens in the winter due to the inappropriate use of the space. Excess moisture in the living space which is confirmed by the recent study of thermal comfort during the winter in Belgrade residential buildings is, in the first place, a result of a habit of drying laundry on heating devices, higher cooking frequency or higher occupant density, but without the proper ventilation of the space [11]. Thus, for some time relative humidity could rise to 80% and more.

3.3. The method of calculating the impact of the thermal bridge

The impact of the thermal bridge is calculated on the basis of the risk of surface condensation. The potential risk is traced on 4 characteristic points of the wall-floor connection, marked on the Figure 2. The interior surface temperatures for these points were calculated and compared with the dew point temperature for the given project conditions (temperature and relative humidity in the room):

- T1 - on the wall, 5cm before the connection to the ceiling;
- T2 - on the ceiling, 5cm before the connection to the wall;
- T3 - on the wall, 5cm before the connection to the floor; and
- T4 - on the floor, 5cm before the connection to the wall;

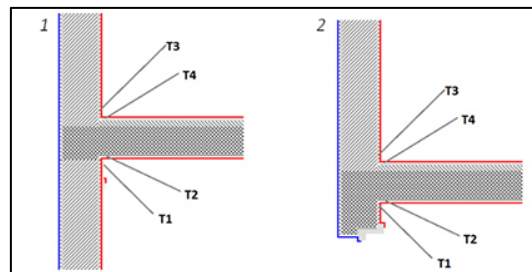


Fig. 2. Characteristic points on the wall-floor connection – Model 1 (left) and Model 2 (right)

On the basis of the calculated temperatures, the temperature factor f_{Rsi} is calculated, through which the risk of condensation is assessed. Temperature factor at the steady state condition can be expressed by the formula as:

$$f_{Rsi} = \frac{T_{si} - T_{se}}{T_i - T_e} \quad (1)$$

where :

- T_{si} is surface internal temperature,
- T_{se} is surface external temperature,
- T_i is the temperature of the internal environment, and
- T_e is the temperature of the external environment

Temperature factor f_{Rsi} depends only on the structure itself. Once calculated for certain values of T_i and T_e , it can be used to calculate the surface temperature under different conditions, using the formula:

$$T_{si} = T_e + f_{Rsi} \cdot (T_i - T_e) \quad (2)$$

In order to prevent the formation of mould, it is necessary to fulfil the condition that every point on the inner surface has a temperature or temperature factor greater than or equal to the critical. [12] This condition therefore depends on the external temperature, the internal air temperature, and the relative humidity of the indoor air.

Correlation of these parameters can be expressed as:

$$f_{Rsi} \geq \frac{\left((0.0125 \cdot \varphi)^{0.1247} \cdot (109.8 - T_i) - 109.8 - T_e \right)}{T_i - T_e} \quad (3)$$

where

- φ is relative humidity of indoor air [%],
- T_i is internal air temperature [°C], and
- T_e is external air temperature [°C].

In order to prevent the condensation risk and the growth of the mould, it is necessary to fulfill the condition that each point on the inner surface of the wall has a temperature or the temperature factor that is greater than or equal to the critical - under the explained climatic conditions ($T_i=+20^\circ\text{C}$ and $T_e=-12^\circ\text{C}$) [12]. The temperature factor f_{Rsi} is determined for different combinations of the internal design temperature and different values of the relative humidity. (Table 2).

Table 2. Boundary values of the temperature factor for different values of relative humidity

φ [%]	50	55	60	65	70	75	80
$f_{Rsi, \min}$	0.77	0.81	0.86	0.89	0.93	0.97	1

Therefore, the calculated values of f_{Rsi} obtained for the characteristic points of the analysed models should be higher than the boundary values, in which case there is no risk of condensation on the critical places of the connected structures. All calculations of relevant thermal characteristics of the analyzed cases of energy optimization were carried out using the original software package T-Studio [7].

4. Results and discussion

As already explained, two typical models were created (simple junction of the façade wall and the floor construction, and junction of the façade wall and the floor construction in the contact zone with a facade opening) and for each of them, different cases of partial interventions on the façade wall are

investigated. Analyzed cases correspond to actual situations in which energy improvement was partially realized, and was not applied either in the upper apartment, or in an apartment below the observed one.

In the case of the Model 1, the following situations were analysed:

- Case 1 (original state – no intervention): a connection between the uninsulated facade wall and the floor construction;
- Case 2 (upper flat without intervention): the wall is uninsulated above and isolated below the floor construction;
- Case 3 (lower flat without intervention): the wall is insulated above and uninsulated below the floor construction; thermal insulation overlays the floor construction;
- Case 4 (lower flat without intervention): the wall is insulated above and uninsulated below the floor construction; thermal insulation does not overlay the floor construction;

For all of the analysed cases, internal surface temperatures T1-T4 were calculated with corresponding temperature factors f_{Rsi} for different values of internal relative humidity. These values are presented in the Table 3. Condensation risk is estimated in the table by comparison of the calculated values with the boundary ones for each value of relative humidity and commented as no (does not satisfy the boundary conditions) or yes (satisfies the boundary conditions).

A similar analysis was carried out in the contact zone with a facade opening (window). The following cases were analysed:

- Case 1w (original state – no intervention): a connection of uninsulated façade parapet on the upper floor, uninsulated lintel over the window on the lower floor, with a floor construction
- Case 2w (upper flat without intervention): a connection of uninsulated façade parapet on the upper floor, insulated lintel on the lower floor, with a floor construction
- Case 3w (lower flat without intervention): a connection of insulated façade parapet on the upper floor, uninsulated lintel on the lower floor, with a floor construction; thermal insulation overlays the floor construction;
- Case 4w (lower flat without intervention): a connection of insulated façade parapet on the upper floor, uninsulated lintel on the lower floor, with a floor construction; thermal insulation does not overlay the floor construction;

Condensation risk for the Model 2 is presented in the Table 4, in the same manner as in the case of the previous model.

Table 3. Review of the condensation risk potentials of the Model 1

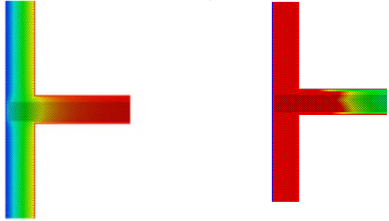
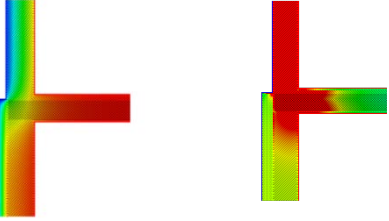
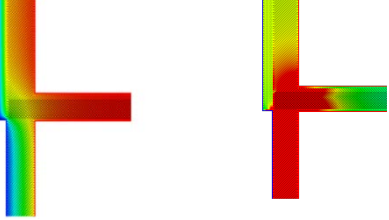
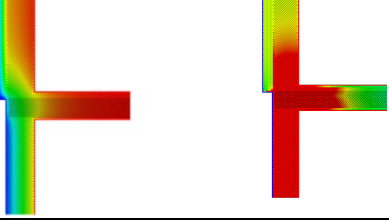
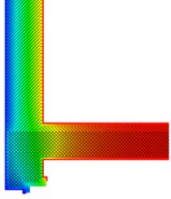
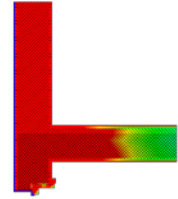
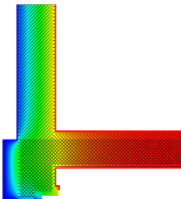
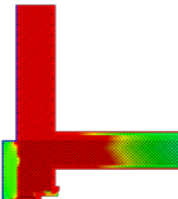
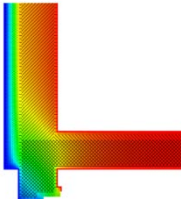
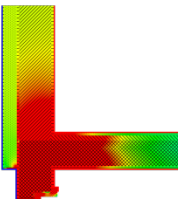
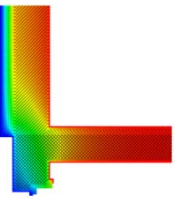
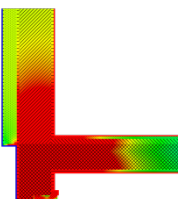
Temperature field	Temperature flux		$T_1[^\circ\text{C}]$ f_{Rsi}	$T_2[^\circ\text{C}]$ f_{Rsi}	$T_3[^\circ\text{C}]$ f_{Rsi}	$T_4[^\circ\text{C}]$ f_{Rsi}	ϕ [%]
Case 1		satisfaction of the boundary conditions	11.08	11.40	11.44	13.30	
	0.72		0.73	0.73	0.79		
	no		no	no	yes	50	
	no		no	no	no	55	
	no		no	no	no	60	
			no	no	no	65	
			no	no	no	70	
Case 2		satisfaction of the boundary conditions	15.80	15.59	14.22	15.93	
	0.87		0.86	0.82	0.87		
	yes		yes	yes	yes	50	
	yes		yes	yes	yes	55	
	no		no	no	yes	60	
			no	no	no	65	
			no	no	no	70	
Case 3		satisfaction of the boundary conditions	14.44	15.16	16.20	16.60	
	0.83		0.85	0.88	0.89		
	yes		yes	yes	yes	50	
	yes		yes	yes	yes	55	
	no		no	yes	yes	60	
			no	no	yes	65	
			no	no	no	70	
Case 4		satisfaction of the boundary conditions	11.87	12.35	13.21	14.33	
	0.75		0.76	0.79	0.82		
	no		no	yes	yes	50	
	no		no	no	yes	55	
	no		no	no	no	60	
			no	no	no	65	
			no	no	no	70	

Table 4. Review of the condensation risk potentials of the Model 2

Temperature field	Temperature flux	T_1 [°C]	T_2 [°C]	T_3 [°C]	T_4 [°C]	ϕ [%]
		f_{Rsi}	f_{Rsi}	f_{Rsi}	f_{Rsi}	
Case 1w		6.38	9.26	10.86	12.44	
		0.57	0.66	0.71	0.76	
	satisfaction of the boundary conditions	no	no	no	no	50
		no	no	no	no	55
		no	no	no	no	60
		no	no	no	no	65
		no	no	no	no	70
Case 2w		10.29	12.34	12.58	12.98	
		0.69	0.76	0.77	0.77	
	satisfaction of the boundary conditions	no	no	yes	yes	50
		no	no	no	no	55
		no	no	no	no	60
		no	no	no	no	65
		no	no	no	no	70
Case 3w		9.38	12.11	14.81	15.18	
		0.67	0.75	0.84	0.85	
	satisfaction of the boundary conditions	no	no	yes	yes	50
		no	no	yes	yes	55
		no	no	no	no	60
		no	no	no	no	65
		no	no	no	no	70
Caase 4w		7.07	9.99	12.89	13.89	
		0.60	0.69	0.78	0.81	
	satisfaction of the boundary conditions	no	no	yes	yes	50
		no	no	no	yes	55
		no	no	no	no	60
		no	no	no	no	65
		no	no	no	no	70

The conducted analysis shows the following:

- Satisfactory results are obtained for relative air humidity in the interior up to 55%, but in those cases when it has a higher value (60% or more), the risk of condensation exists.
- Proximity to the window, that is, the small length of the wall beneath the floor construction contributes that satisfaction of the boundary conditions is less likely to be achieved in the case of the Model 2.
- In the case of both models, boundary conditions are most frequently satisfied on the position of the point 4, i.e. on the upper side of the floor construction.

5. Conclusion

At the end of the conducted research, in brief, it could be concluded, that in the case of incomplete thermo-insulated facades, owners/tenants who have individually isolated corresponding part of the façade, do not necessarily receive all the expected thermal comfort, largely due to the negative impact of thermal bridges, resulting from the close contact of the uninsulated border positions of the adjacent apartment below or above.

For the complete success and the achievement of the full effects of the undertaken measures of energy improvement in multi - storey buildings, it is necessary to have the synchronous operation of all the tenants, i.e. on all the apartments in the building. Otherwise, there is a real possibility of occurrence of negative effects and construction damages.

This would also mean that, in addition to the expressed need for energy improvement of existing buildings defined through appropriate legislation, the state should support and assist such intentions of the owners and users by measures of financial incentive, but also by adopting appropriate standards and recommendations that would direct them towards the joint action.

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