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ANALIZA PRIPREMNE DIJAGNOSTIKE ZGRADA ZA ENERGETSKO RENOVIRANJE

Key words: energy refurbishment; preparatory building diagnostic; residential building stock state; thermal imaging; measuring heat flux

PREPARATORY BUILDING DIAGNOSTIC ANALYSIS FOR ENERGY REFURBISHMENT

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Proces energetske obnove uključuje početno prikupljanje podataka koje je obavezno tokom faze dijagnostike zgrade. U ovom radu bavimo se izgradnjom zgrada i materijalima, tehničkim parametrima, lokacijom i oblikom zgrade. Glavni cilj je postaviti okvir kroz primere metoda prikupljanja podataka za holističku energetsku obnovu. Predmeti ove studije su dve stambene zgrade koje pripadaju opštini 8. okruga u Budimpešti, a sastoje se od 109 i 100 pojedinačnih stanova. Podaci su prikupljeni na licu mesta, a uzorci građevinskog materijala testirani su u laboratoriji. Testiranje je uključivalo merenja ukupne toplotne provodljivosti zidova i koeficijenta prenosa toplote cigle. Monitoring je sproveden tokom 72-časovnog perioda na licu mesta koristeći merač protoka toplote. Istraživanje razmatra proces merenja i rezultate laboratorijskih testova kako bi se formulisali dalji koraci i prekretnice tokom procesa energetske obnove ovih specifičnih i sličnih zgrada.

The energy refurbishment process involves an initial data collection which is mandatory during the building diagnostics phase. In this paper we address the building construction and materials, technical parameters, building location and form. The main goal is to set up a framework through examples of data collection methods for holistic energy refurbishment. The subjects of this study are two social housing buildings which belong to the 8th district Municipality in Budapest, consisting of 109 and 100 individual dwellings. On-site data was collected and building material samples were tested in the laboratory. The testing included measurements of the overall thermal transmittance of walls and heat transfer coefficient of a brick. The monitoring was conducted during a 72-hour period on-site using a heat flow meter. The research discusses the measurement process and laboratory testing results to formulate further steps and milestones during the energy renovation process of these specific and similar buildings.

1. Introduction

As the effects of climate change becoming increasingly apparent, it is essential to first identify and address its underlying causes wherever possible. Numerous studies, booklets and materials provide suggestions on how to reduce the carbon footprint of major consumers. As Figure 1 shows, total activities of households account for almost one quarter of all air emissions in the 27 member states of the European Union (EU) [1]. In terms of the building sector, relevant emissions are of even greater importance.

Approximately 709 million tCO2eq of greenhouse gases (GHG) are emitted by 200 million households across the EU [1], reflecting a wide range of energy performance levels that vary by country, settlement, neighbourhood, housing type, climate zone, and wealth differences. Achieving the EU's goal of reducing net carbon emissions to zero by 2050 will require substantial efforts to improve household energy efficiency and shift towards primarily non-fossil energy sources.

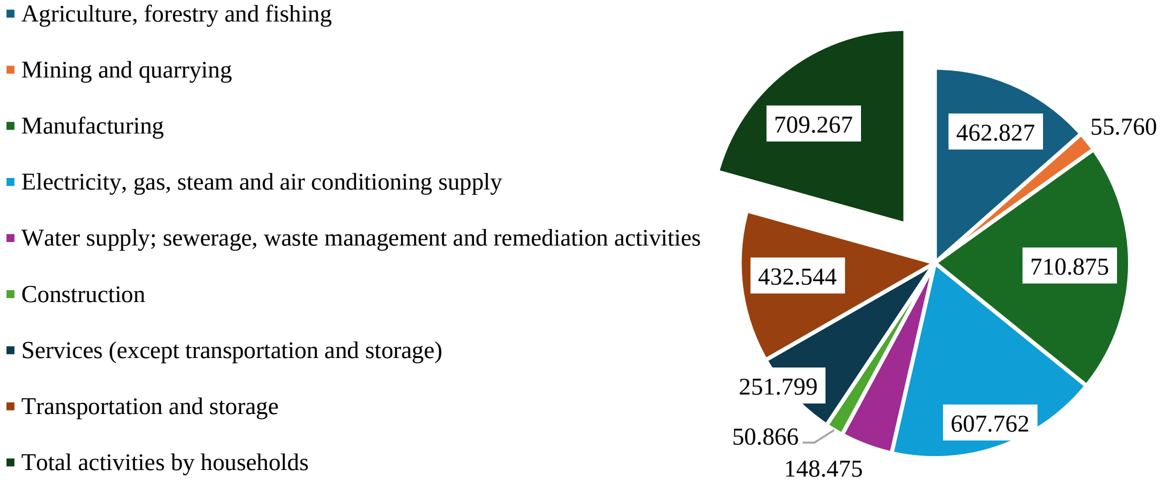

Figure 1. Air emissions accounts for greenhouse gases in 2023 [thousand tonnes] [1]

The final energy consumption (FEC) of Hungarian households [2], which is ~32% of the total FEC in the country [3], is represented on Figure 2 *below:*

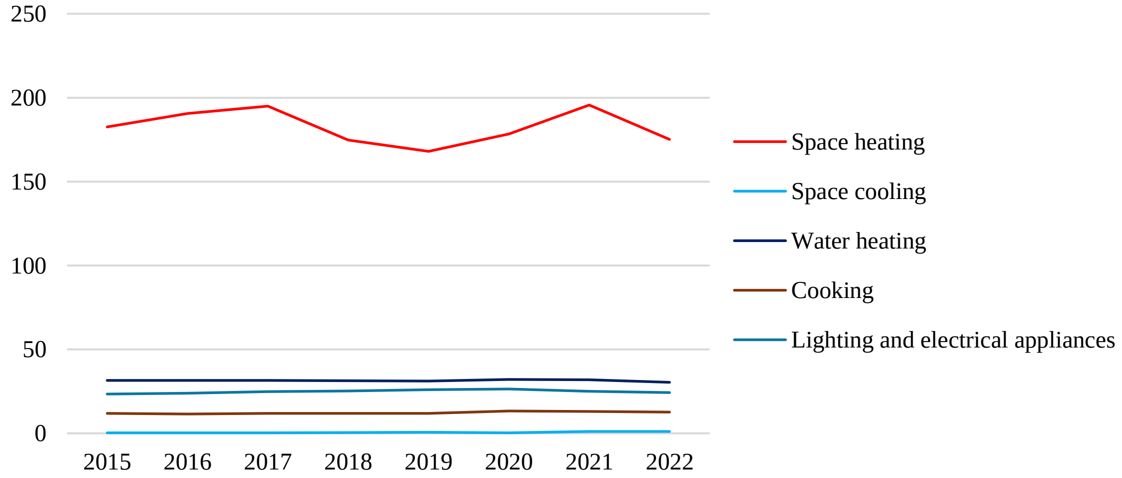

Figure 2. The FEC of households by purpose [PJ] [3]

The amount of energy used by households is higher than the EU average and the gap has been widening since 2019 [4].

Regarding refurbishment, numerous studies reveal the current state of the building stock and the potential for energy savings. In accordance with EU regulations, Member States are required to submit a national energy climate plan (NECP), that focuses on five cornerstones for achieving climate goals: decarbonization; energy efficiency; energy security; internal energy market; research, innovation and competitiveness [5]. In Hungary, the final version of this report was submitted in 2019 by Ministry of Innovation and Technology of Hungary, prioritizing building stock and its renovation. Based on multiple reports, a detailed picture emerges [6]:

- A survey included in National Building Energetics Strategy (NBES), based on on-site inspections, involving 20,842 residential buildings in 2015, Table 1 [7];

Table 1. Result of survey regarding building envelope renovations [7]

	Single-Family House	*Multi-Family Building*	*Panel Building*
Row housing or semi-detached houses	9-40%*	>50%	
Insulated	5-30%**		
Partially insulated + insulated	5-60%		50%
Fenestration replacement (built before 2001)	27-75%	40-50%	20-50%

*Depending on the settlement
**Depending on the settlement, but below 16% in case of houses built before 1980

- A sociological survey conducted by Construction Quality Control and Innovation Nonprofit Ltd. in 2014, in connection with NBES and involving 2 230 residential buildings, Table 2 [8]:

Table 2. Results of sociological survey regarding energy refurbishments and building stock state [8]

Building element	*Percentage*
Fenestration replacement or fenestration insulation	74%
Façade insulation	62%
Roof insulation	41%
Upgrading heating system	36% (renewables: 2%)

- Survey of the Hungarian Energy Efficiency Institute (HEEI), conducting 2 507 phone interviews in 2016 [9]. The results derived from interviewees for the total population indicated that, 41% performed some kind of renovation works. 67% of them changed fenestration, 42% insulated the facades and 31% replaced the heating system (heater only).
- A micro census performed in 2016 by the Hungarian Central Statistical Office, Table 3 [10].

Table 3 - Renovation works performed in households between 2006 and 2016 [10]

	Fenestration replacement	*Insulation of walls*	*Heating system replacement*
Total	1 468 907	895 310	670 625

According to a more recent data regarding the state of the residential building stock in Hungary, a representative survey (with 2000 interviewees) and study was published in 2021 by HEEI [11]. The followings findings were reported:

- *There is a significant potential for reducing energy consumption in the residential sector in Hungary, as two-thirds of residential* buildings *are considered obsolete in terms of energy efficiency.*
- *The average renovation rates between 2012-2016 were approximately 3% for light, 1% for medium and 0,1% for deep renovations.*
- *Major portion (57%) of the population undertook renovation works at some level in the previous 5 years.*
  - *Three-quarters of these interventions involved only one building element and were not combined with other renovation efforts or system changes.*
- *Regarding the future, 59% of the interviewees believe that energy refurbishment will be necessary.*

The latest NECP draft [4] suggests that out of ~4,6 million households [12], 2,6 million must undergo energy refurbishment at some level. In accordance with a strategy published by the Ministry of Innovation and Technology [13], by 2030, 20%; by 2040, 60% and by 2050, 90% reduction is aimed at decreasing emissions from household-related energy consumption.

2. State of the art in Hungary

To achieve the aforementioned goals in Hungary, large-scale preparatory and implementation efforts are necessary. Many research papers and reports discuss the mapping of key barriers, incentive factors, trends, and opportunities, providing insights into the future.

The processes that occur in the residential and building sector depict an improving landscape regarding renewable energy and overall energy consumption as well. According to the census conducted in 2022, a radical shift occurred in the type of heating systems in favour of electricity [14]. Table 4 illustrates the transition in the number of households and the corresponding percentage changes. Electricity from renewable sources is also gradually capturing a larger share of overall electricity consumption (Figure 3) [15], space heating and space cooling. Between 2011-2022, the total number of households (inhabited dwellings) increased by approximately 100,000 [16], although FEC of households has stagnated [2].

Table 4 - Fuel type of heating systems of inhabited households [14]

	2011	*2022*	*Change*
Natural gas	1 743 971	1 788 022	+2.53%
Electricity	32 257	129 294	+300.82%
Firewood	702 236	619 573	-11.77%
Other fuel	27 581	21 006	-23.84%
Natural gas and electricity	21 047	164 084	+679.61%
Natural gas and firewood	598 513	543 928	-9.12%
Other fuels	179 246	123 910	-30.87%
District heating	607 578	618 724	+1.83%

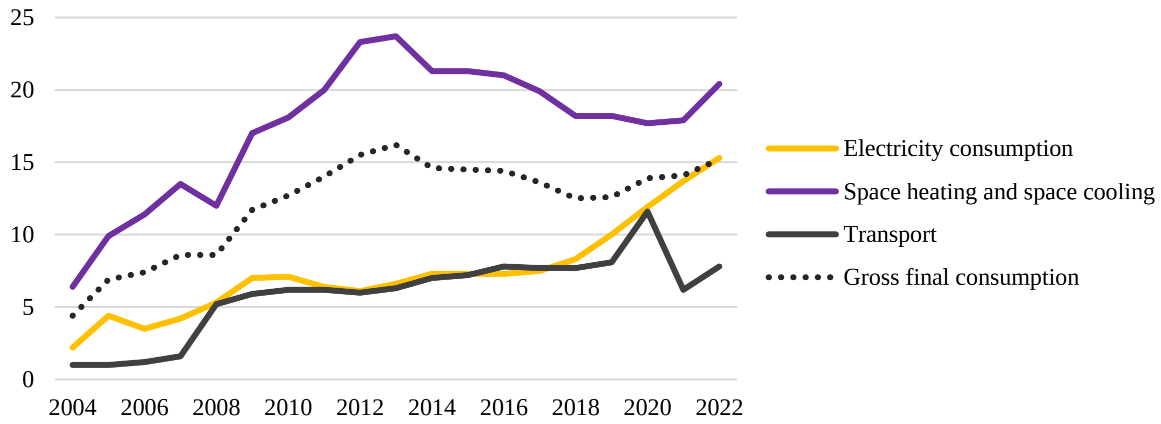

Figure 3. Share of renewable energy by intended use [%] [15]

The growing adoption of novel technologies in this market, such as heat pumps and photovoltaic (PV) panels, can be attributed to the combined effects of increased attention to climate change, frequent and significant changes in the legal environment regarding the energy performance of buildings, volatile energy prices, and the associated payback periods, all of which influence public mindset. Stakeholders, including lawmakers and investors, are constantly searching for opportunities to overcome the typical barriers that hinder primarily deep renovations. Numerous researchers have investigated the potential for refurbishing the country's existing building stock and have identified the need for large-scale interventions. Sugár et al. investigated energy performance of buildings in the 7th district of Budapest, proposes renovation scenarios and concluded that there is a fair correlation between architectural type and energy saving potential [17]. Marking critical areas and blocks for investors, lawmakers and colleagues of municipality in advance. Hrabovszky-Horváth et al. conducted research regarding residential building typology to assess the potential of GHG mitigation at urban level, pointing out settlements with the highest potential [18]. Vámos et al. analysed 5 years of data of 619 buildings with district heating [19]. It was concluded that the implemented energy refurbishments may fall short of modelled expectations due to the significance of user behaviour and a gap between 17-39% could occur. The National Typology of Residential Buildings in Hungary categorized the main residential buildings, serving as a base for many research projects and studies investigating effect of large-scale energy refurbishments [20].

2.1. Scope in detail

The aim of conducting such investigations is to prepare a package containing the cornerstones for energy refurbishing a traditional residential building. Key aspects address include:

1. On-site inspections, mapping, and measuring building characteristics related to building envelope and building service engineering systems,
2. Surveys regarding occupant habits, with a particular focus on the use of the building and building service engineering systems,
3. Assessing desired versus current comfort levels,
4. Developing renovation scenarios and evaluating their effectiveness,
5. Carrying out refurbishments (optional),
6. Conducting follow-up assessment of completed project (optional).

Addressing a traditional residential building necessitates emphasizing the impact of all six stages to achieve improved energy performance and avoid the energy performance gap. This phase of the package focuses on the first stage, which involves the standardized measurement of the heat transfer coefficient of a wall, the thermal conductivity of a brick, and thermal imaging.

3. Methodology and results

3.1. Sample building for the study

As most of the buildings located in this district can be attributed to a specific period, this traditional residential building might have been built around the turn of the previous century. Its licensing documentation was submitted by Mórné Hoffmann and approved by the authority in 1896, and as in case of many other buildings in the street, its apartment blocks were rented out [21].

Figure 4. Diószegi Sámuel street 18., facade

Although, its façade and ornament suggest a rather prestigious appearance compared to contemporary plain surfaces, its primary function was to accommodate workers in need. Initially, wet blocks were not included in every flat in its time. However, current residents have partially adapted them to modern standards wherever possible. Presently, all units in this building are municipally owned and are occupied exclusively by disadvantaged tenants.

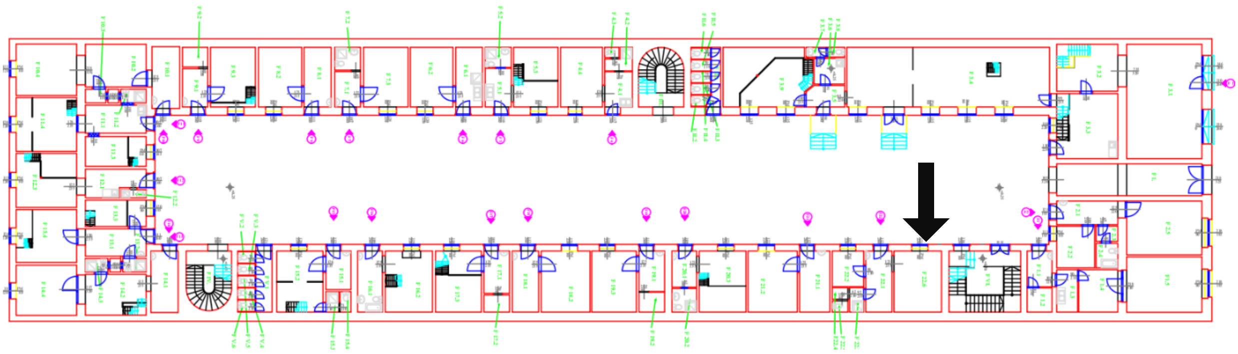

Figure 5. General floorplan of the building (measured wall marked with arrow)

Due to limited number of resources, renovations usually took place individually rather than in a holistic, centralized manner. Covering all aspects of necessary refurbishment poses a financial burden. Based on questionnaires and on-site inspections, it can be stated that occasionally tenants themselves allocate money for improvements to increase comfort level in their flats. Another reason for undertaking energy refurbishments is when a flat is needs to meet certain conditions before a tenant moves in. This is similarly implemented as the previous case and results in only stand-alone refurbishments.

3.2. Measuring heat transmittance of a wall located on the ground floor

For the first measurement, a wall on the ground floor facing the inner courtyard was selected. The process lasted for 3 continuous days (72 hours) with a device (data logger: AHLBORN

ALMEMO 26908A [22], heat flow plate: AHLBORN FQA018 [23], connector for thermocouples: AHLBORN ZA9020FS [24]) registering the heat flux via measuring inner and outer air temperature and inner and outer surface temperature of the wall at every 5 minutes. According to ISO 9869-1:2014 [25], for an appropriate result, a sufficient and stable temperature gradient between the two spaces must be ensured, avoiding effect of multidimensional heat flows (e.g. thermal bridges in corners, near slabs or side jambs of windows).

Figure 6. Sensors placed outside

Figure 7. Heat flux meter and temperature sensors installed on the inside

During the process, the measured value of the thermal transmittance showed correlation with research performed on traditional buildings in Budapest. Sugár et al. mentions values of the external brick walls from similar period extending from 0.98 to 1.66 W/m^{2}K [26]. Some unevenness can be seen due to ventilation or the coarse regulation of wall-mounted gas convector. Figure 8 shows the calculated thermal transmittance coefficient (U-values), Figure 9 shows the measured temperature of inner and outer wall surfaces and inner and outer air and Figure 10 the measured heat flux.

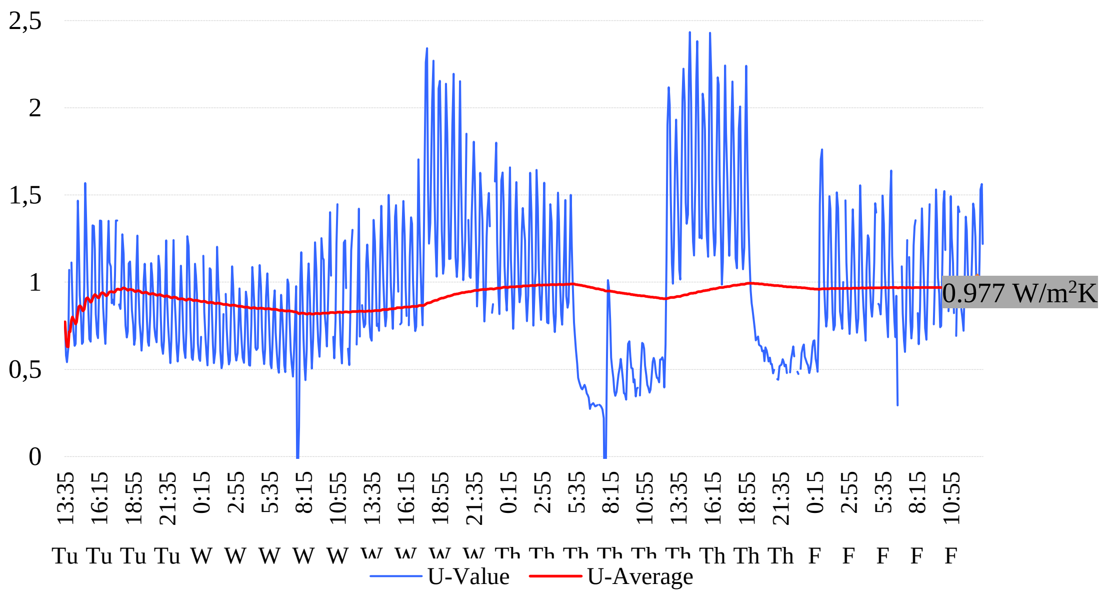

Figure 8. Calculated U-values, instantaneous and average [W/m^{2}K]

The result was that the 50 cm thick brick wall with one-sided plaster has the U-value of 0.977 W/m^{2}K.

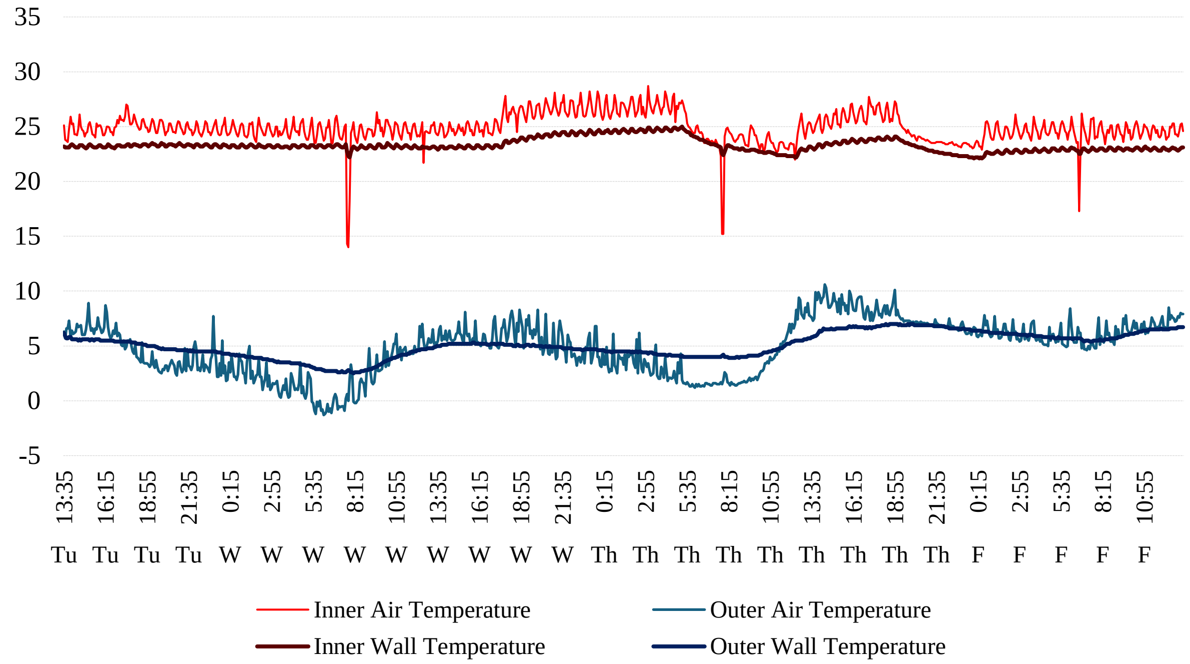

Figure 9. Measured temperatures [°C]

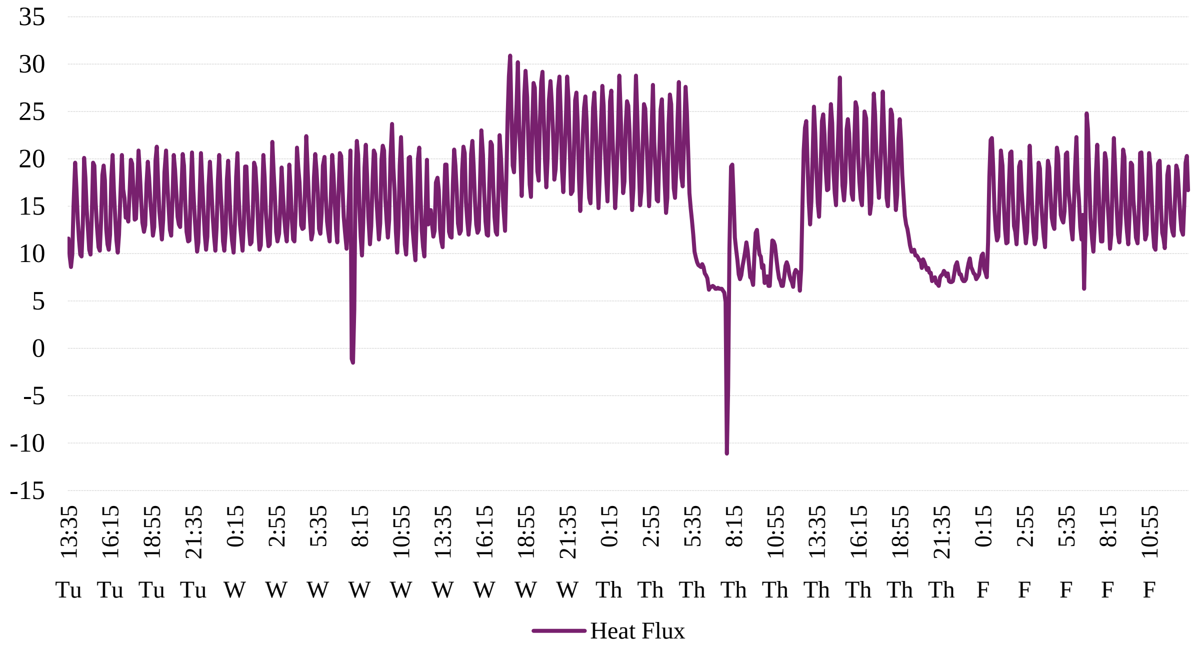

Figure 10. Measured heat flux [W/m^2]

3.3. Measuring the thermal conductivity of a masonry brick

A masonry brick was collected from the building and its thermal conductivity was measured, see Figure 11 [27]. The brick was produced by the Kőszénbánya' s Téglagyár Társulat Pesten [28] [29] (Coalmine and Brickworks Company in Pest) brick factory.

Figure 11. Masonry brick used for the building [27]

The brick was cut, grinded and dried in ventilated oven to constant weight according to EN ISO 12570. Physical and hygric characterization was measured in a climatic chamber at 10°C and 10% relative humidity, then Modified Transient Plane Source method was used to determine thermal conductivity in 3 different perpendicular direction (average value was considered) [27].

Table 5. Characterization of the sample masonry brick [30]

Characterization	*Measured value*
Thermal conductivity	0.414 W/mK
Specific heat capacity	1.090 kJ/kgK
Density	1375 kg/m^3

3.4. Thermal imaging

To gain a better understanding, critical areas in the dwelling were captured using a thermal camera (Fluke Ti32) [31]. Mainly potential thermal bridges, fenestration and effect of unoccupied dwellings were mapped via this method.

The images (from Figure 12 to Figure 30) suggest the following issues with the apartments:

- Wall dampness occurs, causing plaster detachment (see Figure 18) and reducing the wall's thermal insulation capacity up to a height of ~1-1.2 meter,
- Major heat loss and air leakages through the single glazed windows and deteriorated entrance door (explained by warm surfaces above the window, see Figure 17),
- Unfavourable effect of unoccupied neighbouring apartments,
- Unfavourable effect of building construction elements (steel beams, consoles, see Figure 25),
- Allows for conclusion whether a neighbouring unoccupied apartment is sealed or lacks fenestration (major difference between wall temperatures on Figure 30 and Figure 24).

Apartment: 01, ground floor

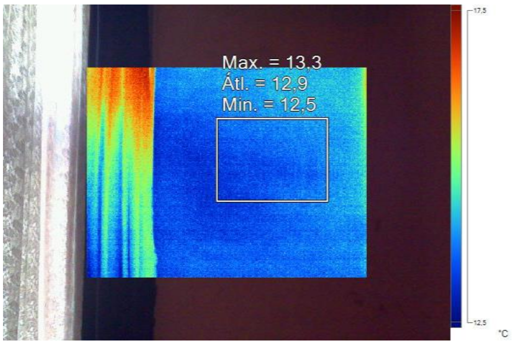

Figure 12. Outer wall, next to window

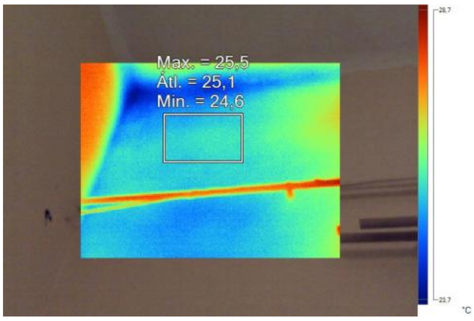

Figure 13. Upper corner, below unoccupied flat and neighbouring firewall

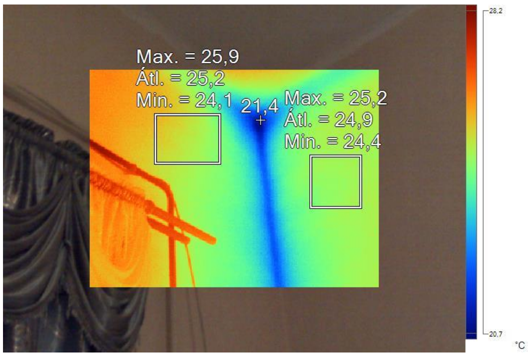

Figure 14. Upper corner, below unoccupied flat, facing to the courtyard

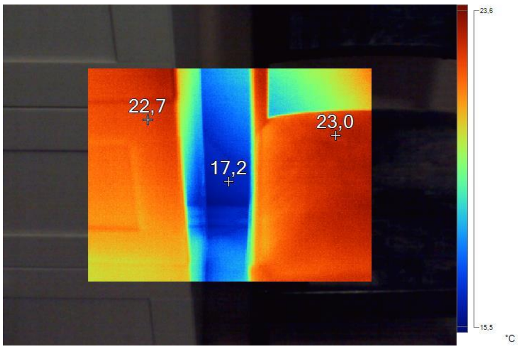

Figure 15. Lower corner, above unheated basement, facing to the courtyard

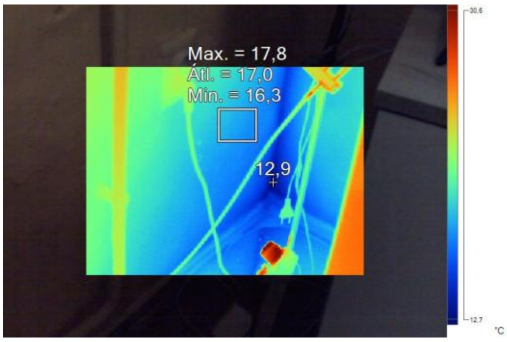

Figure 16. Lower corner, above unheated basement, facing to the courtyard

Figure 17. Façade (facing courtyard) with window

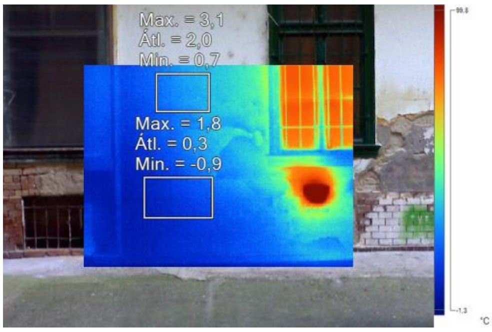

Figure 18. Façade (facing courtyard) with window and wall-mounted gas convector flue exhaust

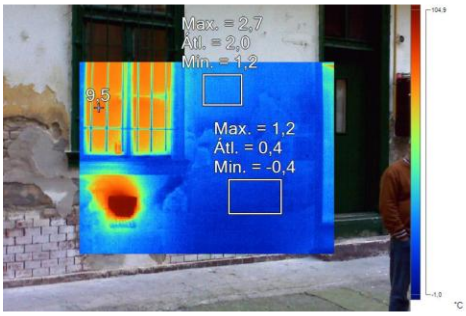

Figure 19. Façade (facing courtyard) with window and wall-mounted gas convector flue exhaust

Apartment: 02, 1st floor

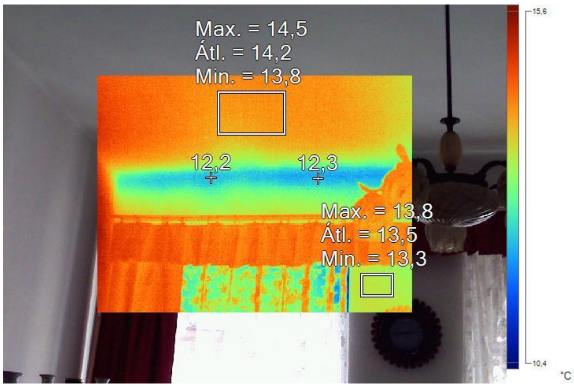

Figure 20. Upper corner on façade (facing the street) wall

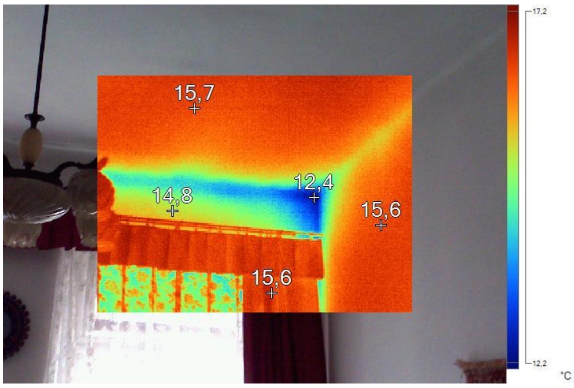

Figure 21. Upper corner on façade (facing the street) wall

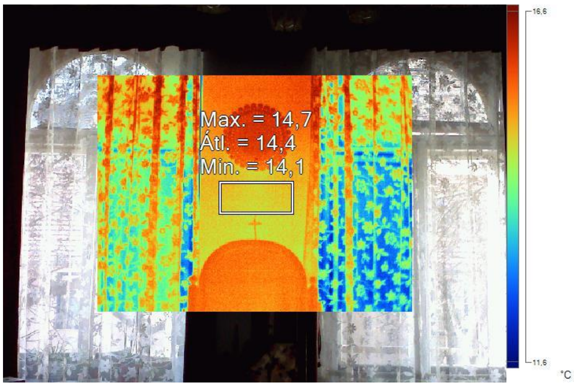

Figure 22. Façade wall, facing the street

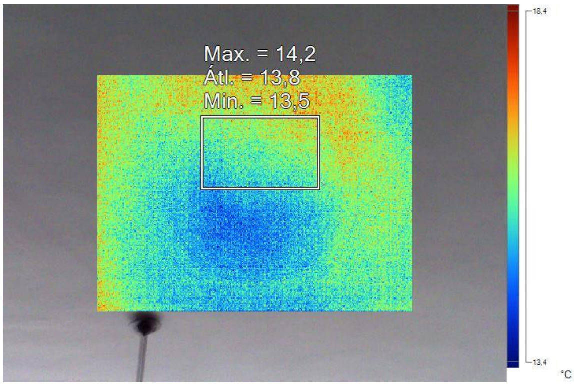

Figure 23. Ceiling under unoccupied flat

Apartment: 03, 1st floor

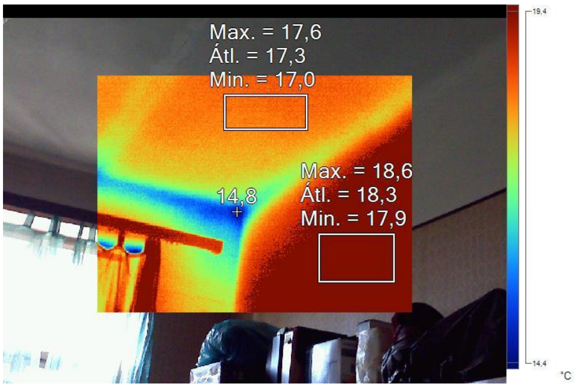

Figure 24. Upper corner on façade (facing the street) wall

Figure 25. Upper corner on façade (facing the street) wall

Figure 26. Façade wall, facing the street

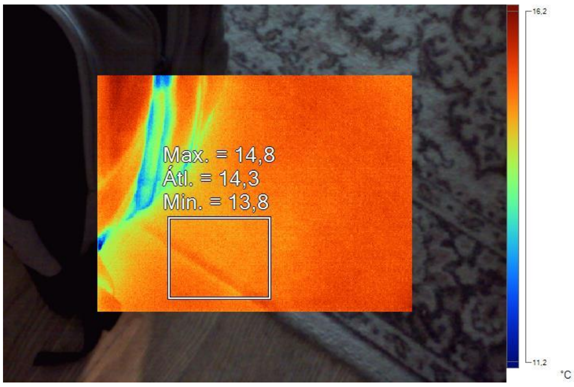

Figure 27. Floor above unoccupied flat

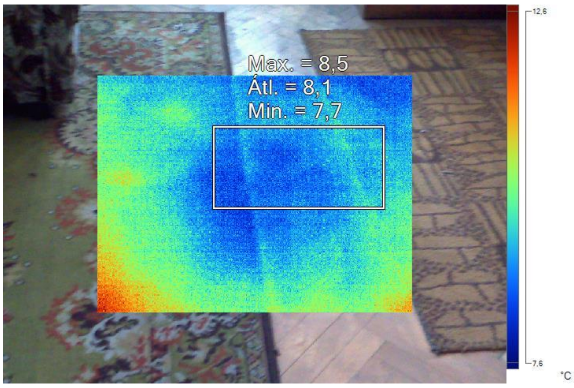

Figure 28. Floor above unoccupied flat

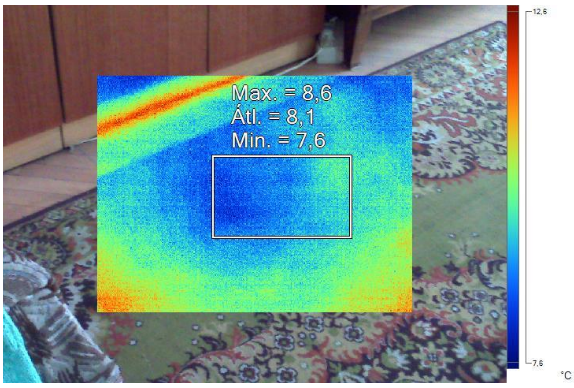

Figure 29. Floor above unoccupied flat

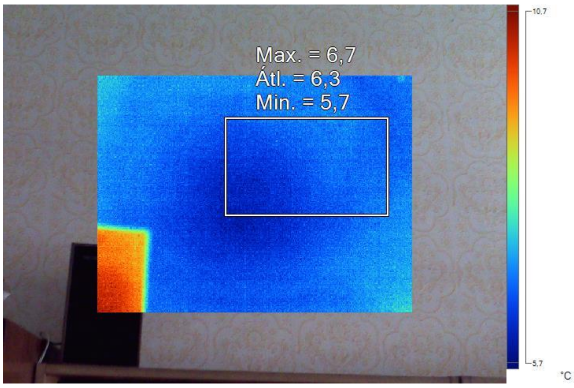

Figure 30. Separating wall next to unoccupied flat

4. Discussion

The thermal transmittance coefficient of the façade wall of the ground floor apartment is 0.977 W/m^{2}K, falling short by 75% compared to the minimum requirement (0.24 W/m^{2}K) mandated by a decree regulating energy performance of buildings [32]. This can be addressed by adding 10-12 cm of mineral wool insulation with insulated plaster. Regarding the potential outcomes of such investigations, more information about the building envelope, materials and user habits (including occupancy, electrical appliances, utilities and fees, comfort level) must be collected. A set of dynamic building simulations must be performed, aiming to find optimal levels of intervention in line with needs, opportunities and actual state of the building.

Considering the sensitivity of the inhabitants and (primarily) financial barriers, the least possible investment must also be assessed along with others focusing on different key points of energy performance of a building. A life cycle assessment regarding harmful agents emitted, payback period and comfort level must also be concluded from detailed simulations.

Table 6 suggests possible renovation scenarios to improve the building energy performance.

Table 6 - Proposed renovation elements in different scenarios

	Scenario 1.	*Scenario 2.*	*Scenario 3.*	*Scenario 4.*
Openings	Replacement	Replacement	Refurbishment	Refurbishment
Walls, roof, floor	Insulation	Insulation	Insulation	Insulation
Heating system	Replacement*	Replacement**	Refurbishment	Remains
AC/Ventilation system	New*	New**	-	-

*Centralized; **Individual

5. Conclusion

The results of the aforementioned measurement processes are to be assessed and used to develop holistic energy renovation scenarios. In the social housing sector, it can be concluded that when an apartment is neglected, unoccupied, and left without maintenance for a period, there is a significant drop in comfort of adjacent apartments. Based on the observation and measured wall characteristics, critical point of the building can be seen as outdated openings and increased heat flux through separating walls between the observed apartment and adjacent unheated apartment. Given the lack of a centralized heating and ventilation system, refurbishment of openings, rather than replacement, must be considered, taking into account the moisture conditions in each apartment. Comfort level can further be improved by introducing cooling in certain apartments. For the current issue with the alternately occupied and unoccupied apartments, a building level system must be introduced.

Acknowledgement

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Nomenclature

kg/m^3	Density
kJ/kgK	Specific Heat Capacity
PJ	Peta Joule
tCO_2eq	tonnes of CO2 equivalent air pollutants and greenhouse gases
W/m^2K	Thermal Transmittance Coefficient
W/mK	Thermal Conductivity Coefficient

Abbreviations

FEC	Final Energy Consumption
EU	European Union
GHG	Greenhouse Gas
HEEI	Hungarian Energy Efficiency Institute
NBES	National Building Energetics Strategy
NECP	National Energy Climate Plan
PEC	Primary Energy Consumption

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