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# External Thermal Insulation Composite Systems—Past and Future in a Sustainable Urban Environment

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**Abstract:** In recent decades, the sustainable development of the planet has been negatively affected by a number of factors, including the construction industry. The construction industry includes, among other things, the highly topical energy reconstruction of existing prefabricated residential housing, which is implemented to improve their condition from a thermal engineering and energy perspective. Composite materials, known as external thermal insulation composite systems (ETICSs), have come to the fore, bringing a number of undeniable benefits to society. After more than 20 years of experience, it turns out that in addition to the benefits, ETICSs also bring new research challenges to the discussion, which are related to the issue of the biocorrosion of the external envelope of ETICSs, and also to the issue of the indoor microclimate. Based on the literature review and case studies, we aim to show that ecologically friendly building materials require a multidisciplinary approach. At the same time, we want to contribute to the discussion of whether the diversity of microorganisms on ETICS composites is a potential source of health risks and whether the transport of microorganisms to the indoor environment can be ruled out through natural ventilation from the outdoor environment to the interior.

**Keywords:** urban environment; residential housing; external wall; composite materials; biodegradation; microorganism; sustainability; quality of indoor microclimate

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## 1. Introduction

In recent decades, we have seen increased demands for energy savings. The European Union's strategic goals for 2030 and 2050 imply that energy measures, $CO_2$ reduction, climate neutrality and emphasis on the Green Deal [1] strongly accentuate the construction industry, in addition to new construction and renovations of panel residential housing, which are implemented using prefabricated technologies [2–7]. Increasing the energy efficiency of buildings, which started in the European Union countries at the end of the second half of the last century, has gradually led to the mass application of composites, known as ETICSs (external thermal insulation composite systems) [8,9], especially for existing residential housing, including apartment buildings built using panel (prefabricated) technology. The EU considers the application of ETICSs as a technology that brings positive benefits to society. As the author [10] states, the EU understands the ETICS as a composite material and technology that is environmentally friendly, is part of the circular economy and, last but not least, as a structural and architectural measure that leads to the aesthetic improvement of prefab residential housing estates and to the improvement of the quality of prefabricated residential housing.

Set and in reality, systematized energy measures in the form of ETICSs in the reconstruction of residential housing from the second half of the last century lead, on the one hand, to energy savings, while on the other hand, we encounter negative impacts in the form of modern defects [11–13]. This includes in particular, the biodegradation of the external envelopes of residential housing with ETICSs and the deterioration of indoor air quality [14–18].

In the case of the biodegradation of ETICS envelopes in panel residential housing, it appears that these undesirable manifestations started to increase with the gradual increase in the composite thickness, in accordance with the increasingly stringent energy requirements defined by the EU and their implementation in the legislation of EU member states. The secondary impact was the already mentioned deterioration of air quality in the EU internal environment (legislation: legal harmonization of the 2010/31/EU Directive; Energy Efficiency, Council Directive of the European Parliament, 2012/27/EU; Directive No. 78/2013 Energy Performance of Buildings, Directive 2018/844/EU; EPBD I., II., III., Inc. Recast; Code 73 0540-2, 2011/CZ (the physical connections of "biodegradation x increasing" the thickness of the composite are presented in Appendix A).

The issue of biocorrosive facades with ETICSs has led to calls for building microbiology to be more widely integrated into interdisciplinary research and standards legislation relating to the quality of the external envelope and the quality of the indoor microclimate of existing buildings. These challenges lead, in principle, to fulfilling the environmental building requirements for buildings to be healthy, not showing the so-called "Sick Building Syndrome" (SBS). At the same time, these challenges make it so that the implemented energy renovations are effective, ecological and extend the life of residential housing by at least 25–30 years, assuming systematic maintenance [19–23].

The issue of modern defects and failures in the context of building microbiology, biocorrosion of the facades of residential housing, deterioration of indoor microclimate quality and environmental contexts is currently not clearly demonstrated and the opinions on this issue are varied [24–28].

The aim of this article is to draw attention to the persistent problems of the biodegradation of the facades of residential housing, which are equipped with external ETICS composites, and the issue of the quality of the internal microclimate.

We aim to compare the results of our research work with findings from abroad. Using the example of a case study and their selected locations and other findings from the literature, we aim to verify the diversity of microorganisms in a biologically degraded facade. At the same time, we aim to verify whether the biologically degraded external shell with ETICSs can have an impact on the quality of the internal microclimate of residential housing.

## 2. Materials and Methods

Our research was divided into two parts:

- Study of literature and established scientific knowledge. The aim of the research was to achieve an overview of the literature related to the issue of the biodegradation of ETICSs. Articles were evaluated according to keywords, as shown in Figure 1. Studying the articles allowed us to understand the issue in a wider range of presented findings from research. At the same time, it was possible to confront the issue with the results of our research work (Appendices A and B).
- The comparison of results from conducted research (according to the results of case studies, see Appendix A, selected locations CS 2 and CS 3, and in the text Appendix A) with the results determined according to points outlined above results in the following objectives, namely:
    - (a) Comparison of results from conducted research include determination of the diversity of microorganisms on the example of 2 selected locations from the case study (a selection of locations with a label CS 2 and CS 3);
    - (b) To document whether the increasing thicknesses of the ETICS composite, as a result of standard regulations, can have a negative impact on the quality of the internal microclimate;
    - (c) To document whether the migration of microorganisms from the surface of ETICS towards the internal environment of apartment buildings can be harmful to health or not.

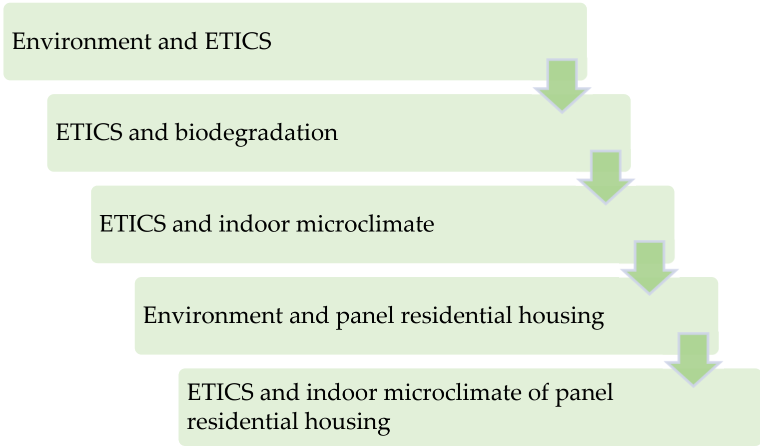



**Figure 1.** Defining keywords.

### *2.1. Study of Literature*

We were inspired to prepare the overview failures of composite ETICSs and their biodeterioration by research articles. The review allows us to familiarize ourselves with the results obtained from the articles and allows us to gain an understanding and to find out what direction to evaluate composite ETICSs. The survey of articles was focused on examining the Web of Science (WoS) by keywords, as shown in Figure 1. According to keywords, 176 articles in the WoS database were found. The articles were represented by authors from the USA, China, Poland, Portugal, Italy and Czech Republic. It is clear from the timeline of the period 1995 to 2022 that the reconstruction, housing construction and energy reconstruction is gaining in importance over time and that the focus of the research activity is on ETICS composites, as shown in Table 1.

**Table 1.** Overview of articles (by keywords) and overview by country.

| Year and Country 1995 to 2022 | Environment and ETICS | ETICS and Biodegradation | ETICS and Indoor Microclimate | Environment and Panel Residential Housing | ETICS and Indoor Microclimate of Panel Residential Housing |
|---|---|---|---|---|---|
| Poland | 10 | | | | |
| Portugal | 10 | | | | |
| Czech Republic | 5 | 2 | 2 | 8 | 2 |
| Estonia | 4 | | | | |
| USA | | | | 29 | |
| China | 4 | | | 16 | |
| Italy | | | | 7 | |
| South Korea | | | | 7 | |
| Other countries | 8 | | | 62 | |
| | 41 | 2 | 2 | 129 | 2 |

Note: The numbers in the column indicate the most represented keywords for the articles.

The literature review confirms that the issue of energy rehabilitation of panel residential housing needs to be given continued attention. This is also confirmed by the presented results. It is confirmed that around the 1980s, ETICS composites started to be applied in Europe to the envelope of panel residential housing, and after a lifetime of about 25 years, there is an opportunity to evaluate them, both in terms of positives and negatives. A certain parallel can be found in the development of energy legislation and the ever-increasing requirements for energy savings, as shown in Table 2. It can also be seen that around the year 2000, more emphasis is placed on the quality of the indoor microclimate of panel residential housing, which is, among other things, related to the issue of ETICS composites and increasing their thickness due to increasingly stringent energy legislation.

**Table 2.** Development of thermal technical requirements and EU Green Deal strategy until 2050.

| **1949** | **1950–1960** | **1963** | **1979** | **1992–1994** | **1997** | **2002** | **2005** | **2007** | **2000–2020** | **2024–2030** | **2030–2050** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Code 1450 | 1st Code 73 0540 (CZ) for thermal technique | Code 73 0540 | Revision Code 73 0540 | Revision Code 73 0540 Thermal protection of buildings | Code 73 0540—Change 1 | Code 73 0540 Novel of part 2 | Code 73 0540 and its composition of new 4 parts | Code 73 0540 and the introduction of new quantities | EPBD I., EPBD II. | EPBD III, IV. and Emission strategy | Emission strategy |
| Perimeter wall thickness [mm] and material for additional contact insulation | | | | | | | | | | | |
| 450 Brickwork | | | | | 240, 270, 300 Perimeter panels based on lightweight concrete (e.g., slag concrete, gas silicate) | | | | Fit for 55 Emission-free strategy | | |
| Thickness of additional contact insulation based on extruded polystyrene (XPS) or mineral waves (MW) [mm] | | | | | | | | | | | |
| 0 | 0 | 0 | 0 | 0 | 60 | 60<br>80 | 80<br>100 | 100<br>120 | 120<br>150 | 150<br>180<br>200 * | Emission free |

* exceptionally.

The issue of composite ETICS and the stressing of these composite ETICSs by climatic influences is the subject of the article on the topic "resilience of biocide free ETICS to microbiological growth in an accelerated weathering test". The main objectives of the study were to evaluate whether biocide-free ETICSs have adequate resistance to biocolonization of facades, whether the resistance behaviour of ETICSs can be predicted based on the physical properties of the products or whether the behaviour needs to be verified by laboratory testing. An accelerated weathering test in a laboratory environment was developed for the purposes of the research. At the same time, the physical context was considered, which shows that moisture condensation when the dew point drops at night and wind driven rain are among the main factors known to promote algae growth on insulated facades. The results present that biocide-free external plaster ETICSs and ETICS coatings, for example on the German market, can show good resistance to microbiological growth. Of the 15 sample combinations tested, only 2 samples showed low to moderate resistance [29].

Other articles dealt with surface temperature and pigmentation of ETICSs and subsequent degradation of the composite surface (for documentation: Bishara, A. et al. 2017 [22]). The authors state that more intense colour shades are used for external thermal insulation composite systems than ETICSs on energy efficient facades. However, the surfaces become extremely hot and cause damage to the ETICS. By using suitable pigments with optimized near-infrared (NIR) reflection, surface temperatures and degradation processes can be reduced. Nevertheless, temperatures above 70 °C are still unavoidable in practice.

Other articles focused on the necessary maintenance of ETICSs over time [30]. For example, ref. [31] states that the removal of biocorrosion coatings from ETICS structures using chemicals and preservatives (biocides) is currently the only effective and also most widely used technology. However, the uncontrolled leaching of used biocides is unacceptable for the environment. Current scientific knowledge points towards the replacement of biocides currently used in facade treatments with environmentally friendly biocides that have no negative effects on people or the environment.

A number of articles have emphasized the characteristics of microorganism habitats, diagnostics and environmental contexts in research. In principle, the information was based on the fact that microorganisms are highly viable and are able to survive in extreme conditions [32,33]. This is confirmed by a number of other professional publications [29–33].

The other studies compare different types of buildings with different thicknesses of additional insulation in combination with ventilation. The results state that the technical specification of ventilation rates for energy efficient buildings are given as 0.20–0.35 $h^{-1}$, which is completely contrary to the codification that states that the minimum ventilation rate should be 0.50 $h^{-1}$. This means that energy savings are already more of a concern when designing reconstruction work than the quality of the indoor environment and other contexts (for documentation: Asere, L. et al. 2016 [27]), such as the biodegradation manifestations of the ETICS composite. Our results show that the quality of the indoor microclimate in residential housing, without controlled ventilation, is insufficient, and there is an increase in the concentration of $CO_2$ (Appendix B).

Based on analyses of articles that looked at the impact of energy efficiency measures in buildings on human health and well-being, some authors concluded that energy efficiency measures have a small but demonstrably positive impact on health. On the other hand, the authors state that indoor environmental quality in highly energy efficient buildings is still an under researched topic. We see that the current opinions in research are not the same.

Other studies present the view that insulation measures, apart from the biocorrosion of ETICSs, have a rather negative impact on human health and well-being, mainly due to the deterioration of indoor air quality. Energy measures usually reduce the natural infiltration of air into buildings, resulting in insufficient fresh air supply to indoor spaces. Poor indoor microclimate quality is often associated with the development or worsening of respiratory problems (e.g., asthma), headaches, impaired concentration, etc., and we consider indoor microclimate quality to be of great importance for public health. Some authors claim in their studies that people living in buildings after energy saving reconstruction are more likely to suffer from asthma or other respiratory problems. According to them, the reason for this is the limited ventilation of the building, which often creates suitable conditions for mould growth (especially due to increased humidity) and thus the risk of allergic diseases and asthma caused by moulds (e.g., Aspergillus, Penicillium, Alternaria or Cladosphorium) increases. This highlights the need to reflect on the impact of building insulation, with its negative impact on the increase in indoor humidity and the associated occurrence of mould inside buildings [34]; in connection with the natural ventilation of the window, it is necessary to solve the infiltration of microorganisms in the internal environment.

### *2.2. Comparison of Results from Conducted Research*

In the second half of the last century, residential housing in the Czech Republic was mainly characterized by prefabricated technologies. Around 1998, reconstruction works were started in order to improve the thermal technical and energy properties of the panel (also called prefab) residential housing. Current knowledge and practice show that panel residential housing, which has been provided with ETICS composites, in many cases, shows signs of biodegradation, which negatively affect not only the appearance of the facade but can also have an impact on the quality of the indoor microclimate, as the diversity of microorganisms can have pathogenic character. The distribution of microorganisms from the external surface of ETICSs towards the internal environment, for example during direct window ventilation or air conditioning, is very likely (no article was found to confirm this hypothesis).

Microorganisms colonize the external surfaces of buildings most often in the following order: bacteria, algae and fungi—with the fact that it is impossible to clearly determine their biodegradation and health hazards without knowing the concentration and species representation [35,36].

The issue of biodegradation of ETICS composites can be documented in case studies (Appendix A, Section 2.3). For comparing the diversity of microorganisms, localities are selected that are within a radius of approximately 15 km, with a label CS 2 and CS 3 (Appendix A, Table 4). In these locations, monitoring and sampling took place in order to determine the diversity of microorganisms [37,38].

The following parameters are monitored for basic comparison:

- Orientation of the residential housing towards the world parties,
- Facade shading;
- Proximity to greenery and water bodies;
- The thickness of the ETICS composite (the thickness of the ETICS composite was determined according to the overview in Table 2 and Figures 2 and 3 in accordance with the development of requirements according to standards (code) and legislation (for CZ and the development of requirements according to EU legislation);
- Architectural design of the apartment building, division of the facade and solution of details in the perimeter shell;
- Laboratory diagnostics.

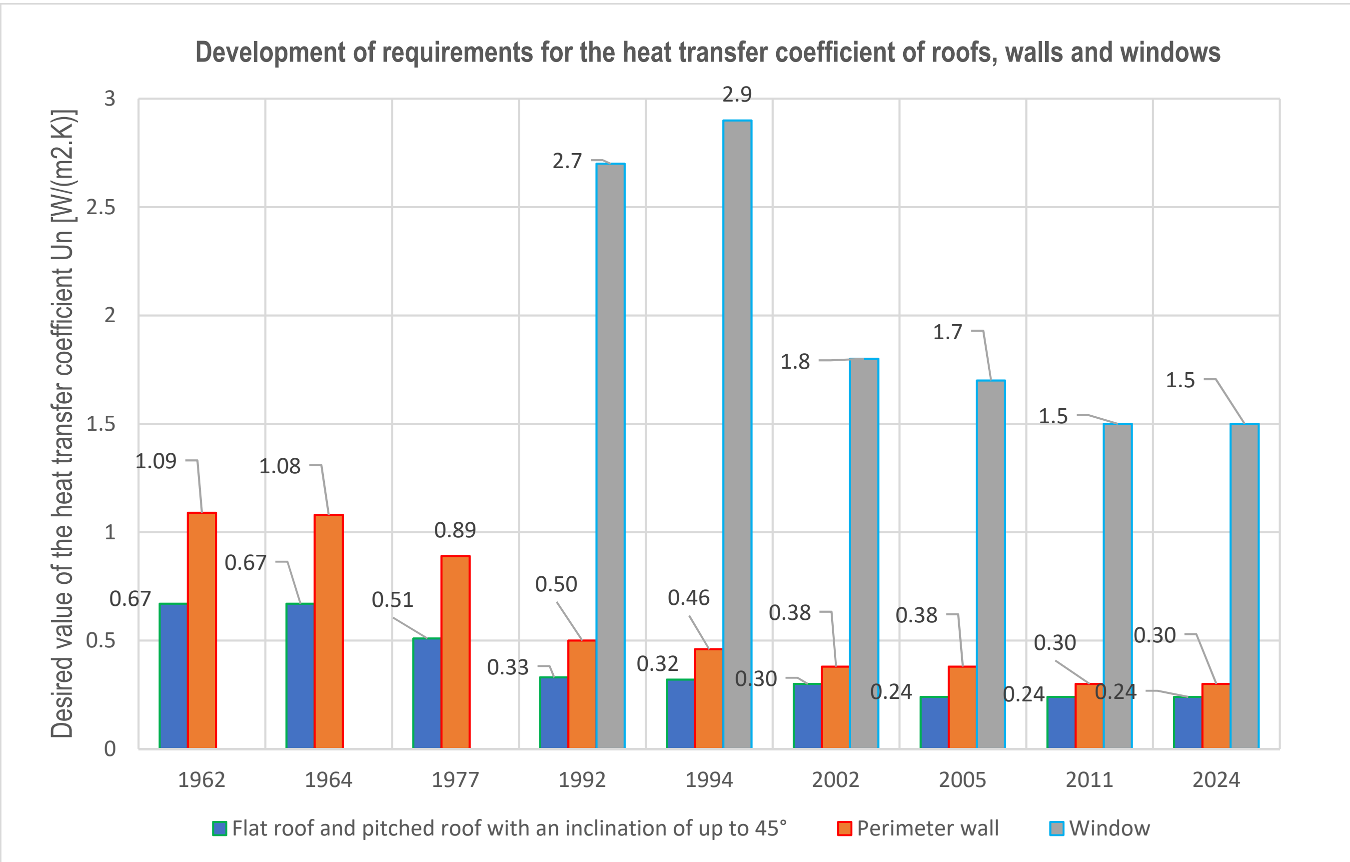



**Figure 2.** Development of requirements for the heat transfer coefficient of roofs, walls and windows.

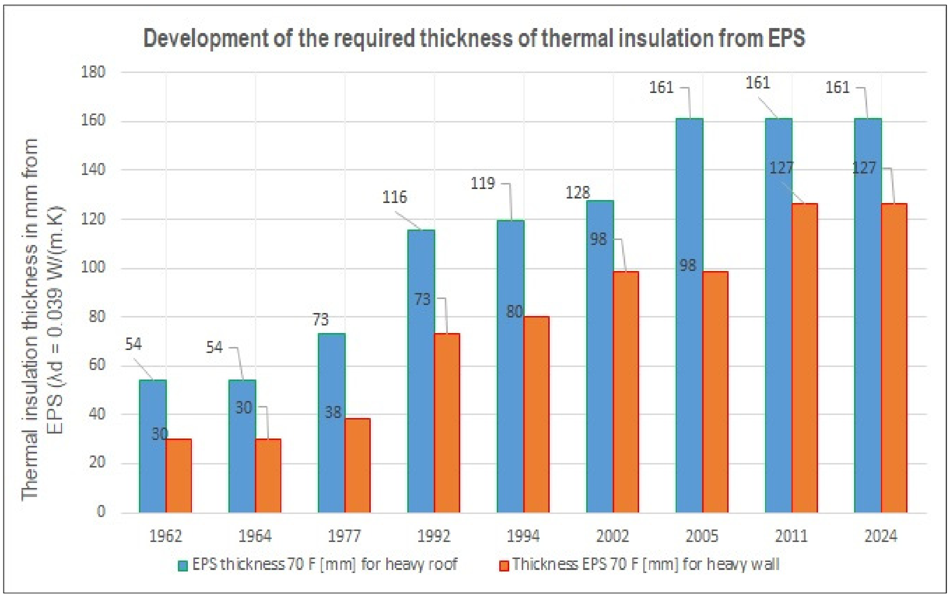



**Figure 3.** Development of the required thickness of thermal insulation from facade polystyrene (EPS).

2.2.1. Selection of Locality CS 2 for Defining Species Diversity of Microorganisms for the Area 90 ha

CS 2: The area of the investigated site was approximately 90 ha (Appendix A, Figure 3, Table 4). Sampling for laboratory testing took place in the autumn months, according to the parameters for monitoring.

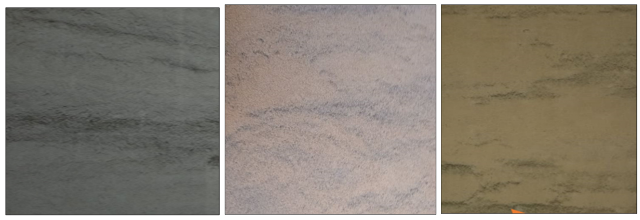
It follows from monitoring and testing (see Tables 3 and 4, and see Figure 4a,b) that in the given locality, algae predominated in approx. 80% and fungi in approx. 20%. Figure 4a shows the state of the biodegraded area before sampling.

**Table 3.** Information about monitored parameters.

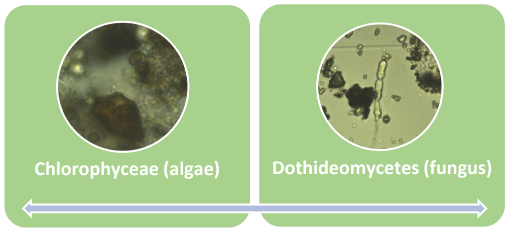
| Parameters and Comparison of Selected Locations CS 2 and CS 3 | Location CS 2 with an Area of 90 ha | Location CS 3 with an Area of 50 ha |
|---|---|---|
| Orientation of the residential housing to the cardinal points. | mainly the north | mainly the north |
| Facade shading. | Yes | Yes |
| ETICS composite thickness [mm]. | 120–150 | 120–150 |
| The architectural solution of the residential housing, the division of the facade and the solution of details in the perimeter shell. | partially (loggias, balconies), strip architecture | partially (loggias, balconies), strip architecture |
| Laboratory diagnostics, in situ diagnostics. | Yes | Yes |

**Table 4.** Diversity of microorganisms and results from selected locations CS 2 and CS 3.

| Parameters and Comparison of Selected Locations with Area CS 2 and Area CS 3 | CS 2 with an Area of 90 ha | CS 3 with an Area of 50 ha |
|---|---|---|
| Chlorophycae (algae) [39] Figure 4b | 80% | 90% |
| Dothideomycetes (fungus) [39] Figure 4b | 20% | 10% |
| Other (see Appendix A, Table 3) | - | - |



(**a**)




(**b**)

**Figure 4.** Facades with biodegradation: (**a**) sampling area (surface condition of the ETICS composite prior to sampling); (**b**) algae and fungi (detected microorganisms after laboratory testing).

#### 2.2.2. Selection of Locality CS 3 for Defining Species Diversity of Microorganisms for the Area 50 ha

CS 3: The area of the investigated site was approximately 50 ha (Appendix A, Figure 3, Table 4). Sampling for laboratory testing took place in the autumn months, according to the parameters for monitoring.

It follows from monitoring and testing (see Tables 3 and 4, and see Figure 4a,b) that in the given locality, algae prevailed in approx. 90% and fungi in approx. 10%.

#### 2.2.3. Overview of Monitored Parameters for Selected Locations CS 2 and CS 3

Tables 3 and 4 present the comparative results for locations CS 2 and CS 3.

### *2.3. Diagnostic Options*

Diagnostics of the biodegradation of the residential housing envelope included parameters (see Section 2.2). To determine the genus of microorganisms, we collaborated with the Department of Nanotechnology [39]. The collected samples were analyzed microscopically, using a light transmission microscope at a magnification of 400×. The aim was to determine the genus of microorganisms [40]. The samples were always demonstrably inhabited by autotrophic organisms that could participate in the biodeterioration of the ETICS composite.

In some cases, thermal analysis can be used [41]. The goal of this diagnostic is to compare the composition of the external plaster of the ETICS composite with a reference sample. This method is usually used in cases where we have doubts about the quality of the ETICS material.

A suitable non-destructive diagnostic method can be considered as thermographic targeting of the perimeter casing with the ETICS composite. This method can be used especially after the completion of the composite, because it reveals to us “weak spots” in the envelope that predict moisture (Appendix C). It is true for all microorganisms that they need moisture to live and colonize the composite facade. Such a weak point can be considered, for example, thermal bridges and thermal bonds in the envelope, technological indiscipline, etc. [42].

It should not be forgotten that the diagnostic procedures can include the use of software supports, with which we can model weak spots in the envelope and determine areas that predict the start of the biodegradation process.

Both thermographic orientation and software support will allow us to start the controlled treatment of the facade with protective coatings ahead of time. In general, failure prediction eliminates defects and damage, as reported by [43].

The diagnostic procedure can be documented using the example of Figure A1:

- Thermal imaging targeting of the external wall and detection of weak points in the external wall;
- Verification of the thermal insulation thickness of the ETICS composite and comparison with the legislation, whether the thickness is satisfactory or not;
- Software modelling of the external wall and comparison of models with the results of thermal imaging;
- Taking samples from the surface of the external wall in the place of significant biodegradation and in the place of windowsills;
- Laboratory diagnostics and determination of the type of microorganism.

The results of the diagnostics will eventually lead to the proposal of remedial measures. The procedure can be documented in Figure 5, where the outer external wall is significantly affected by biodegradation.

**Figure 5.** Significantly degraded facade of the residential housing due to biodegradation (photo: D.K.). Note: biodegradation—a consequence of the inhomogeneity of the original external wall based on lightweight based on slag concrete, construction and physical connections (on the external wall, there is no surface biodegradation, and under the windows, there is a radiator for heating in the interior, see Appendix D).

## 3. Results and Discussion

The results of the literature review show that further research is needed to focus on the issue of testing the biological sensitivity of microorganism in ETICSs.

How far certain species of microorganisms or microbial phototrophs react to the colour and structure of ETICS and how they react to biocidal or photocatalytic coatings, etc., are discussed. For example, the research results to date confirm the importance of the microorganisms Chroococcidiopsis and the green microalgae Chlorophyta were standard phototrophic microorganisms when testing bioreceptivity and biodeterioration in ETICSs [44–49]. These microorganisms have the potential for widespread colonization of ETICSs, which has a very negative impact on the residential development.

In summary, we make the following conclusions:

- The results showed that the vegetation near the housing development is affected by the same types of microorganisms as the outer surface of the ETICS composite. Green terrestrial algae Chlorophycae, which are predominant in the case study overview, live locally, in colonies and on other surfaces, such as palisades, gutter walkways, among others. It turned out that the area of greenery or water bodies (forests, parks, rivers) does not have a major influence on the overall extent of colonization of the facade by microorganisms. An important factor for the initiation of biodegradation is the time exposure of the ETICS composite to moisture loading, the orientation of the panel residential housing with respect to the cardinal points and, most likely, the direction of the prevailing winds, which helps the natural transport and migration of microorganisms to other apartment buildings. The adherence to strict technological discipline is also an important factor. The exposure to moisture is documented in Figure A1 (Appendix C).

- The transport of microorganisms into the interior during window ventilation is highly probable. This transport phenomenon can have a negative impact on the health of the population, and a negative impact on human health cannot be ruled out, especially on children or the elderly population, who are more prone to developing health problems. While studying the literature, we did not come across a study that conducted research for ETICS composites in an interdisciplinary manner [50–55].
- The predominant areas of research are those that focus on the issues of building microbiology inside buildings, such as the effect of moisture on occupant health, mould formation, etc. The issues of external building microbiology and its link to building indoor quality, taking into account the environmental setting, are addressed to a lesser extent. However, it is important to note that a number of authors state that the issue of building microbiology along with environmental context needs to become an essential part of the criteria for assessing building quality.
- From the point of view of multidisciplinary research "natural sciences, construction and architecture, environment", the scientific discourse refers to the confirmation or refutation of the fact that the inhalation of undesirable microorganisms from the ETICS composites migrating into the inner space of residential housing through direct ventilation is harmful to health.

Energy legislation in EU countries with a link to the ambitious Green Deal sets the direction for municipalities and cities in member countries. It turns out that the ETICS composite has al large and positive role in energy reconstruction, especially in panel housing construction in the second half of the last century. The ETICS composite application technology supports the goals of sustainable development until 2050 and is in line with the "Fit for 55" strategy.

## 4. Conclusions

The issue of reducing the energy consumption in panel residential housing underdoing renovation, along with improving energy efficiency, leads to a wider open discourse on whether the implemented measures actually create a healthy or unhealthy indoor environment and microclimate. Undesirable microbial growth on thermally insulated facades of residential housing has been documented in a number of European countries, and biological growth has been identified as one of the main negatives of ETICS composites.

Current trends in construction are mainly oriented towards reducing the energy demand of the building. On the other hand, it is necessary to take into account all aspects of the creation of the internal environment and sustainability. Complexity ultimately leads to the need for a multidisciplinary approach to the interactive links of the entire building.

External thermal insulation composite systems are certainly an interesting technology for external walls, but despite their thermal and energy benefits, ETICSs face very serious problems with biodegradation. Currently, no methodical procedure or simple tool for predicting the risk of damage to ETICSs can be used by designers, architects, engineers and the construction industry. A specific technical standard ETAG 004 [56] for the technical approval of external thermal insulation composite systems with plasters is available in the EU (European Organisation for Technical Approvals, EOTA [57]). DIN series standards are also available. ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers [58]) standards can also be used. The creation of a new tool or methodology would lead to better sustainability not only for the panel residential housing in the second half of the last century, but realistically for all housing and civic buildings. This approach would eliminate reinvestment in the removal of biocorrosion in the building envelope with composite ETICSs and support the environmental context in construction projects.

**Author Contributions:** Conceptualization, D.K.; methodology, D.K.; software, K.K.; validation, D.K.; formal analysis, D.K. and K.K.; investigation, D.K.; resources, D.K., H.A., O.K.M. and K.M.; data curation, D.K.; writing—original draft preparation, D.K. and K.K.; writing—review and editing, D.K.; visualization, D.K. and K.K.; supervision, D.K.; project administration, D.K.; funding acquisition, D.K. and H.A. All authors have read and agreed to the published version of the manuscript.

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**Conflicts of Interest:** The authors declare no conflicts of interest.

## Appendix A

*Sustainability* **2023**, *15*(11), 8449; https://doi.org/10.3390/su15118449 [59].

## Appendix B

*Sustainability* **2020**, *12*(23), 10119; https://doi.org/10.3390/su122310119 [60].

## Appendix C

Thermal imaging diagnostics is a non-destructive diagnostic. It is advantageous for measuring the external wall of housing construction and the ETICS composite. In real time, it provides us with enough information about the defects in the cladding and the composite [61,62].

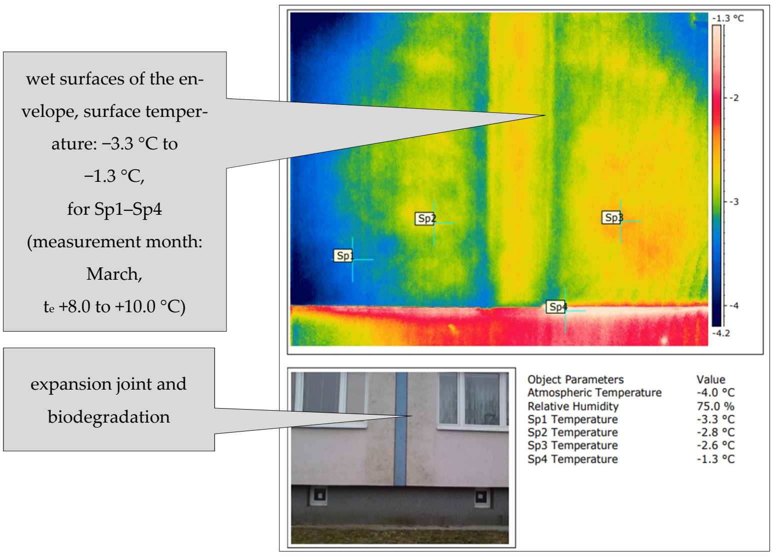


**Figure A1.** A view of part of the apartment building—the area of the expansion joint is quite damp and creates favourable conditions for the growth of microorganisms and the emergence of biodegradation.

## Appendix D

The construction and physical context in Figure A2 shows the difference in the distribution of the relative humidity on the example of a panel external wall based on lightweight concrete. As a result of reduced heat transfer, less thermal energy reaches the outer surface of the composite. This means that the outer perimeter wall heats up less. The surface of the composite is cooler, and it is loaded with moisture for a longer time. Prerequisites for the settlement of microorganisms are created.

In Figure 5, a failure caused by the fact that the external wall showed an inhomogeneity of lightweight concrete and the thickness of the composite not being in accordance with standard requirements (valid for CZ) is shown. Radiators are installed in the places of the windowsills, which de facto heat up the wall in the heating season, eliminating the effects of biodegradation.

One of the reasons why these degradation factors occur in ETICSs is the altered temperature–humidity regime of the wall coverings and the higher amount of organic components used in the plasters. Another reason may also be the greater popularity of using bold colours, on which microorganisms are more visible.

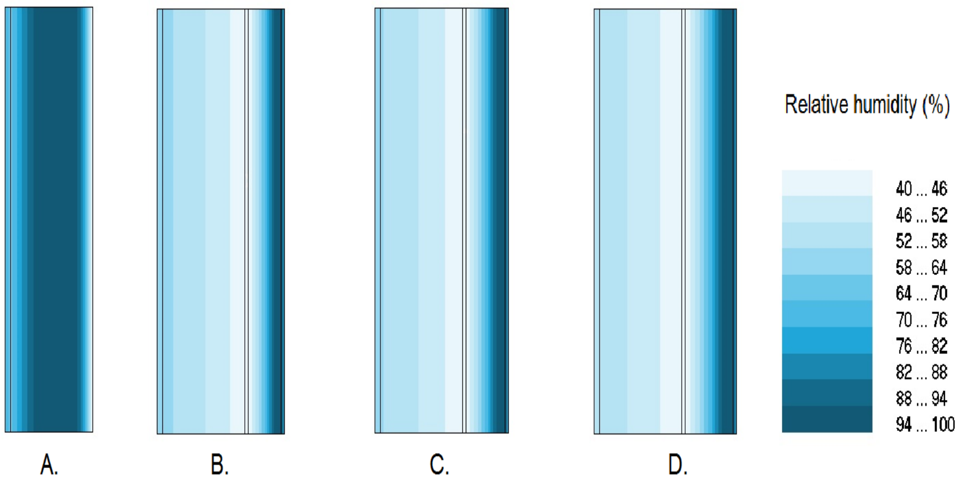


**Figure A2.** Course of relative humidity of gable external (panel) wall. (**A**) Original wall without thermal insulation; (**B**) wall with thermal insulation EPS th. 110 mm; (**C**) wall with thermal insulation EPS th. 130 mm; (**D**) wall with thermal insulation EPS th. 160 mm [63].

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