Revitalization of Lightweight Cladding of Buildings and Its Impact on Environment

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Abstract. The presented study reveals that the revitalization of lightweight claddings installed before 1990 can have a positive impact on the environment and on the reduction of greenhouse gases in particular. The main focus is placed on the revitalization of a structural system known as OD-001, commonly called the ‘Boleticky panel’ system, which was frequently utilised all around the Czech Republic in the period before 1990. Only revitalization methods utilizing contemporary structural designs and current materials were verified during this study. The ‘Boleticky panel’ system was the type of façade cladding most frequently installed on administrative buildings in what was then Czechoslovakia. It is a panel system where load-bearing structure of the panel itself consists of closed profiles that are suspended from the building’s load-bearing structure. This type of system saw a great deal of use for more than 20 years. From today’s point of view, its thermal and technical properties are completely unsatisfactory and the gradual structural degradation of such systems, with a direct impact on their mechanical resistance, has been monitored over the last few years. However, these defects can be completely eliminated by the selection of a suitable type of revitalization. Cladding revitalization can be divided into three main categories. Each category represents a different level of impact on the structure of the above described cladding system. The first category only involves the replacement of windows, while the second consists in the replacement both of the windows and the existing panel sections. The third category of revitalization entails the complete removal of the existing cladding system and its replacement with a new one. The Life Cycle Assessment method (LCA) was used for environmental impact assessment. The aims and intentions of this method are not to search for the most economical or technically perfect product, service or technology, but to find the most environmentally friendly product with properties that can be guaranteed to last throughout its whole service life. The obtained results showed that revitalization has a positive impact on the environment. It can significantly reduce the consumption of energy that is used to heat the building in the winter, and thus reduces greenhouse gas emissions. On the other hand, it will cause a slight increase in the demand for cooling energy in the summer, which is mainly due to the reduction of the air permeability of the structure, making it more difficult to cool the interior of the building down, e.g. during the night, causing inhabitants to make greater use of air-conditioning. However, the revitalization itself, even if this term is taken to include the installation of the new cladding system, its maintenance and its future demolition, has a negligible impact on the environment compared with the old system. Therefore, based on the evaluated data the authors of the presented paper can highly recommend and encourage the revitalization of OD-001 lightweight cladding systems.
1. Introduction
The influence of the indoor environment of a building on the psyche and the intellectual development of a person has become a very frequent subject of research projects and specialised studies in recent years. As these are studies from different branches of science, researchers often arrive at completely different conclusions regarding the aspects of a healthy indoor environment. However, almost all of them agree that the average modern person spends the majority of their life in an enclosed space, i.e. within buildings. Time outside is mostly spent in routine “migration” between one’s home and one’s workplace or school, or buildings where leisure activities usually take place. For this reason, it is very important to fully understand what the term “healthy indoor environment” means - buildings should have a positive influence not only on our health but also on our mental balance and intellectual development.

It is completely logical that with the development of society, the demands on buildings, their structural design and the origin of the construction materials used keep increasing. This is, of course, inherently connected with energy consumption. The production of energy in traditional ways (from coal, oil or natural gas) is a burden for the environment and damages it irrevocably. At the same time, it also has a negative impact on human life, which is affected by the production of emissions of carbon dioxide – CO₂, nitrogen oxide – NOₓ, sulphur dioxide – SO₂, ammonia – NH₃, etc:

- CO₂ – causes global warming via the greenhouse effect and subsequently damages the stability of the environment,
- NOₓ – lowers the oxygenation of the organism,
- SO₂ – causes diseases of the respiratory tract, irritates lungs and eyes,
- NH₃ – damages mucous membranes [1].

These harmful effects have resulted in the production of requirements aimed at limiting the emission of harmful gases, with an emphasis on the preservation of present standards in terms of quality of life for future generations. The promotion of a comprehensive approach to energy consumption involves not only its lowering but also searching for a way to achieve this goal economically and ecologically. For example, one of the most frequently employed options is to build structures that make greater use of recycled materials or materials with a minimum ecological footprint. As operating costs increase, it is natural that the pressure to achieve savings in that area also rises. The right design can achieve energy savings of up to several tens of per cent compared to the existing situation. Unfortunately, these days the lowering of environmental impact is seen as a secondary product of reductions in operating costs. However, the energy requirements of a building are greatly influenced by the thermal and technical properties of the building envelope, which are themselves directly influenced by the choice of technologies and building materials used to construct the envelope. In the Czech Republic, the costs arising through the use of buildings by individuals make a contribution to total energy consumption that is as high as 80%. The EU average is approximately 40% [2]. In order to achieve the minimum standard of the European Union, it is necessary not only to build new buildings with good thermal and technical properties, but also to adjust existing ones. There is less and less space for new buildings as the population increases, and therefore designers are forced ever more often to develop ecological and economically advantageous solutions for the reconstruction of existing buildings. Even though the reconstruction of buildings is one of the most demanding tasks in the construction industry, it is a fully-fledged and often financially less demanding alternative of regeneration of current buildings.

The study focuses on the revitalization of the structure of lightweight claddings commonly installed on buildings at a time when the Czech Republic was part of Czechoslovakia. Nowadays, there are a large number of structures which do not comply with the modern principles stated above. Consideration was not given to building operating costs at that time as they were the property of state-
run institutions or the state itself. Even the term “environmental protection” was no more than a meaningless phrase in Czechoslovakia before 1990.

1.1. The structure of the OD-001 “Boleticky panel” lightweight cladding system

The structure selected to undergo revitalization is the OD-001 lightweight cladding system, which was one of the most frequently installed systems of this type in pre-revolution Czechoslovakia. It is mainly known locally as the “Boleticky panel” system, which primarily saw use in Bohemia and Moravia, and only occasionally in Slovakia. It is a panel system where load-bearing structure of the panel itself consists of closed profiles that are suspended from the building’s load-bearing structure. The original OB-001 system can be seen in figure 1 (a).

The production of this cladding system started back in the 1960s at industrial plants in Boletice nad Labem that manufactured prefabricated components for the construction industry. Production subsequently expanded to other factories in Czechoslovakia, e.g. Pozemní stavby, n.p. Bratislava and Zukov, n.p. Prague. When production was at its height the output was more than 100 thousand m² per year. The Boleticky panel system was produced until the end of the 1980s in various variants and modifications. It was mainly used for administrative and civic buildings without high hygiene requirements. It was not installed on hospitals or kindergartens. The system could be used on buildings of up to 100 m in height. The service life was expected to be thirty years from initial installation [5].

The structural height of one panel was designed to fit the height of one floor, so 3.3 or 3.6 m. Parapet panels were 3.9 or 4.2 m high. The basic widths of the panels were 0.6; 0.9; 1.2 and 1.5 m. The composite thickness of the panels was 90.0 mm. The load-bearing structure around the perimeter was formed from 90.0 × 40.0 mm closed steel thin-walled profiles with a wall thickness of 2.0 mm. The under-sill and head parts were made from open U-profiles with the same dimensions. The metal elements were treated with a synthetic, anticorrosive coating. The vertical joints between the panels were constructed on the basis of “clamping”, covered with aluminium strips on the outer side and with boards made from the same material as the interior sheathing on the inner side. These were usually asbestos cement boards. The horizontal joints overlapped, with the top of the lower panel being covered by a drip edge that was part of the panel above it. Chipboard was installed on the inner side of the cladding panel. In cases when there were higher fire protection requirements, 15.0 mm thick asbestos cement board was installed. The board was attached to the load-bearing structure with steel screws. Thermal insulation was inserted between the peripheral and under-sill/head profiles of the cladding. The insulation was made from either foam polystyrene, foam polyurethane or mineral/glass
fibre with a thickness of approx. 60.0 to 80.0 mm. The thermal insulation was covered either by waterproofing foil with a steel grid, or asbestos cement board. There was also a ventilated gap with a thickness of approx. 25.0 mm. To provide sufficient ventilation, there was a gap at the under-sill and horizontal joints with a height of approx. 5.0 mm and a width equal to the inner distance between the steel profiles of the load-bearing structure. The outer surface was made from hardened opaque or enamelled glass. It was attached to the load-bearing structure via aluminium rails. The individual panels were anchored at four points using hanging brackets (two upper and two lower ones) attached to previously installed anchor plates at the locations of load-bearing beams. These anchor plates were attached to the load-bearing structure of the building via welding through steel plates or screwing to load-bearing beams. Realignment was thus enabled in three directions. Vertical realignment by up to 20.0 mm can be performed using oval openings in the plane of the facade via which the hanging and anchor brackets can be mutually shifted. In the perpendicular direction, horizontal pressure screws can be used to rectify the alignment by up to 15.0 mm. After realignment was complete, all the screws were welded so that they cannot turn and thus enable deviation from the required plane. The panels were transported from the factory to the place of installation either fully assembled or in a partially completed state. In order to prevent the formation of a galvanic cell between the metal elements of the cladding (steel and aluminium), the gaps between them were insulated with permanently flexible cements and, in a few cases, profiles made from chloroprene rubber or polyvinyl chloride were inserted between them. The structure is characterised by its perpendicular division using vertical elements that protrude from the front of the facade. Horizontal division was completely suppressed [6]

At the time, roughly speaking, the price of the windowed part was approximately 1000,- to 1300,- CZK per m², while the panel cost around 450,- CZK per m², not including installation [7]. The general technical parameters of the panel are shown in table 1.

| Specification                  | Unit       | Value       |
|-------------------------------|------------|-------------|
| Panel weight                  | kg · m⁻²   | c. 50       |
| Structural width              | mm         | 600, 900, 1 200, 1 500 |
| Structural height             | mm         | 3 300, 3 600 |
| Structural thickness          | mm         | 90          |
| Window height                 | mm         | 1 600, 1 800 |
| Window sill height            | mm         | 1 000       |
| Average panel thermal resistance | m²·K·W⁻¹ | 2.020       |
| Panel fire resistance         | s (min)    | 1920 (32)   |

1.2. Defects and limitations of the original cladding

From the very beginning, the system suffered from limitations mainly stemming from its inadequate structural design and the materials used. The issues were mainly of a thermal and technical nature, and they had a direct impact on the mechanical properties of the system. The temperature of the outer layer could reach up to 70°C during the summer due to solar radiation. Polystyrene foam, which was one of the thermal insulation options, cannot cope with such heat and deteriorated gradually. On the other hand, in the winter this layer was losing its thermal insulation properties due to the condensation of water vapour as well as rime within the thermal insulation layer. Uninterrupted thermal bridges arise in places where the load-bearing frame and window frames were. The thickness of the thermal insulation was only 60.0 – 80.0 mm in the panel part, while the windows had double glazing without any metal coating. From the current point of view, the fittings and insulation of the window frames are already worn out and failing to function as they should. Some windows will not close properly, and sometimes it is not even possible to open them. The poor structural design of metal sheeting often allows rainwater to leak into the structure. Moreover, there is no decompression chamber in the
window panels which would balance out possible overpressure. This defect is multiplied in effect when wind-driven rain is forced in on the leeward side. Due to the high air permeability of the cladding, water vapour condenses within the structure. It often happens that the outer opaque or enameled glass plates fall out, see figure 2 (a). This could even injure passers-by, meaning the building can become dangerous. The loss of glass panel might increase leakage into the structure to an extreme degree, as well as the degradation of other components, e.g. internal cladding, see figure 2 (b).

![Figure 2. Illustrative views on degraded thermal insulation (a) and degraded internal cladding (b).](image)

The structure does not have the ability to accumulate energy - it cannot balance out sudden changes in temperature caused by, e.g. heating energy blackouts in the winter. The absence of air conditioning, lack of shade-giving elements and poor thermal and technical properties of the cladding all combine to cause excessive overheating in the summer. Thermal comfort can only be achieved at the price of high heating costs in the winter period.

In addition, carcinogenic asbestos was built into the cladding structure in order to provide fire protection. Asbestos is a dangerous substance which is harmful to human health. Inhalation causes the appearance of cancerous cells.

2. Methodology

2.1. Revitalization options

The revitalization categories described below are based on real cases which have been selected from across the whole of the Czech Republic. The revitalization systems were implemented in different seasons, to varied extents and on a number of variants of the original cladding. For this reason, it was necessary to unify all of the different variations of possible revitalizations before comparing them with each other, see chapter Methodology. Furthermore, certain revitalization projects had to be altered slightly due to their poor structural design in combination with the material used [8]. Revitalizations, verified in the presented study, can be divided into three categories which represent the scope of the structural alterations that are carried out.

2.1.1. 1st category. The 1st category of revitalization consists in the replacement of existing, original windows with new ones. These are plastic-framed windows with double glazing to provide insulation. Revitalization results in a significant reduction in air permeability and also in decreasing energy losses due to conduction. This type of revitalization does not have a significant effect on the appearance of
the building, however, work can take place while the building is in full operation as it is only necessary to limit operations in the room where work is currently being carried out.

2.1.2. 2nd category. In contrast, when executing a revitalization project of the 2nd category, the thermal and technical parameters of the cladding can be improved significantly, accompanied this time by a change in appearance. The revitalization process again involves changing the windows, but the panels are also altered by adding thermal insulation. This type of revitalization leaves the functional units of the original cladding as they are; the load-bearing structure remains. It is only necessary to make local alterations and, if necessary, adapt the method to the given cladding variant. The asbestos which is built into the structure in the form of asbestos cement boards mostly remains. Uninstalling this dangerous material is very financially demanding. As far as the legal aspect is concerned, in the Czech Republic it is permitted to leave asbestos in the structure providing the dangerous material is left untouched. The effect on the operation of the building during the revitalization process is a lot more significant than in the case of the 1st revitalization category. When work is being carried out, the room in question has to be completely empty. During this research, a total of five structural variants that underwent this degree of revitalization were evaluated. They are listed in table 2. One of the variants is shown in figure 1 (b).

2.1.3. 3rd category. The greatest changes to the original structure occur in the case of the 3rd category of revitalization. The original cladding is completely removed and replaced with a new structure. It can be a light peripheral cladding system using the Element panel system, or heavy cladding made up of porous concrete blocks with an external thermal insulation composite system.

2.2. Simulated building
In order to evaluate the effectiveness of individual structural revitalization projects, it was necessary to create a simulated building where the different revitalization variants would be applied. The size, disposition and shape of this simulated building were chosen on the basis of a real structure currently existing in the Czech Republic.

The building is a free-standing structure located in the residential area of a municipality. It is used for administrative purposes. The building’s footprint is 224.2 m², the dimensions being 13.84 × 16.20 m. The height (measured from ground level to the parapet wall) is 7.66 m. The building has two floors with a flat roof that is not intended to be walked on and it does not have a basement. The load-bearing structure of the building is a precast reinforced concrete frame of the MS-KO type.

The thermal and technical properties of the building envelope of the simulated building had to be improved in the following areas:
- roof cladding (original state: a single skin flat roof which is not to be walked on, with a standard order of layers; new state: a single skin roof which is not to be walked on, with a combined order of layers),
- heavy gable walls (original state: ceramsite concrete panels; new state: ceramsite concrete panels with external thermal insulation composite system),
- lightweight cladding (original state: OD-001 “Boleticky panel” system; new state: revitalization – 1st, 2nd or 3rd degree).

In the case of a 1st degree revitalization project when only the windows were changed, the roofing and the gable wall were not altered.

2.3. Evaluation method
The selected evaluation method, Life Cycle Assessment (hereinafter LCA), does not aim to find the most economical or technically perfect product, service or technology; the intention is to determine the
most environmentally friendly product with properties that can be guaranteed to last throughout its entire service life [9]. Each structural element which is incorporated into a structure, used and finally disposed of has its own life cycle. The individual stages of the life cycle feature delimited system boundaries. The rules should conform to the ČSN EN 15804+A standard [10].

The production stage comprises processes taking place “from the cradle to the gate”, i.e. from the initial extraction of the raw material up to the production of the element which is to be incorporated, its transport to the processor/producer, and the production itself. The construction stage includes processes such as the transportation of the material from the producer to a construction site and its incorporation in a structure. This stage also includes internal construction site transportation (via a crane, assembly platform or scaffolding), storage, heating or cooling during construction, ancillary work as well as the material and waste and all processes and energies which produce waste and emissions during construction [10].

The usage stage is the longest one as far as the life cycle is concerned. It includes all processes from the completion of the structure up to the start of demolition. The product is used after the construction stage has been completed. Each incorporated element has its own lifetime. The length of the lifetime depends on the technical properties of the product/structure and on the way it is used, as well as “climatic and mechanical stress”. Maintenance should take place during the period of use in order to achieve the maximum extension of the structure’s lifetime. This stage includes all processes involved in maintaining the functionality and technical properties of the structural elements (for example: the painting of window frames and doors, boiler maintenance, etc.). Another degree of lifetime extension is the performance of repairs. The system boundary includes the disposal of existing elements, the production of new elements and their incorporation (for example: the replacement of a windowpane). If an element cannot be repaired, it has to be replaced. The system boundary includes the disposal of current elements, the production of new elements and their incorporation (for example: the exchanging of partition walls, roofing, windows, etc.) In the case of extensive construction work involving alterations to building layout or the cladding of the building, or necessitating the replacement of technical equipment, this is considered to be reconstruction. The system boundary includes the disposal of existing elements, the production of new ones, and their incorporation [10].

When a building is used, energy is consumed (to provide heating, cooling, etc.) Calculation of energy consumption is carried out in accordance with the ČSN EN ISO 13790 standard [11] and Decree No. 78/2013 Coll. [12]. Also related to this is the consumption of water utilised during the operation of the building, i.e. water consumed by the heating system, ventilation, humidification, irrigation, etc., and not water used during reconstruction work, repairs, the replacement of elements, or maintenance.

After the end of a structure’s lifetime, it is necessary to dispose of it. This stage includes the disassembly of the structure and the transportation of its components either to a waste dump or to places where they can be processed and waste processed for re-use or recycling. The boundary “Removal” includes the post-transportation handling of waste that is needed before waste disposal itself can take place.

The last stage quantifies the environmental impacts related to the re-use of materials, or their recycling or use as an energy source. These processes enable the minimization of environmental impact when they render it unnecessary to dump waste or extract raw materials for the production of new elements, or involve the use of waste materials as a source of energy.

The calculation method is based on indicators which represent the individual environmental impacts of a structure throughout its lifetime.
The calculation (1) is based on implementation of indicators stipulated in ČSN EN 15 978 [13].

\[
GWP_i = a_{1,i} \cdot GWP_{a_{1,i}} + a_{2,i} \cdot GWP_{a_{2,i}} + a_{3,i} \cdot GWP_{a_{3,i}} + a_{N,i} \cdot GWP_{a_{N,i}}
\]

(1)

where

- \(GWP_i\) the potential of mass global warming for for the \(i\)-th building module
- \(a_{n,i}\) the amount of mass, energy or service \(n\) used in the \(i\)-th building module
- \(GWP_{a_{n,i}}\) the potential of mass global warming, energy or services \(n\) in the \(i\)-th building module

3. Results and Discussion

In order to create thermal comfort inside a building or make structural alterations, sources of energy are needed which are directly connected with the production of greenhouse gas emissions. The production of such emissions has a negative impact on the environment. The less energy needed for a given activity, the lower the emissions produced. The values shown in table 1 are considered for the whole lifetime of the revitalization, which is designed to be 50 years. In the case of the 1st degree of revitalization, no consideration is given to repairs or changes to structures which are not part of the revitalization, i.e. OD-001 parts (panels), roofing, gable walls, etc. Despite this, these structures have to be maintained in a functional state during the evaluated period and thus the production of emissions increases.

Table 2. Ecological burden of implemented revitalization category during the lifetime – amount of CO₂ (t) [4].

| Construction                                  | Extraction of raw materials, processing | Execution of revitalization (50 years) | Maintenance (50 years) | Energy – cooling/ heating (50 years) | Demolition | Total    |
|-----------------------------------------------|----------------------------------------|---------------------------------------|------------------------|--------------------------------------|------------|----------|
| OD-001 (original cladding)                    | -                                      | -                                    | 3 369.061              | -                                    | 3 369.061  |          |
| Change of windows (1st degree)                 | 5.186                                  | 0.086                                 | 6.014                  | 2 267.883                           | 0.250      | 2 279.422 |
| Cement bonded particleboard (2nd degree)       | 37.218                                 | 3.953                                 | 30.733                 | 616.751                             | 1.392      | 690.049  |
| Corrugated iron (2nd degree)                   | 34.239                                 | 3.854                                 | 28.183                 | 615.849                             | 1.032      | 683.159  |
| Cassette facade system (2nd degree)            | 37.664                                 | 4.138                                 | 28.172                 | 616.751                             | 1.133      | 687.857  |
| Gypsum fibreboard (2nd degree)                 | 32.238                                 | 3.860                                 | 28.983                 | 619.708                             | 0.982      | 685.771  |
| Sandwitch panels (2nd degree)                  | 50.701                                 | 3.918                                 | 28.259                 | 627.780                             | 0.980      | 711.638  |
| Element panel system (3rd degree)              | 40.509                                 | 3.691                                 | 23.952                 | 626.300                             | 3.347      | 697.800  |
| Porous concrete blocks (3rd degree)            | 35.655                                 | 4.732                                 | 21.757                 | 598.441                             | 2.786      | 663.371  |

The largest proportion of all greenhouse gas emissions produced during the lifetime of a structure arise during the stage when it is operational and consuming energy in order to provide thermal comfort to its users. For revitalization of the 1st degree it is up to 99%, see figure 3. In the case that 2nd or 3rd category of revitalization is implemented, the emissions produced during the provision of thermal comfort while the structure is in use constitute up to 90% of total emissions, see figure 3. The rest of greenhouse gas emissions are related to the structure itself (its establishment, maintenance and disposal).

Overall, the smallest ecological footprint occurs in the case of the 3rd degree of revitalization when porous concrete blocks are used, see table 2. However, there are only minimum differences in comparison with other 2nd and 3rd degree revitalization projects. In contrast, the most emissions are produced during the operational phase in the case that only the first category of revitalization is employed, i.e. simply changing windows. It is clear from the results that revitalization projects have a major influence on lowering the amount of greenhouse gases released into the atmosphere.
Figure 3. Comparison of produced amount of carbon emissions.

It can be seen from table 2 that revitalizing the cladding of a building will bring a considerable reduction in energy consumption for heating. In the case of the first category of revitalization, the savings can reach up to 35%. In the case of 2nd and 3rd degree revitalization projects, the savings can be as high as 85%. Of course, the energy consumption for cooling will increase slightly in the summer season, as is shown in table 2. However, the main reason for this increase is that revitalization lowers the air permeability of the structure, meaning that the inside of the building takes longer to cool down, causing users to make greater use of air-conditioning in the summer months. As global temperatures gradually increase, the energy requirements for cooling will keep growing. This growth will be less for revitalized structures than for buildings that still have their original cladding.

4. Conclusions
Investors do not like to hear about revitalization as they see only the initial financial sums which need to be spent on it. Unfortunately, they often do not realize that the operation of the building will be more and more expensive as energy prices for heating and cooling increase in connection with the current worrying developments in the area of the environment: global warming and the damage it is doing to the natural world is unstoppable. Summers will be ever hotter in Europe and the climate simultaneously less stable (temperature fluctuations, worse weather events). The energy needed to lower the air temperature by 1°C is almost three times greater than that needed to raise it by the same amount. It is a vicious circle in which more energy will be needed to maintain thermal comfort in buildings, which will result in the creation of more greenhouse gas emissions, which then will further affect the increases in global temperatures and climatic instability.

In the case of the 1st category of revitalization, the basic problems which accompany structures with inadequate cladding are not removed. The gradual degradation of the cladding continues, with a negative influence on user comfort. Still, if initial finances are lacking for a more thorough upgrade, lower energy consumption and thus also lower greenhouse gas emissions can be achieved via the replacement of windows. These problems are completely removed by the 2nd and 3rd degree of revitalization. The thermal and technical properties of the revitalized cladding are quite similar to those of newly built cladding.
Sustainable construction depends on lowering the energy requirements of buildings, along with the associated operating costs and environmental impacts (emissions, waste). All of this can be achieved via the performance of appropriate structural alterations, as a result of which better interior environments can also be provided to building users.

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