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Sustainable Building Policies in Central Europe: Insights and Future Perspectives

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Abstract: Achieving carbon neutrality by 2050 is one of the European Union's key priorities. Yet, the attitude of numerous politicians, of the professional community, and of society in general towards the threat posed by climate change is ambivalent. Arguments are frequently heard about the transition to a low-carbon economy that will be very costly, with increased unemployment, and that in reality climate change may not even be that severe. Added to this, there are human rights and freedoms, and in the case of architects and designers, the right to freedom of creation, to choice of materials, etc. The present article seeks to show that the issue of sustainable architecture and construction is not a whim, but an absolute necessity, and that true freedom lies in recognizing this fact and adapting our actions accordingly. However, even if we have the good intentions to adapt the needed actions, there is still the question of how to react in the right way, without causing myriad unwanted side-effects or being completely counterproductive. As there is not yet any comprehensive account of the history of energy-efficient and sustainable building and architecture, this paper has attempted to give a brief overview of developments in this field from a Central European perspective. Furthermore, the aim was to point out some conceptual mistakes that have been made in the past and that should be avoided.

Keywords: sustainable building; energy efficiency; embodied energy; emissions of greenhouse gases

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1. Introduction

The world-famous Russian writer Lev Nikolayevich Tolstoy in the final part of his novel War and Peace [1] seeks to define modern historiography not as a simple description of life events and as a search for their causes in the freedom of choice of individuals or nations, which he said is impossible, but rather as an effort to seek laws of necessity, which led humanity, nations, and individuals to act. He makes an analogy with mathematics as he declares that, in the moment "when this most accurate of the sciences reached an infinitesimal quantity, it abandoned the process of fragmentation and embarked on a new process of adding infinitesimal unknowns. The mathematics left the notion of cause and seeks the law, that is, properties common to all unknown, infinitesimal elements" [1]. Tolstoy is of the opinion that historical events are not a product of people's free will, but their actions are conditioned by external circumstances, e.g., geographical, ethnographic, or economic. He claims that "it is true that we do not feel our dependency (note: on external conditions), but if we admit that we are free, we will come to nonsense, but if we admit our dependence on the outside world, on time and causes, we will reach laws [1]". The current pandemic caused by the new coronavirus SARS-CoV-2 seems to confirm this thesis. If we choose to ignore a virus that cannot be seen or felt and insist on the freedom of assembly, travel, etc., without preventive measures, the chances of becoming infected increase rapidly. However, if we accept the threat and adapt our actions accordingly, that is, we give up our assumed freedom for a specific period of time, the chances that we survive the pandemic unscathed grow. Therefore, our real freedom lies in recognizing the fact of the existence of the coronavirus and in the need to take preventive measures.

A similar sequence of necessities can be observed in the history of construction and architecture. This has led to the current state, where steps are being taken against the deterioration of the environment and the dire need for sustainable architecture and construction are being emphasized.

2. Historical Development

It is clear that the primary purpose of buildings has always been the protection of people from the effects of climatic conditions. Furthermore, they aim to create suitable conditions for life and human activity. The climatic conditions appear to be the most important factor that must be respected when designing buildings for permanent residence. The key is the outer envelope of the building serving as a protection from wind, rain, cold and/or heat. Another significant objective is to create sufficiently large and healthy indoor spaces enabling the development of human activities. This need rises with the development of humanity and with the gradual transfer of its main work activities from the external to the internal environment. Other factors are the economic possibilities of builders, the availability of building materials, population density, etc. It is vital to remember that construction is the main occupational activity of a large number of people. It is quite ambitious to pinpoint the time in history at which all these factors, as well as many others, merged into one big challenge aiming to provide, for the highest possible population, high-quality, human-dignified living, and working spaces. Perhaps it was the period of the economic boom in the United States at the turn of the 19th and 20th century, and maybe it was in Europe in the 1930s between the two world wars.

In 1946, Paul Dunham Close published the third edition of his book Building Insulation [2] in Chicago, in which he discussed in great detail the principles and possibilities of using thermal and sound insulation in buildings. It deals, among other things, with the basics of heat transfer in building materials, their properties, calculation of heat loss of buildings, economics and efficiency of thermal insulation and their impact on the dimensioning of the heating system, water vapor condensation on interior surfaces, etc. Already at that time, he presented a graph of the effect of the thickness of thermal insulation on the reduction of heat flow, stating that "no thermal insulation with final thickness (or commercial thermal insulation) can have 100% efficiency" [2]. Furthermore, Close offered a graphic solution for the optimal thickness of thermal insulation in terms of reducing the cost of heating the building. This principle was later related by other authors to the heat transmission coefficient (U-value) and to other relevant independent variables. For example, Árpád Csík [3] brought a similar, albeit more complex, numerical solution for optimizing the global costs of renovation and operation of buildings, where the input independent variable was the cost of insulation of the building envelope. In all these cases, the basic precondition is a sufficiently high and stable or, best of all, rising price of oil as the main representative of fossil fuels, to the price changes of which the heat sources gas and coal are linked. After an initial rise in the late 1940s, the crude oil price stabilized at a relatively low level that lasted until the first oil crisis. The issues of energy efficiency and building insulation were not focused on. Especially in the USA, the all-night lighting was characteristic of this period in both residential and office buildings. A great shock came in 1973 during the Israeli–Arab conflict, also called the Yom Kippur War, and the ensuing oil crisis that was triggered by a sharp rise in its price due to an embargo on its exports by oil-producing Arab countries [4,5]. The second crisis occurred in 1979 as the result of the Islamic Revolution in Iran [4]. Both events represent a major milestone for energy supplies and for the way they have been used. The Western world realized its existential dependence on oil and gas from exporting countries, especially the Middle East and North Africa and, later, Russia (Figure 1). The political response of the United States and, in particular, of Western Europe manifested itself in two main directions—by promoting energy saving from fossil fuels and, at the same time, by supporting research aimed at finding new energy sources. The energy saving from fossil fuels was ensured by both restrictive and motivational means. The first included, and still do, increased fuel taxes and various legislative measures. In the construction industry, they meant mainly the growing requirements for thermal resistance of the building envelope, and, later on, for the total maximum specific heat loss generated by heat conduction and ventilation. The recommended standard values of the thermal resistances of individual parts of the building envelope and of the maximum specific heat loss became legislatively mandatory requirements (e.g., the first Regulation on thermal protection (of buildings) approved in the Federal Republic of Germany in 1976—Wärmeschutzverordnung 1977 (WschVO 77) [6]). However, it is to be mentioned that the obligatory thermal resistances, that is, the heat transmission coefficients (U-values) of the main components of the building envelope, based on the standards of the time, were to a great extent mild in terms of today's perception. However, they gradually became strict. The whole process was accelerated by the discovery of the ozone hole in 1982 [7] as a consequence of Freon emissions into the atmosphere and of the observation of temperature increase in the earth's surface caused by greenhouse gas emissions [8]. The world began to perceive a global threat to the environment. Spontaneous communities of environmentalists emerged, many of which later transformed into political parties, especially in Western Europe (e.g., the Green Party was formed in 1980 in the Federal Republic of Germany [9]). Their primary agenda was environmental protection, reduction of greenhouse gas emissions, lessening of energy dependence on fossil fuels, support for renewable energy sources, decommissioning of nuclear power plants, etc. In terms of the principle that the best saved energy is the one that does not need to be produced at all, the focus was put on reducing the operational energy demand of buildings, especially with the help of thermal insulation. The issue of environmental quality of building materials, in this case, thermal insulation, was of no interest, however. The results of scientific research from this period confirmed the stated idea, since it was argued that good thermal insulation is the basic prerequisite for reducing energy when heating buildings [1,10]. However, the construction industry was not fully prepared for this situation. The ever-higher required thermal resistances became continuously demanding to achieve and, at the same time, they increased the input costs when procuring the building. Although heat losses through heat conduction were significantly reduced, the heat losses caused by ventilation in buildings, as one of the basic conditions for a healthy life for people, remained unchanged. The use of renewable energy sources as an alternative way of heating buildings was in its beginnings and was largely unable to cover all the consumption. In the early nineties of the last century, Dr. Wolfgang Feist brought the idea of an energetically passive house based on heat recovery from ventilated air [11]. Thus, significant reduction in heat loss through ventilation was achieved. Obviously, the low heat transmission coefficients (U-values) of individual parts of the building envelope are the basic prerequisite for the functioning of such a house. A demanding heating system with water as the heat transfer medium becomes in passive houses superfluous [11]. A hot-air heating with heat recovery is used as a standard. Local installations using renewable energy sources, in particular heat pumps and solar collectors or photovoltaic panels, are able to balance the annual energy balance. In this case, houses with nearly zero energy consumption based on burning fossil fuels are indicated [12]. Local installations are to be placed in or on the house or on the plot of land, whereas the house may or may not be connected to the public energy network. If there is no such connection, it is referred to as an autarkic, energetically self-sufficient house [12]. It was not possible to define such complex buildings by a simple value of the average heat transmission coefficient or by the specific heat loss anymore. The specific climatic conditions, heat gains from solar radiation, interior equipment and inhabitants of the buildings themselves, efficiency of the heating (cooling) and the ventilation system, possibilities of using renewable energy sources, etc., had to be taken into account. A dire need for a more accurate and methodologically more uniform way of assessing energy performance of buildings arose. In addition to CEN (Comité Européen de Normalization, European Committee for Standardization), various interest groups, mainly environmental activists, passionate experts, and academics were promoting the idea of voluntary energy certification of buildings. They were convinced that energy certification would contribute to an increase of the value of energy-efficient buildings on the real estate market, and it would force the owners of uneconomical buildings to invest in possible improvements. Unfortunately, the market did not accept this idea and continued to consider the location of the building as the most decisive factor. However, the thermal insulation industry, which was traditionally strongly represented on the relevant CEN standard-setting committees, took the chance and was greatly lobbying for standards and legislation in order to increase the energy performance of buildings. That way, the concept of low-energy, passive (or ultra-low-energy), and nearly zero-energy buildings found application in European legislation.

Figure 1. A timeline marking important historical moments defining energy efficiency and sustainability policies for buildings in the Western world.

2.1. European Directives

In 2002, the European Parliament approved the first directive on the energy performance of buildings (2002/91/EC) [13], which aimed to promote better energy performance of buildings in the European Community, while taking into account external climatic and local conditions as well as indoor temperature and efficiency requirements in relation to:

(a) a general framework for a methodology for calculating the integrated energy performance of buildings;
(b) the application of minimum requirements on the energy performance of new buildings,
(c) the application of minimum energy performance requirements for large existing buildings that are undergoing major renovation;
(d) energy certification;

and

(e) regular inspections of boilers and air-conditioning systems in buildings and, in addition, to an assessment of heating installations in which the boilers are more than 15 years old.

That way, the directive [13] allows the legislation of each Member State to define the specific calculation procedures, the minimum requirements for the energy performance of those buildings, as well as the certification scale. Nevertheless, the European Commission mandates CEN to develop and to adopt standards for methodology, calculation of integrated energy performance of buildings, and environmental impact assessment in accordance with the adopted directive. Until now, more than 200 new or substantially updated standards relating directly or indirectly to the energy performance of buildings have been developed under the above stated mandate.

In order to meet its long-term commitment to keep global temperature increases below 2 °C and to reduce total greenhouse gas emissions by at least 20% by 2020, as opposed to the levels in 1990, so that it complies with the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), the European Parliament adopted another directive on the energy performance of buildings in 2010 (2010/31/EU) [14]. This Directive [14] already requires Member States, inter alia, to ensure that:

(a) from 31 December 2020, all new buildings are nearly zero energy buildings;

and

(b) after 31 December 2018, all new buildings, in which public authorities are located and/or are owned by them, are nearly zero energy buildings.

While the first directive was rather the result of joint campaigning of the thermal insulation industry, civic associations (previously unsuccessfully trying to establish energy certificates for buildings on a voluntary basis), as well as of sincere environmental activists, that is, their political representatives; the second directive is indeed a response to global societal challenges, and in particular a reaction to the dangerous overheating of the earth's surface due to the greenhouse gases. The third directive [15], adopted in 2018 (2018/844/EU), aims, in addition to supplementing and clarifying the previous 2010 Directive, to promote and to use digitization in order to increase energy performance of buildings.

2.2. Central and Eastern Europe

The states of Central and Eastern Europe, mostly in the position of satellites of the former Soviet Union, operated until almost the mid-1990s on cheap Siberian and Central Asian oil, or by using their own coal reserves. Especially the eighties were characterized by overheated apartment buildings built of prefabricated concrete panels with low thermal resistance. After the fall of the Iron Curtain and after realizing the real energy prices, the required thermal resistance and energy criteria gradually became stricter in the second half of the 1990s. Even before 1989, Czechoslovakia had a revised system of standards ensuring the thermal–technical and hygienic quality of buildings. These standards had the character of regulations, and in its successor states were legally binding until the end of 1996 in Czech Republic [16], until 2000 in Slovakia [17], until 2003 in Poland [18], and in Hungary [19] even only until 1995. Following these milestones, the necessary technical specifications were required by references in the relevant laws, e.g., in relation to national standards resulting from the European Commission's and Parliament's directives on the energy performance of buildings.

Despite the fact that in the countries of Central and Eastern Europe there were enthusiasts of low-energy and environmentally oriented architecture even before the beginning of the new millennium, only the accession negotiations and the joining of the European Union meant the adoption of the concept of passive and nearly zero energy buildings in full scope, both officially and in terms of societal acceptance.

2.3. Ecological Concerns

The described development of improving energy efficiency of buildings focused almost exclusively on reducing energy consumption from the combustion of fossil fuels and related greenhouse gas emissions, especially carbon dioxide during the operation of buildings. Although the result was doubtless an unprecedented technological progress in the field of construction, in particular for installations obtaining energy from renewable sources, ventilation systems and, also, building materials and components (windows, building envelope); the energy consumption issues and related greenhouse gas emissions from the production of building materials and its components, their transport and assembly on the construction site, as well as the dismantling of buildings and the removal of unnecessary building materials (collectively the creation of the so-called gray or bound energy) were not yet taken into consideration. Similarly to the efforts for voluntary energy certification at the beginning of this millennium, one sees attempts to create databases for ecological properties of building materials and products by both civic associations and private or state organizations (see https://www.oekobaudat.de/ [20], accessed on 30 December 2021) with a probable goal of gray/bound energy assessment. It must also be noted that the process of improving energy performance of buildings had its winner, the industry producing thermal insulation, and a loser, the industry producing ceramic products, in particular bricks and ceramic blocks, which had to adapt its products considerably. Fired bricks, later ceramic blocks, as a traditional building material were in Europe unable to compete with their thermal-technical properties against thermal insulation, when the requirements for thermal resistance became stricter, without losing some of their essential properties, e.g., load-bearing capacity, in favor of thermal insulation infill. It is, therefore, possible that there will be in the near future a similar alliance in promoting the assessment of gray/bound energy as the promotion of energy certification in the 1990s. This time, however, it might take place between environmental activists and the ceramics industry.

The set of tools for energy performance assessment of buildings concludes with an energy audit [21,22], which focuses on assessing energy performance of large companies, including their immovable properties, with more than 250 employees. Its aim is to obtain sufficient information on the current state and characteristics of energy consumption needed to identify and design cost-effective energy saving options in the given company, including its existing building or group of buildings. Theoretically, it should be possible to derive the energy certificate of the building from the energy audit of the building. All these instruments concentrate exclusively on reducing energy consumption from fossil fuels and related greenhouse gas emissions. They do not take into account the impact of buildings on the surrounding environment in terms of impact on flora, fauna, air, or water quality, etc. They do not address the quality of the indoor environment of buildings either, although the required calculations should consider legislative and, if any, standard requirements for thermal and light comfort as well as an adequate air exchange.

With the growing awareness of the need to protect the environment, the environmental impact assessments (EIAs) [23] took hold in decision-making processes in the 1960s, especially in North America and Western Europe. Its target was not to meet some predetermined criteria, but to estimate the impact on the environment—especially the direct impact on the immediate surroundings, which was often subject of criticism of this process [23]. Numerous uncertainties arose when setting assessment limits [23]. EIA is used not only in construction, but also in various other areas of human activity, e.g., in industry, agriculture, forestry, transport, etc. In the European Union, it is required of Member States by Regulation 2011/92/EU of December 2011 [24], which is the third amendment to the original 1985 Regulation [23,24].

2.4. Sustainability

The idea of sustainable development that mainly stems from the 1987 report of the United Nations Commission on Environment and Development (also known as the Brundtland Commission Report [25]) is perceived as a result of growing concerns for the environment that began in the second half of the last century. "Sustainable development is an organizational principle to meet human development goals while maintaining the ability of natural systems to provide the natural resources and ecosystem services on which the economy and society depend. The desired result is a state of society, in which living conditions and resources are used to meet human needs, without compromising the integrity and stability of the natural system. Sustainable development can be defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Further development of the principle of sustainability led to differentiation and to a focus on sustainable economic and social development and on environmental protection for future generations. It was suggested and, more or less, established that "the notion of 'sustainability' should be considered as a target state of human–ecosystem balance, while the notion of 'sustainable development' should refer to a holistic approach and temporary processes, which lead us to the goal of sustainability". Following the idea of sustainable development of the society, initiatives are being developed in the field of architecture and construction for a formalized assessment of sustainability of buildings as an auxiliary decision-making tool in the process of building planning [26]. These resulted in European standards (EN 15643 [27]) describing a methodology for assessing the economic, social, and environmental sustainability of buildings. The stated three aspects are termed as pillars for assessing sustainability of buildings. The aim of the assessment is not the certification of buildings in terms of their sustainability but to influence the planning processes and essential decisions in a way that they concentrate on sustainable development. Assessing the sustainability of buildings is not yet mandatory. Sustainability assessment systems for buildings, developed by private companies or non-profit organizations, and by academic institutions, showing certain features of certification, are non-binding and often commercial. When misunderstood, they can lead to complications or even be counterproductive to the goals of sustainable development.

The Great Recession from 2008 to 2015, caused by the global financial crisis at the turn of 2007 and 2008, as well as the migration crisis in 2015, temporarily pushed the issue of environmental deterioration into the background. Moreover, certain stagnation was being noticed in the field of construction and architecture when promoting the principles of sustainable construction. The relatively established concept of passive and nearly zero-energy houses was of primary importance. The environmental protection was gaining new momentum and was accelerating after a series of school strikes initiated by the young Swedish activist, Greta Thunberg, in 2018/19 [28]. The 2019 newly elected European Commission and the parliament reacted to this movement and declared the so-called European Green Deal [29], i.e., a plan to reduce the greenhouse gas burden on the environment by increasing the use of renewable energy sources instead of fossil fuels. The aim is to slow down, preferably to stop, the process of climate change caused by the greenhouse effect and the consequent overheating of the atmosphere. In the field of construction and architecture, the plan focuses mainly on the "process of building new and renovating existing buildings due to the unsustainable methods that currently prevail in it, as it still uses a lot of non-renewable resources. The plan therefore aims to promote the use of methods leading to energy-efficient buildings, such as designing climate-resistant buildings, increasing digitization and tightening enforcement of energy efficiency rules for buildings. One of the ambitions of the plan is to support the renovation of social housing in order to reduce the cost of energy bills for those, who are less able to finance these costs. The plan is also to triple the rate of renovation of all buildings in order to reduce pollution caused by the operation of these building" [30].

Despite these ambitions, one cannot avoid the feeling that the Commission does not have a clear idea about the direction that is to be taken in construction and architecture in terms of sustainable development. This way, the question of priority support also remains unanswered. This implies from the questionnaires meant for the professionals and especially academics, the aim of which is to generate ideas, even though certain directions of development are already indicated. One of the problems is, however, that the goals of environmentalists are often contradictory.

According to the report by the Swedish Ornithological Society from 2012 [31], one wind turbine in Europe or North America kills an average of 2.3 birds and 2.9 bats per year. In the case of wind farms, there are often high numbers of birds killed, not infrequently protected species. The mentioned report suggests placing the wind farms correctly outside the migration routes and habitats of these birds, which, of course, is not always entirely possible. Therefore, there are occasional disputes between environmentalists and wind farm owners. Both parties are in principle trying to protect the environment—the first party the local, whereas the second the global environment. Here, the word "local" must be enclosed in quotation marks, as the protection of endangered species of fauna is in the interest of the entire planet. In the case of construction and architecture, it is possible to observe a conflict between the objectives of sustainable economic and social development on the one hand and environmental protection on the other. It is obvious from the discussion above that there are numerous well-meant decision-making and evaluation tools that can be implemented to design new and to evaluate already existing buildings. Nevertheless, the result may not always ensure the desired effect, or it could be accompanied by undesirable phenomena. The application of the principles of passive and nearly zero-energy houses brings problems, both in terms of construction practice and environmental character.

The following overview of "already learnt lessons", which does not claim to be complete yet, is mainly based on experience gained through programs targeting the reduction of energy intensity of houses and residential buildings, especially with the help of additional thermal insulation in Central Europe—Czech Republic (governmental program "Green to the Savings" since 2009), Austria (housing support linked to the energy efficiency of buildings—varies by federal state, e.g., in the federal state of Salzburg since 1993), and Slovakia (governmental building insulation program since 2009).

3. Energy Price

One of the most commonly stated arguments of the proponents of building insulation is the reduction of heating costs and thus financial savings. One has to bear in mind that it comes at a price of high investments, which, at fossil fuel prices, especially gas, may never be paid off or, if they are, then only in the long run. Fossil fuel energy prices are linked to the price of oil, having a relatively high volatility (Figure 2), which is advantageous from an investment point of view if timed correctly. The issue is that even if the investment timing fits in terms of oil price developments on world markets, most countries regulate fossil fuel energy prices in order to mitigate the impact of oil price volatility on world markets. That way, energy prices match the domestic purchasing power and do not reduce industrial competitiveness. This is caused by reserve stocks made in "better times", by long-term contracts, etc. The energy prices thus remain relatively stable but, at the same time, they are not very motivating for investment in building insulation. The state support for thermal insulation, more efficient heating systems, and renewable energy sources is therefore absolutely essential. The support can be seen as an investment in a "green" economy, which puts pressure on the reduction of fossil fuel energy prices, e.g., due to an increased use of energy from renewable sources. If states, especially industrial ones, did not do so and the world continued to depend only on fossil fuels with limited supplies, the price for fossil fuel energy would most likely rise. The above mentioned idea that building insulation reduces heating costs and thus enables financial savings, seems to be true only from the macroeconomic aspect. It is not the case of small investors without state support.

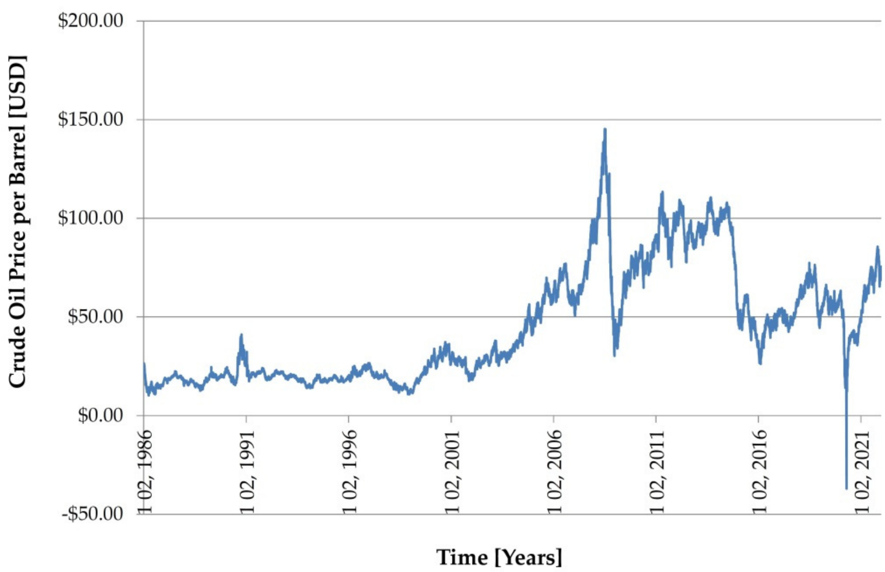

Figure 2. The crude oil prices per barrel back to 1986 based on open data from U.S. Energy Information Administration [32].

4. Thermal Insulation

In Central Europe, the current standard requirements for very low values of heat transmission coefficients (U-values) lead to large thicknesses of conventional thermal insulation, and they allow rather limited possibilities for discussion about potential optimization. This section points to some of the controversial implications of such a policy.

For example, polystyrene-based insulation materials are relatively affordable, so it is generally recommended not to spare them. The issue is that the relation between the thickness of the thermal insulation and the heat transmission coefficient (U-value) is not linear but exponential. At very low values of the heat transmission coefficient (U-value), the curve of their mutual relation approaches the limit of infinity, while an increase of the thickness of thermal insulation does not mean a significant reduction of the heat transmission coefficient (U-value) (Figure 3). At present, the standard values of the heat transmission coefficient required for individual components of the building envelope are probably at the edge or even beyond the optimum limit of conventional constructions. The subsequent consequences appear both in terms of practical application as well as in terms of the environment.

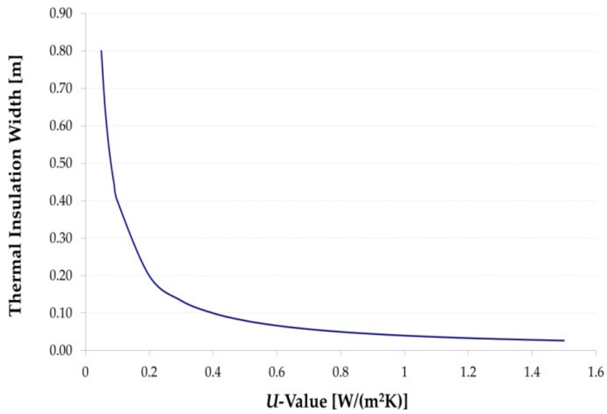

Figure 3. The course of function $U = 1/(R_{si} + d/\lambda + R_{se})$ for $\lambda = 0.04$ W/(m.K) and d = thermal insulation width as variable, while internal and external surface resistances (R_{si} and R_{se}) were neglected for the sake of simplicity.

Very thick thermal insulation does not allow overheating and drying of the perimeter walls up to the outer surface, which would create favorable conditions for the formation of algae and mold on sunless facades, i.e., those that are almost never exposed to sunlight, especially during transitional periods (spring and autumn) [33]. The outer surface of the sunless façade remains cool even with rising outdoor air temperatures with a constant common temperature of around 20 °C inside. With repeated fluctuations in the temperature of the outside air, moisture can form on such external surfaces, which is a breeding ground for fungal and algal spores [33]. Fungi and algae, in turn, create an environment for aerial plants and subsequently for small insects. Their activity causes small cracks, which rain and wind gradually enlarge. The ingress water and overall moisture reduce the effectiveness of thermal insulation. In order to avoid deterioration of insulated façades, technically and visually, it is necessary to regularly maintain them by cleaning or even by applying coatings with antifungal additives at intervals of 10–15 years [33]. Of concern is, that fungi and algae washed away by rain or cleaning get into the groundwater and thus into the water cycle [33,34]. By removing oxygen from the water, they worsen the environment for aquatic animals, which, at excessive concentration of algae, either die or migrate away from such waters [34]. In addition, it is well-known that the extreme thermal insulation of the building envelope and its high tightness increase the overheating of buildings in summer. The consequent cooling of the buildings, together with the associated technology, worsens the energy-economic performance of the buildings.

A specific problem of thermal insulation based on polystyrene is its high flammability. Gabi Greiner, an ORF journalist, writes in her 2014 [35] article that (indirectly quoting) "until about the end of the first decade of this millennium, this problem was addressed by adding non-flammability enhancers, often based on hexabromocyclododecane (HBCD).

This substance was recognized by the European Chemicals Agency as very worrying in 2008. Hexabromocyclododecane is a persistent and bio-accumulative toxin in the environment, so it remains permanently in nature and accumulates in organisms. It also reportedly reduces the reproductive capacity of organisms. In 2013, the use of HBCD was banned. Due to the long-term use of HBCD products, while their ban also allowed for various long transitional periods, polystyrene-based thermal insulation impregnated with HBCD represents a recycling problem. Today, commercially available thermal insulation systems have an average life of 30 to 40 years. Then it will be necessary to replace a huge amount of polystyrene. Its recycling won't be possible enough due to flame retardants and it will have to be disposed of as problematic waste. Greenpeace therefore demands from the chemical industry flame retardants that can be used in an environmentally friendly way" [35].

The optimization of the thickness of thermal insulation adjusted to the needs of a specific building is therefore justified, even though the current legislation based on by standards required low values of heat transmission coefficients does not require it. Legislatively required is the fulfillment of energy efficiency criteria of buildings such as the need for thermal energy for heating and hot water; the needed energy for cooling, ventilation, and lighting; or the need for primary energy for the operation of the building. The values of the heat transmission coefficients are only recommended, but without reaching them, it might be challenging to meet the required energy efficiency criteria, i.e., by a commonly used standard calculation. Common builders, especially owners of family houses or smaller apartment buildings who cannot afford costly calculations based on computer simulations of the future behavior of the building in question, tend to prefer simplified standard calculations, although the standards do not exclude simulations. This often results in very thick thermal insulation and in an inadequate size of windows, which is barely meeting the required minimum dimensions. Windows represent the weakest link in the building envelope. In an effort to reduce the heat transmission coefficient, the light transmission of windows decreases with the number of glazing panes (lower U-values), which leads, together with the minimum dimensions, to a worsening of daylight and, counterproductively, to an increase of energy needed to light the indoor space.

5. Global Environment and EPDB

Climate change is currently one of the key topics being dealt with worldwide. It is being discussed by scientists, vulnerable communities, non-governmental and non-profit organizations, and sensitive communities and individuals, who see the impending global threat induced by man-made artificial greenhouse gas emissions. People's representatives, i.e., politicians and governments, tend to react rather slowly to the exerted pressure and often without knowing the matter in depth. However, the urgent nature of the negative effects of climate change on society is calling for specific actions. Politicians have basically two types of tools—restrictive (legislation) and motivational (tax relief, and investment resources from taxes). Legislative measures are generally effective, but politicians may lose voter support. The tax relief, the subsidies, etc., are more popular, but the financial resources may then be lacking in other sectors of the state. A clever strategy seems to be the combination of both instruments, especially, if they are thoroughly structured, have a clear informative value, lead to competitiveness, have a longer-term character (i.e., do not require an immediate one-off change) and the individual's financial gains outweigh the losses, or are balanced. A suitable example of such an instrument is the mandatory energy certificate of buildings, which can be effortlessly combined with subsidy instruments. Its disadvantage is that it is primarily aimed at reducing the consumption of fossil fuels and the resulting CO_2 emissions during the operation of the building. Environmental product declaration for buildings (EPDB) has the potential to sufficiently supplement or replace the energy certificate. Furthermore, it takes into account the pre-operational phase of the building's life, i.e., its production and manufacture, or other factors such as transport of the components and materials to the construction site, waste disposal, etc. The whole life cycle of a building could be taken into consideration, but in that case, the description of the phase after the end of the building's operation could appear too theoretical. The preparation of environmental product declarations (EPDs) is dealt with by renowned research institutes as well as by the European Commission. That way, the question is not whether the EPDB comes or not, but rather, in what form. EPDB may not necessarily only focus on the issue of embodied/gray energy, but it can look at the potential of ozone layer depletion (ODP), oxygenation, or eutrophication (see fungi and algae from building façades) in terms of EN 15643 [27]. However, the most pragmatic approach represents the narrowing of the assessment to the total primary energy demand (PEI) from fossil fuels, i.e., from non-renewable sources, and the global warming potential (GWP), i.e., equivalent CO_2 emissions as a proxy indicator of greenhouse gas emissions. Several studies show (e.g., [36]) that low average values of the heat transmission coefficient of buildings result in a longer time when reaching the point, where the equivalent CO_2 emissions due to the embodied/grey energy are balanced with the emissions due to the operation of the building. The use of heat recovery underlines this fact (Figure 4). Although this situation is desirable, it should not be achieved at the expense of greenhouse gas emissions due to the embodied energy.

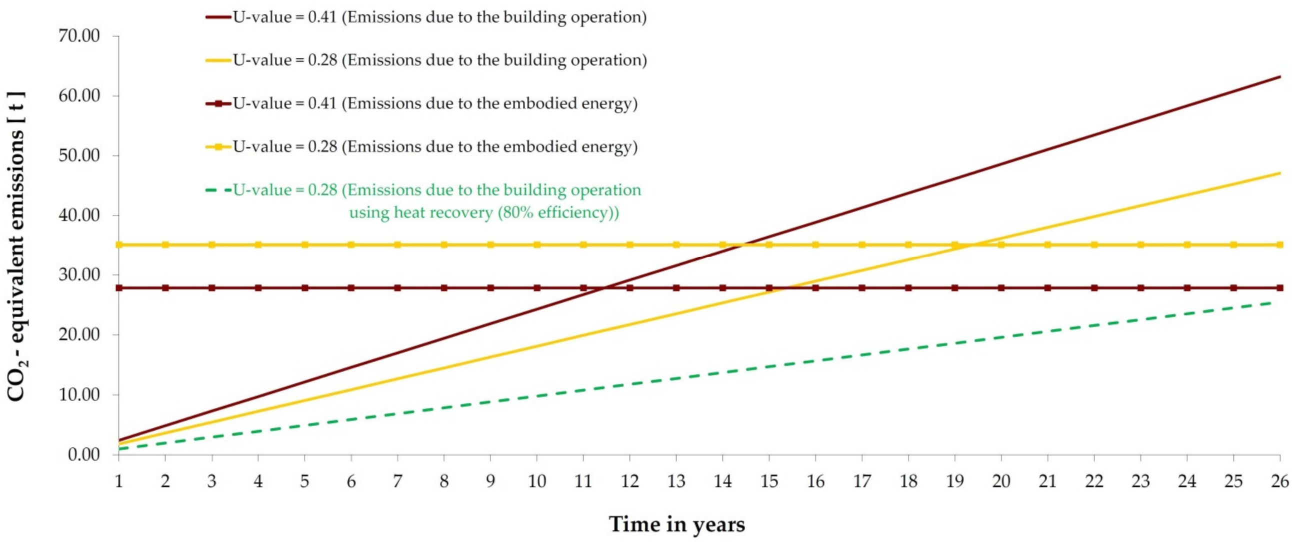

Figure 4. Time needed to achieve the "break-even point" equalizing the CO_2-equivalent emissions due to the embodied energy with CO_2 emissions due to the building operation in dependence on the mean *U*-values (W/(m^2.K)) of a massive house. The CO_2-equivalent emissions due to the embodied energy are expressed by constant lines and the CO_2-equivalent emissions due to the building's operation are represented by ascending lines.

6. Methodology

The environmental assessments of buildings are now enjoying more and more attention, especially in the context of a changing climate, thinning of the protective ozone layer, and influence of the buildings on the production of greenhouse gases. An essential part of the environmental assessments is the energy balance of the building in terms of primary energy input (PEI). This consists of three main parts—energy needs for the construction of the building, its operation, and its dismantling after its service life. The amount of primary energy is the basis for comprehensive assessment of the impact of buildings on the environment during their life cycle. The comprehensive assessment is usually associated with an assessment of the building and its components in terms of [34]:

- Global warming potential (GWP)
- CO_2 storage (in products made from renewable raw materials)
- Ozone depletion materials (ODP)
- Acidification potential (AP)
- Eutrophication potential (EP) or nutrification potential (NP) (excessive fertilization)
- Photochemical ozone creation potential (POCP)

- Space requirements

Although currently the assessment of the impact of buildings on the environment during their life cycle cannot be performed routinely, the existing European standards [27] establish the general principles, content, and form of such assessments the individually used methodologies should comply with. The quality of the methodology used and the total output therefore depends on the assessor, whereas probably the most difficult decisions are the ones that give weight to different aspects, e.g., GWP, CO_2-storage, etc. (different products namely comply with the various aspects in varying degrees). The comprehensive assessment is rather more typical for construction products than the total building. In case of total buildings, it obtains a complex character, and so some form of simplification is almost always necessary. Such simplification, for example, can be limiting the assessment only to GWP or just to PEI.

Unlike the notion PEI, which is quite comprehensible, the notion GWP should be explained at this point. The GWP represents not only a production of net CO_2 emissions but also other greenhouse gases that also contribute to the global warming and have the same impact as a comparable amount of CO_2 emissions, e.g., methane, NO_x, or particles. Hence, it is more the measure of all relevant greenhouse gases converted and added up to CO_2-equivalent emissions [37]. Examples of such PEI/GWP analyses are introduced in the work of Eyerer and Reinhardt [38].

Since the best and most processed data are available in the areas of PEI and GWP, the presented case study focuses on the analysis of embodied and operational primary energy input and related production of equivalent CO_2 emissions and mutual relation between built and operational indicators (both PEI and GWP). This approach is also related to the fact that both European and national legislation has long been trying to reduce primary energy needs based on fossil fuels and greenhouse gas emissions. The embodied energy and related CO_2 equivalent emissions are very important complementary data, which provide in particular for ultra-low and nearly zero-energy buildings an additional space for improving their environmental quality. They are also relatively easier to document. The study stresses the fact that towards ultra-low and nearly zero energy houses, the portion of embodied (grey) energy on environmental balance of buildings significantly increases.

7. Case Study

One option of the assessment within EPDB could be some form of comparison of greenhouse gas emissions due to embodied/grey and operational energy. A study by Rabenseifer and Jamnický [36] compared the expected energy demand of a detached house in the course of its service life and the energy input (embodied energy) necessary for its assembly and for the manufacture of the individual building products. The operation of the building during its service life was described using a computer-aided building performance simulation. The input data related to the embodied energy were based on information from classical works on life cycle analyses. The authors compared two alternatives of the building envelope, massive and light construction, each for five average *U*-values of the envelope.

For the purposes of this article, the operation of the most energy efficient variant of a massive house (*U*-value = 0.28 $W/(m^2K)$) was also simulated using mechanical ventilation with heat recovery (Figure 4). Reducing the heat loss through ventilation obviously leads to a reduction in the need for operating energy. The possible use of renewable sources for heating and eventual cooling would make the house nearly zero energy building (nZEB). In the case of nZEB, therefore, the further potential for reducing PEI and GWP lies only in reducing the embodied energy. A similar assessment can be made for almost every building. However, the administrative complexity of such an assessment would probably be rather high. According to the World Bank's 2020 ranking [39], the number of administrative procedures and the number of days needed to obtain a building permit in Central European countries is already quite high, e.g., Austria 222 days, Czech Republic 246 days, Hungary 192.5 days, Poland 137 days, Slovakia 300 days and Slovenia 247.5 days. In addition to it, in most Central European countries, it is already necessary to carry out an energy efficiency assessment of the building as part of the application for a building permit. An energy performance certificate is then required for the building's commissioning.

It would therefore be ideal if the production of building materials and products entering the market already met strict environmental criteria and architects and building designers did not have to deal with the assessment of PEI and GWP at all. This would reduce the administrative burden, and their focus could be laid on the essence of architecture—the organization of the space, the quality of the indoor environment, the aesthetic expression, and the design of the building. One of the possible ways to contribute to this aim would be a support for emission exchange in Leipzig, Germany, and enhancing the emission trading by the European states on the one hand and the EU Commission and Parliament on the other. This would ensure a reduction of greenhouse gas emissions from the very beginning of the construction process, while the role of the designers would still be the optimization of the quality of the building envelope and of the operation of building in terms of energy.

8. Results

There are times in history, when it is good to reflect on the road travelled and what needs to be done. It is clear that the deteriorating state of the environment and the threat of climate change are facts and that action is needed. The pursuit of sustainability in architecture and construction is one possible response to these challenges, and the question is not whether to pursue it but how to pursue it. We are currently witnessing the unprecedented development of new technologies, the use of which is often accompanied by a great deal of uncertainty and the emergence of new problems. In Central Europe, these have become fully apparent during the boom in the thermal insulation of buildings in an attempt to increase their energy efficiency. The present paper has sought to highlight some of these issues, which place the current direction of sustainability efforts in buildings in a slightly different light. These include the uncertain life-time of thermal insulation materials, the problems associated with their recycling, and the increase in grey/embodied energy and associated greenhouse gas emissions, but also the formation of molds and algae on the sub-cooled external surfaces of well-insulated solar-less façades, the increase in summer overheating of buildings, the high tightness of the building envelope, and the need to use mechanical ventilation and cooling. These problems do not have a simple solution, especially as they are interlinked and built on the current method of assessing the energy efficiency of buildings, based on the often lifeless fulfilment of energy criteria. One way forward could be an increased emphasis on life-cycle optimization of buildings and the promotion of computer-aided optimization tools by both legislation and standardization. On the other hand, the administrative complexity of such optimization needs to be kept within reasonable limits and accessible to small builders and investors. Some aspects of building optimization might not even need to be addressed by architects and planners, e.g., the amount of grey/embodied energy, if EU governments could ensure that only low PEI and GWP products are entering the market.

9. Discussion

The European Commission recently approved the so-called European Green Deal. In the construction sector, it is accompanied by the New European Bauhaus initiative, which aims in particular to bridge the gap between different backgrounds, cutting across disciplines and to promote participation at all levels, which would target transformation along sustainability, aesthetics and inclusion. Nevertheless, it seems that the Commission is not quite sure how to move forward in the construction sector, while at the same time being determined and willing to act in accordance with its precautionary principle as is usual in EU policy making.

For the time being, it is directing its efforts and finances mainly towards the renewal and modernization of the existing building substance. It is certainly also aware that, following the significant tightening of energy efficiency requirements for buildings, the further potential for reducing PEI and GWP, especially for new buildings, lies in optimizing buildings in terms of securing the indoor comfort and the technological maturity of building envelope and also in reducing the amount of embodied energy. In order to demonstrate this reduction, there are considerations for the introduction of environmental product declarations for buildings (EPDBs). In the case study described, the paper tries to show that the processing of EPDBs by designers represents an additional administrative burden in the already demanding (and long) building permitting process in some countries.

The PEI and GWP due to embodied energy are indicators that illustrate the overall energy intensity of a building and the burden caused by its greenhouse gas emissions well. However, there are currently no benchmarks to say when a building is still acceptable and when it is not. Such benchmarks are also very difficult to establish in the case of embodied energy. Hence, it would certainly be preferable if only environmentally friendly products in terms of low embodied/grey energy and associated CO_2 emissions were marketed, and if architects and designers did not have to deal with EPDBs at all. One possible way to contribute to this goal would be to strengthen and consistently promote emissions trading to ensure that greenhouse gas emissions are reduced from the start of the construction process.

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