Zero Heating Building 2021

Multipane glazing based zero-heating building

Background and starting point

The European Green Deal Agreement[1] covers many areas, namely the provision of energy from renewable sources, mobility, agriculture, construction, waste management, etc. One important segment is buildings, as their construction, use and renovation accounts for as much as 40% of the energy consumed[2]. Heating is one of the largest sources of CO_2 emissions, as it can be attributed to as much as 70% of all emissions in residential and 52% in non-residential buildings[3]. It is estimated that 59% of losses on heating of buildings represent transmission losses, so advances in technologies and products for quality buildings are extremely important. The objectives in the field of energy performance of buildings[4] are consistent with the Energy Efficiency Action Plan and the EU Directives, namely the Energy Performance of Buildings Directive 2010/31/EU (EPBD) and the Energy Efficiency Directive 2012/27/EU[5].

The problem of replacing fossil fuels with alternative sources is illustrated in Figure 1, which shows a typical seasonal imbalance in energy consumption for Britain. The graph suggests that removing fossil fuels used for heating would increase today's balanced demand for electricity in the winter period, when electricity with renewables is difficult to obtain. This means that classical heat generation in winter is difficult to replace alternative sources that can generate energy mainly in summer until the issue of seasonal energy storage is resolved. In Germany, which obtains a significant part of electricity from alternative sources, it is similar, and it has repeatedly happened in winter that, due to a multi-day lack of wind and solar, electricity has been imported from neighboring countries, where it has also been low at the same time, leading to the near-collapse of the EU's electricity system[7]. However, technical solutions with seasonal heat storage[8] or by storing hydrogen[9] for the purpose of heating are not commercially viable today[10].

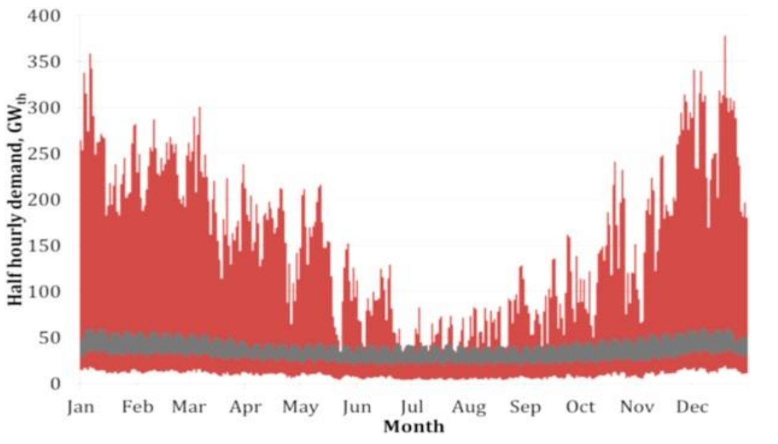


Figure 1 Typical seasonal imbalance in energy consumption for heating demand[6].

In order to achieve the climate target, we believe that it is necessary to increase the renovation of buildings in a way that is more energy efficient in a way that removes the winter spike in heating needs.

[1] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_sl
[2] Eurostat, Energy balances (Energetske bilance), izdaja 2019, končna poraba energije v letu 2017.
[3] Europe's buildings under the microscope, 2011, http://www.bpie.eu/publication/europes-buildings-under-the-microscope/#
[4] National Energy Efficiency Action Plan 2020, https://ec.europa.eu/energy/sites/ener/files/si_neeap_2017_en.pdf
[5] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en
[6] Watson, Lomas, Buswell: Decarbonising domestic heating: What is the peak GB demand? Energy policy, 2019
[7] https://www.cleanenergywire.org/news/european-power-grid-disturbance-has-german-energy-industry-worried
[8] Böhm, Lindorfer: Techno-economic assessment of seasonal heat storage in district heating with thermochem. mater. Energy, 2019
[9] Samsatli, Samsatli: The role of renewable hydrogen and inter-seasonal storage in decarbonising heat–Comprehensive optimisation of future renewable energy value chains. Applied Energy, 2019
[10] Paiho, Hoang, Hukkalainen: Energy and emission analyses of solar assisted local energy solutions with seasonal heat storage in a Finnish case district. Renewable Energy, 2017

Nowadays, two concepts are mainly applied: the concept of passive house[11] and the concept of nearly zero energy house (nZEB)[12]. The first is an important cost-effective approach to reducing heat losses, thus reducing the ecological footprint of the building due to low heating and cooling needs. The second concept is technically more complex, since the building at the annual level has to produce a large part of the energy it consumes, which in addition to the good isolation of the house requires the production of energy, which is usually carried out with photovoltaics, and energy storage. The latter should not increase the carbon footprint[13] due to the installation of additional materials and equipment with the aim of optimizing energy. The problem with this concept is that it compensates for winter energy consumption by means of summer electricity generation and return to the energy system, which does not address the aforementioned seasonal imbalance and energy dependence on fossil fuels more broadly and requires the maintenance of an expensive winter energy reserve and destabilizes the electricity distribution system[14].

Contrary to the above concepts, it makes sense to resolve the seasonal imbalance in a way that buildings do not need heating in winter. For classical buildings, Feist[15] in 1995 and Vanhoutteghem[16] in 2015 showed that it would be possible to realize a building without heating if the windows had a U-value between 0.3 and 0.4 W/m^{2}K. In Feist's experiment, they installed the windows with thick Styrofoam shutters and close them at night. In this way, with small solar gains through window surfaces, the need for classical heating in winter would disappear, and the energy needs for ventilation and cooling would be largely synchronous with solar radiation, so these needs would be covered by photovoltaic cells[17]. The feasibility of a practically usable house without heating was first demonstrated at a demonstration facility in Estonia, where complex window systems were used for glazing[18].

Nowadays, the bottleneck is also glazing systems for which the European Building Regulations[19] set a permissible value somewhere between 0,6 and 1,6 W/m^{2}K and the standard for passive houses[20] is 0,8 W/m^{2}K, which is far above the minimum required 0,4 W/m^{2}K. In the field of window systems, technical solutions are already emerging in the manner of at least four-layer glazing, which allow for a sufficiently high insulation. In the EU, four-layer glazing is offered by a number of manufacturers, who are technologically capable of adding a fourth pane to the third pane[21]. However, since there are no expert information or guidance available for four-layer glass, they do not usually give full warranty or recommend installation on the north side or in a permanent shade to avoid overheating of the inner chambers in the glazing unit. A

[11] https://gi-zrmk.si/publikacije/bivalno_okolje_gradbena_fizika_in_energija_v_zgradbah/40/nacrtovanje_pasivnih_his/
[12] https://www.energetika-portal.si/dokumenti/strateski-razvojni-dokumenti/akcijski-nacrt-za-skoraj-nic-energijske-stavbe/
[13] Alter: Landmark Study Shows How to Change the Building Sector From a Major Carbon Emitter to a Major Carbon Sink. Treehugger - Sustainability for All, 2019
[14] https://www.instituteforenergyresearch.org/the-grid/negative-prices-how-green-electricity-destabilizes-the-grid/
[15] Feist: Erfahrungen mit Häusern ohne aktives Heizsystem. Darmstadt: IBK-Institut für das Bauen mit Kunststoffen, 1995
[16] Vanhoutteghem, Skarning, Hviid, Svendsen: Impact of façade window design on energy, daylighting and thermal comfort in nearly zero-energy houses. Energy and Buildings, 2015
[17] Drev, Černe, Žnidaršič, Geving, Kralj: Nearly independent, near-zero energy building, PHN17 8th Nord. Passiv. House Conf., Helsinki, Finland, 2017
[18] Thalfeldt, Kurnitski, Mikola: Nearly zero energy office building without conventional heating. Estonian Journal of Engineering, 2013
[19] http://www.arhiv.mop.gov.si/fileadmin/mop.gov.si/pageuploads/zakonodaja/prostor/graditev/TSG-01-004_2010.pdf https://epbd-ca.eu/ca-outcomes/outcomes-2015-2018/book-2018/countries/denmark
[20] https://passiv.de/downloads/03_certification_criteria_transparent_components_en.pdf
[21] https://www.finglas.it/index-en.html https://oknoplast.com/ https://klaasimeister.com/ https://klearwall.com/products/passiv-aluclad-window/ https://www.internorm.com/de-at/produkte/fenster/verbundfenster/#

pioneer in this field is Slovenian Reflex[22], which markets up to a 6-layer Q-Air glazing system, in which we have also participated in the development[23].

Zero-heating building

Zero-heating building or nearly zero-heating building (nZHB) is a building having essentially zero heating demand, defined as having heating demand, Q'_{NH}, less than 3 kWh/(m^2a). The zero-heating building is intended for use in heating-dominated areas. Technically, the building is built similarly as a Passive house, with the main difference in application of the multipane glazing (i.e, glazing having four or more glass layers).

The zero-heating building addresses most flaws of the present high energy-efficient buildings.

- It addresses initial cost through the removal of heating (investment and recurring costs) and removal of modulated exterior shading; the extreme heating reduction and modulated shading truncation are enabled through multipane glazing (i.e., glazing having 4 or more glass panes). There, heat loss in winter can be reduced to the point where internal heat sources and visible light alone provide for the needed heating. In summer multipane glazing is highly seasonally selective due to the higher summer average solar incidence angle. At higher incidence angles solar gain is substantially reduced. Though there is an increased cost for multipane glazing (extra glazing cost is offset by truncated external modulated shading);

- Comfort of living. Building occupants have uninterrupted contact with the environment and zero unmet hours for climate setting that are fully user-adjustable. Users can have 25°C in winter or 23°C in summer with negligible loss of building energy performance. In winter, multipane glazing offers zero cold downdraught zone near the tall windows and in the summer solar gain is never higher than 0,3 which is sufficient not to experience solar radiation discomfort while seating at the window;

- Architectural freedom; in zero-heating buildings, there are no limitations in glazed surfaces. Can be 100% glazed, does not need to be purposefully optimized for passive solar design.

- Removes the need for seasonal energy storage. The need for seasonal energy storage is originated almost entirely in heating energy requirement in buildings. Obviously, the zero-heating buildings need no such storage. Further, even day-over-day energy storage can be less, as cooling energy demand roughly follows photovoltaic power availability;

- Removes the market hesitance on “smart things”. Though well-educated investors might invest in “smart” things, most people don’t understand it and will avoid any product having “smart” options – especially related to energy. Zero-heating building can be offered as a “dumb” fire and forget solution where the occupant does not need to bother about any adjustments, settings or functionality requiring training. Many highly efficient buildings require training which is a no-go for most free-market projects;

- Reduces embodied grey energy and in some cases weight. Multipane glazing features thin (2-3 mm annealed) glass panes that save weight and embodied energy especially as in conventional triple-pane glazing mid glass pane is usually heat treated. Main embodied grey energy saving comes from absent heating and external shading systems.

More on the subject’s history and relevant scientific citations:

[22] http://www.reflex.si/en/q-air

[23] Kralj, Drev, Žnidaršič, Černe, Hafner, Jelle: Investigations of 6-pane glazing: Properties and possibilities. Energy and Buildings, 2019

https://en.wikipedia.org/wiki/Zero_heating_building

Open problems

The architects wonder when the four-layer glazing will become universally applicable[24], as in addition to almost double thermal insulation compared to triple glazing, it also offers an improvement in the living comfort, which includes a decrease in the feeling of cold air movement next to the window and better sound insulation. It also gives them greater design freedom, which is otherwise frustrated by the constraints set by the passive solar design. Leading designers of building construction also want more glazed surfaces[25], which is not possible at triple glazing because winter heat losses increase.

The transition from double to triple glazing took quite some time, as multi-layer glazing does not mean simply adding glass panels. Only recently have triple glazing standards have been established: **guidelines for dimensioning** (DIN 18008-2: 2020 and EN16612: 2019) and the **standard for qualification** of the quality of the sealing system (EN 1279: 2018). In principle, the EN16612 standard could be used in the calculations of four-layer glass if it only allowed the calculation of the non-linear swept volume, which is crucial for calculations with thinner glass and large deflections experienced in multipane glazing.

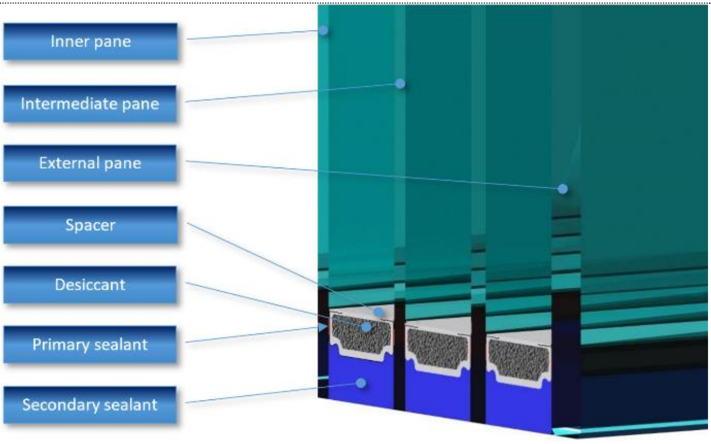


Figure 2 Four-layer glazing element

The correct optical construction of the four-layer glazing shall be without the need for external shades[23], which shall also put such a product ahead of the triple glazing equipped with modulated shades, even according to the carbon footprint criterion of the embedded materials and economic viability. However, if we are also to achieve the multi-decade sustainability of such a product, its design poses a structural challenge.

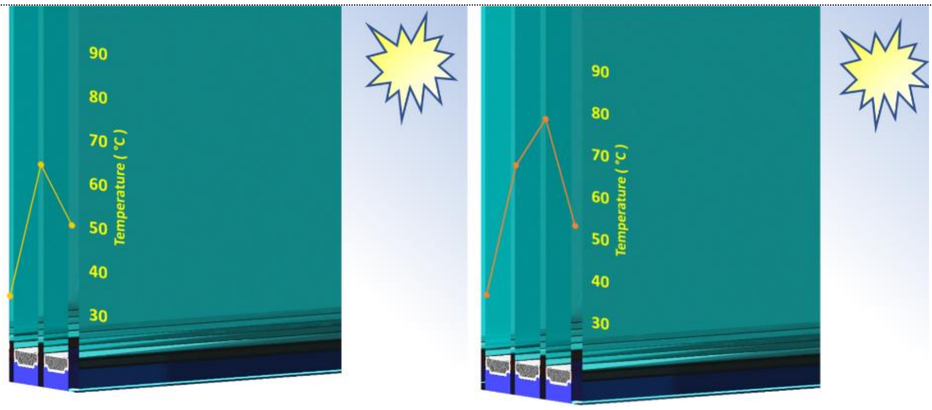


Figure 3 Annual peak temperatures of individual panes in triple and four-layer glazing

A multi-layer glazing element (Figure 2) is, in principle, a composite structure consisting of glass sheets separated by spacers. Few tenths of a millimeter thick primary sealant, connects spacers and glass and seals the single gas-filled chamber. The entire assembly is wrapped with a secondary

[24] Franklin: How Long Until We See Quadruple-Glazed Windows Become the Norm? https://architizer.com/blog/practice/details/quadruple-glazed-windows/

[25] Cihat, Mirzaei, Akhavannasab: On the relationship between building energy efficiency, aesthetic features and marketability: Toward a novel policy for energy demand reduction. Energy Policy, 2019

sealant and is inserted into the window or façade frame.

The problem with the design of such a structure is to ensure its durability. Due to climatic influences, the structure is subject to temperature fluctuations, as the solar energy absorbed in each glass heats the intermediate glass, which is well insulated by adjacent chambers, resulting in a sharp increase in temperature (Figure 3). This not only results in the temperature dilation of the glass sheets, which cause shear deformation of the seals along the spacers, but also increases the pressure in the chambers, which bulges the glass and the strains the seal. In addition to daily temperature fluctuations, there are also seasonal, where the reverse process happens at low winter temperatures. Seals are a critical part of the structure as far as durability is concerned, as glazing no longer has adequate properties if the insulating gas escapes. Seals are constantly subjected to cyclical mechanical load due to temperature variations, which is shown to be a key factor affecting the life span.

For all glazing structures, the mechanical response is importantly influenced by the ratio of the sides, as it is dependent on the double curvature in two rectangular planes when bending the glass panes, as well as the size itself, since the size of the bulging glass and seal tension in small windows are different from those in the large façade panels. The thermomechanical behaviors of the four-layer structures are all the more extreme, which means that the design of such a composition is all the more challenging. To our experience with such glazing, it may not be possible to develop a universal configuration of a four-layer glazing of a particular dimension, but rather the configuration will always depend on the local climate, the position of the room and the position of the glazing on the building according to the direction of the sky.

Four-layer glazing is made of similar components as standard glazing today. However, individual panes can vary in thickness because we want to use thinner, more flexible glass, spacers can be of different width and hybrid composite materials, seals have varying rheological properties throughout the temperature range of glass use, so with the addition of layers the number of possible configurations increases significantly. The optimal configuration of the four-layer glazing for a specific building requires thermomechanics studies, which significantly increases the product cost and makes it difficult to penetrate such products on the market. We know from experience that standards intended for three-layer glazing are by and large useless for the purpose of four- and multi-layered glazing, which is why there is a strong need to make dedicated guidelines.

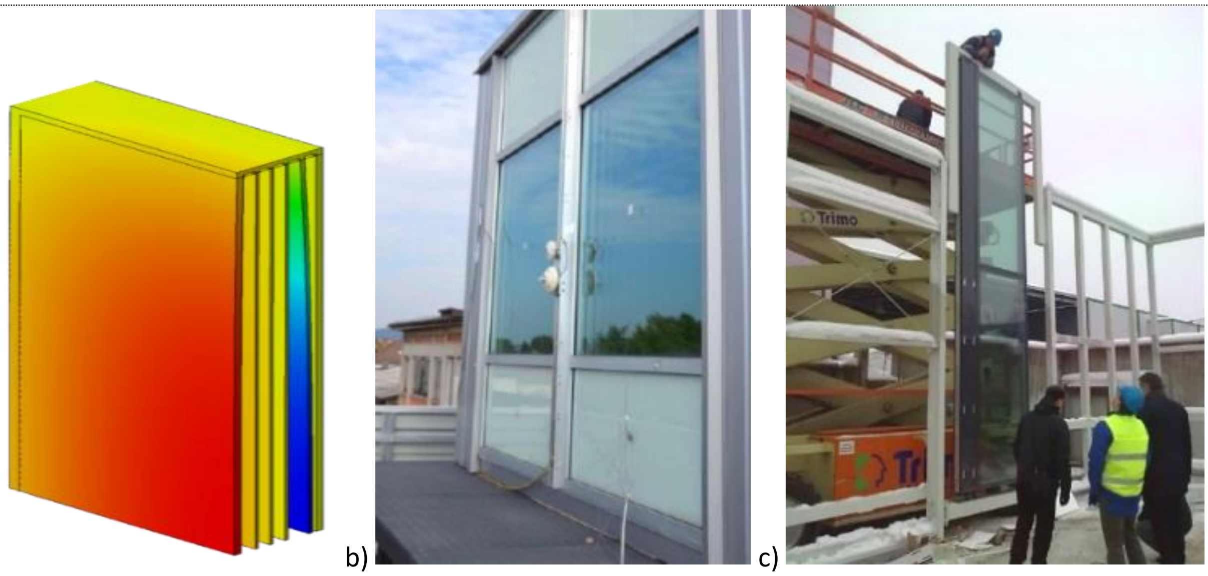
The research carried out so far by the authors

So far, we have done the development of a 6-layer Q-Air façade panel, the solution of which is patent-protected[26,27,28]. Several buildings with this glazing have been built or renovated to date (Figure 4). We participated in both design and dimensioning[29,30], manufacturing, mechanical tests[31], multi-year testing of the solar transmittance impact[32] and monitoring of effects on building [33,34,35] (Figure 5).

[26] Kralj, Hajdinjak: Gas filled insulation construction panel: EP 2340338 B1, 2014.
[27] Kralj, Žnidaršič, Halilovič, Vrh, Štok: Building panel as structure of external and inner plate with intermediate insulation space: EP2464799 (B1), 2020
[28] Kralj, Žnidaršič, Halilovič: Multichamber gas-filled insulated glass unit: EP3323952 (B1), 2020
[29] Starman , Maček, Rus, Obid, Kralj, Halilovič: Primary Seal Deformation in Multipane Glazing Units, Applied Sci., 2020
[30] Halilovič, Rus, Krebelj: Stresses and strains in non-rectangular Q-AIR 5 under climatic loading. 2018.
[31] Case Report: No. P 0020/17-630-1, REPORT about the testing the flexural strength of Q-Air facade panels…, 2018, ZAG
[32] Hafner, Jordan: Glass facades: thermal response of transparent facade panel Q-Air in real weather conditions. Gradbenik, 2018
[33] Rebec Malovrh, Černe: Multipane single and double skin transparent façade building performance in terms of indoor daylight, heating and cooling requirements. Adv. Build. Ski. 12th Conf. Adv. Build., 2017.

Figure 4 Multipane glazing buildings (photo: Reflex)

Since the design of four-layer glazing, Quad Glass Unit (QGU) does not transfer into the individual building analyses in time, we want to develop engineering guidelines and rapid tools for sizing four-layer glazing and associated buildings as part of the proposed project and make them public.



a) b) c)

Figure 5 a) MKE analysis (FS), b) measurements of solar gain (ZAG), c) weathering field testing.

Zero-heating buildings and EU support

Zero-heating buildings lack EU support. The proposed concept is suitable for the **Horizon Europe Green deal: EIC Transition challenges,** due to its maturity level. Unfortunately, **EIC Transition challenges** excludes all R&D that has been done outside previous Horizon programs, which is the case with zero-heating building initiative. **Zero-heating building and its components require development of corresponding design and qualification standards, so its design process could be presented to non-academic architects, construction engineers and investors.**

[34] Kralj, Drev, Žnidaršič, Černe, Hafner, Jelle: Investigations of 6-pane glazing: Properties and possibilities. Energy and Buildings, 2019

[35] Domjan, Arkar, Begelj, Medved: Evolution of all-glass nearly Zero Energy Buildings with respect to the local climate and free-cooling techniques. Building and Environment, 2019