Multi-active façade for Swedish multi-family homes renovation – Evaluating the potentials of passive design measures

Susanne Gosztonyi[1/2], Magdalena Stefanowicz[1], Ricardo Bernardo[1], Åke Blomsterberg[1]

1 Energy and Building Design, Architecture and Built Environment, LTH, Lund University, Box 118, 221 00 Lund, Sweden, +46 46 222 3630, e-mail: {Susanne.Gosztonyi, Ake.Blomsterberg, Ricardo.Bernardo}@ebd.lth.se; s.gosztonyi@tudelft.nl; magdalena.stefanowicz@gmail.com

2 Façade Research Group, Design of Construction, Architectural Engineering and Technology, TU Delft, Julianalaan 134, 2628 Delft, The Netherlands, e-mail: s.gosztonyi@tudelft.nl

Abstract

In order to meet the Swedish energy efficiency objectives for the built environment until 2050, a particular building stock has to be addressed: the houses of the Million Homes Programme, an ambitious housing programme of the 1960s and 70s that resulted in a large number of standardized multi-family houses all over Sweden. These are in need of upgrading the energy and comfort quality to current standards, which provides an excellent opportunity to investigate the potentials of 'prefabricated multi-active' façades for refurbishments on large scale. While 'prefabrication' is linked to cost-effectiveness and high replicability, 'multi-active' addresses the potential of embedded active and passive measures for improved energy efficiency and energy regulation out of the façade. Integrated building services technologies, solar technologies or moveable components, such as shading systems, are considered active measures. Passive measures include physical and constructive measures, such as e.g. thermal insulation or selective coatings of glazing's, and provide a "passive" energy flow control to improve the thermal quality of the building envelope. Many of these strategies are well-known, traditional solutions. Although they do not provide an energy-generating or -supplying function, they dynamically interact with environmental changes; preheating of supply air through the air cavity of a façade construction or adaptive thermal buffer zones are just few of many examples. The question is how traditional passive strategies can be used to contribute most effectively to the demanded energy efficiency. The paper presents first results from an assessment dealing with this question: Two traditional 'passive' façade strategies, a curtain wall system and closed balconies, have been analysed in regards to their impact on energy balance and their thermal behaviour in a defined renovation scenario. The assessment is aims to support the development of a multi-active facade concept suitable for large-scale refurbishments of the multi-family houses in Sweden, which is part of the initial phase in the pre-study "Multi-active façade". The pre-study considers architectural, technological and constructive aspects, energy performance and indoor comfort optimization, but also economic feasibility and constraints to get replicable on large scale. So-called added values that concern the upgrade to modern living standards and expectations by inhabitants and the market value of the building are also touched. The paper discusses, based on a technology screening to identify suitable key measures, the energy saving potential and impact on thermal indoor comfort of two passive renovation strategies for facades.

Keywords

multifunctional façade, multi-active façade, energy renovation, multi-family buildings, passive measures, Sweden

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1 INTRODUCTION

The renovation rate of buildings in Europe is currently at 1%. It is assumed that an increase of the renovation rate to 3% would contribute to the reduction of the *"energy demand in the current building stock [...] by 80% by 2050 compared to 2005 levels."* (BPIE, 2016). Since the residential sub-sector is the largest energy consumer with 26% of the total final energy consumption within the European building sector, applicable solutions are needed to motivate more refurbishments.

This applies also for Sweden. The Swedish building sector focuses currently on a specific residential building stock from the so-called "million homes programme" (miljonprogrammet), which was established in the 'record years' from 1961 to 1975. Facing housing shortage and seeking for higher living standard at that time, about 40.000 multi-family apartment blocks with about 920.000 apartments were erected (Hall & Vidén, 2005, p. 304). These buildings are responsible for more than 30% of the energy consumption from residential buildings in Sweden, with ~151 kWh/($m^2 \cdot yr$) in average (Högberg, Lind , & Grange, 2009) (Boverket, 2012). The majority of the buildings is equipped with mechanical exhaust ventilation systems (without heat recovery) and connected to district heating, which put them on a higher standard than comparable constructions of that time in other countries. The buildings are on-site-cast or pre-cast concrete constructions with, in general, load-bearing inner cores or partition walls. Thus, external walls are normally not load-bearing. They are constructed of either concrete cast with an exterior insulation layer and plaster or brick rendering, or of prefabricated concrete elements or infill walls with studs and thermal insulation in between. A particularity in the million homes programme constructions has been the strong focus on industrial prefabrication and standardization: *"Rational construction in large projects was regarded as necessary to produce affordable housing of good standard"* (Hall & Vidén, 2005, p. 304). The advantage of these wall constructions is to realize physical adaptations in a flexible way without touching load-bearing elements. These adaptations can be done minimal-invasive, by either replacing parts of the façade or adding layers and/or components.

Minimal maintenance ("wear and tear") over the years kept these buildings in function. However, many of them require a major renovation to become upgraded to modern standard. Until 2017, 100.000 apartments shall be renovated, whereas between 10.000 to 20.000 apartments are refurbished per year (Hall & Vidén, 2005). The focus is laid on the exchange of outdated piping, electric cables, ventilation systems, and living facilities (toilet, kitchen and bathroom). Thus, the driving (economic) factors for renovation are to provide a modern living standard of the apartments and to meet the required maintenance standard. This resulted in the situation that too few comprehensive energy renovations have been realized so far. For the required energy efficiency standard of buildings, an upgrade requests better insulated building envelopes and heat recovery on ventilation at minimum. For the constructive improvements of the facade, added thermal insulation and exchange of windows and doors are established strategies. The application of multi-functional or 'multi-active' facades is usually not taken into consideration in such renovation projects. However, it is assumed that these façade systems are potential alternatives to a number of individual measures considering energy efficiency and indoor comfort improvements.

Multi-active facades contribute to energy performance targets by merging passive measures for thermal quality improvement, such as added thermal insulation and thermal puffer zones, and active measures for adaptive indoor comfort, such as integrated ventilation and thermally adaptive components, with measures for decentral energy generation, such as building-integrated photovoltaics or solar thermal systems. Thus, providing energy while influencing actively the indoor comfort and thermal quality is the main target of multi-active facades. However, the employment of such systems for renovations, particularly in the residential sector, is only convincing when performance reliability and so-called 'added values' show advantages in comparison to traditional renovations.

'Added values' for the building owner/manager are aiming at economic, design and construction benefits: Robustness (e.g. easy mounting, low maintenance, accessibility), cost efficiency (e.g. re-use of existing systems/structures, market reliability, initial and maintenance costs), replicability (of standardized, scalable components) and compatibility (plug and play), economic and legal aspects (e.g. warranty), or architectural impact (e.g. design flexibility, structural impact, impact on identity) are few of the 'added value' criteria of which some decide a Go/No-go already in the early design phase and are critical for the decision making process. Furthermore, added value of such systems depends also on their suitability for modern habitats and demographic needs, sustainability requirements and its role as contributor to the urban energy network. The utilization of building surfaces in urban areas has become a central focus in the developments in Europe and in Sweden. Although all these aspects are a project-internal definition for 'added values', it can be anticipated that they are generally matter of debate in regards to the benefits and role of façades as a service-orientated, "useable interface" in a larger system context.

In comparison to the complexity of defining and evaluating 'added values', the performance reliability of multi-active facades can be defined and evaluated easier. To regulate the energy flow actively via such façade systems, active and passive measures are applied: Integrated building services technologies, solar technologies or moveable components, such as shading systems, are considered active measures. Since multi-active facades use often solar technologies, they can be linked to the goals of nearly Zero-Energy buildings (EU EPBD, 2010) and thus, experience an increase. Particularly, building-integrated photovoltaics (BiPV) is attractive for facade integration due to easier installation and maintenance in comparison with solar heating systems. In Sweden, photovoltaics has a current share of 0.03% of Sweden's total electricity use (Johansson & Karlsson, 2015), which is rather negligible. Furthermore, low energy prizes significantly cause low profitability of BiPV. Thus, BiPV is currently not a driver for multi-active façade installations in Sweden. Multi-active façades can employ, however, also other active measures, such as e.g. smart materials (e.g. switchable glazing, adaptive thermal insulation, PCM), automated shadings, or integrated decentralized building services systems. Particularly the existing share of ventilation systems in old residential buildings seems to be an effective start for an upgrade to semi-integration or full integration of ventilation components in the façade. The performance evaluation of active measures can be done by numeric analyses.

This also is valid for passive measures: Passive measures include physical and constructive measures, such as e.g. thermal insulation or selective coatings of glazing's, and provide a "passive" energy flow control to improve the thermal quality of the building envelope. Many of these strategies are well-known and regularly applied solutions. Passive measures can be further designed to interact with environmental changes by e.g. preheating supply air through the air cavity of a façade construction or create adaptive thermal buffer zones. The question is how passive measures can be activated to contribute even more to energy efficiency and thermal comfort likewise. The active role of passive measures is often neglected, since constructive aspects are considered steady and not linked to activation of the building envelope. The need for re-thinking and perhaps re-designing the interrelation of active and passive measures is evident. This paper focuses on the performance aspect of selected passive measure to discuss this.

2 METHODOLOGY

The overall objectives of the research study ‘prefabricated multi-active façades for energy renovation of multi-family buildings’ (*“Förstudie av prefabricerade multiaktiva fasadelement för energirenovering av flerbostadhus”*, 2015-2017, LTH-EBD, NCC) is to develop a façade concept that uses active and passive measures to support an energy-efficient upgrade of the million homes programme in Sweden. Herein, the applicability of such a system in the framework of the Swedish building regulation (energy performance), of economic and social benefits (LCC, sustainability, replicability, prefabrication) in the realm of large productions, as well as of market acceptance (tenants and owner profitability) is treated. A vital motivation for the development of the multi-active façade concept is also the justification for its sustainable applicability on large scale renovations.

The initial phase of the study aims at (a) a technology screening of existing solutions and applied measures, (b) the development of selection criteria for the identification of key renovation measures, and (c) a performance assessment of selected renovation strategies that are suitable for the multi-active façade development. These steps are conducted parallel for passive and active measures to evaluate their specific characteristics. In regards to group “passive measures”, step (c) focuses on the question on how known passive strategies can be applied to contribute actively to energy efficiency goals.

Two renovation strategies from group “passive measures” are presented in this paper with focus on the assessment of their energy saving potential and impact on thermal indoor comfort. The thermal indoor comfort assessment provides indications about possible changes of the indoor surface temperature, although detailed analyses must be done at a later stage. The assessment of the energy saving potential includes parametric studies of certain components in defined renovation scenarios in order to identify their impact. These assessments support the design of the multi-active façade and are a part of a series of simulations targeting at the selection of passive and active measures.

The paper provides first a condensed description of the technology screening of international renovation projects (literature review) and some key measures relating to passive renovation strategies for facades. Furthermore, some key measures are described, based on their application frequency and contribution potential to performance, upgrade of the living standard and architectural appearance. Following the overview and key measure description, the results of the performance analyses of two passive renovation strategies in a reference scenario are discussed. For the paper, only well-established passive measures are shown to address the potential for *activation* of traditional approaches.

Limitations are given in this paper: There is no detailed description of the selection process of the passive strategies. Furthermore, a total building performance assessment and an evaluation of user satisfaction, economic benefits and indoor comfort quality are not investigated, but will be considered at a later stage when the design is more mature.

3 RESEARCH

3.1 LITERATURE REVIEW AND KEY MEASURES

The literature review focuses on innovative façade refurbishments for residential buildings: Relevant case studies, building projects and research concepts have been collected, whereas the scope has been laid on European examples due to comparable objectives (EU EPBD, 2010). About 30 projects have been collected and examined in regards to what and how often façade-related renovation measures are applied. Furthermore, based on the application frequency, the level of innovation and 'added value' criteria defined in the project, 45 key measures have been identified. Fig. 1 shows some of the key measures out of seven categories (A: Natural ventilation, B: Thermal quality, C: Daylight quality, D: Integrated technologies and materials, E: Energy performance, F: Ecological and economical aspects, manufacturing). The key measures and linked parameters, selected for further analysis, are highlighted.

The selection is based on three criteria: The energy saving potential (quantitative), the 'added value' potential (qualitative) and the Swedish framework conditions. The evaluation reveals that robustness, market readiness and replicability seem to be the most important 'added value' aspects in the projects, whereas multi-functionality is the least. Only few passive measures show innovative energy saving potential: Solar adaptive systems and added thermal buffer zones (closed balconies, second skins) receive high ratings as thermal quality improvements. Passive house standard and high prefabrication are also highly ranked criteria in the projects.

In the technology screening, no emphasis has been laid on the impact and application quality of the renovation strategies. This means that major and minor renovations are considered as well as traditional solutions to enable a broad collection of façade renovation strategies and to be able to assess the role of passive measures. The collection contains the project and building type, construction / research year, location and references, as well as the relevant measures linked to the building envelope. In addition, framework requirements and driving factors for the refurbishment to understand the chosen solutions are considered, if available. Although the amount of applied measures in the international projects has been significant, only few measures revealed application potential for the project framework conditions due to the specific constraints of the target: The residential buildings of the Swedish million home programme allow, on the one hand, only certain constructive upgrades, as shown in the reference building of chapter 3.3. On the other hand, only available products and solutions in the Swedish construction market are considered to allow a short realization period. Other decisive criteria are the requirements of the national building code that ask for an average U-value of the building envelope and do not define, in general, specific U-values for building components, such as e.g. the external wall or window. This approach differs from many other European countries.

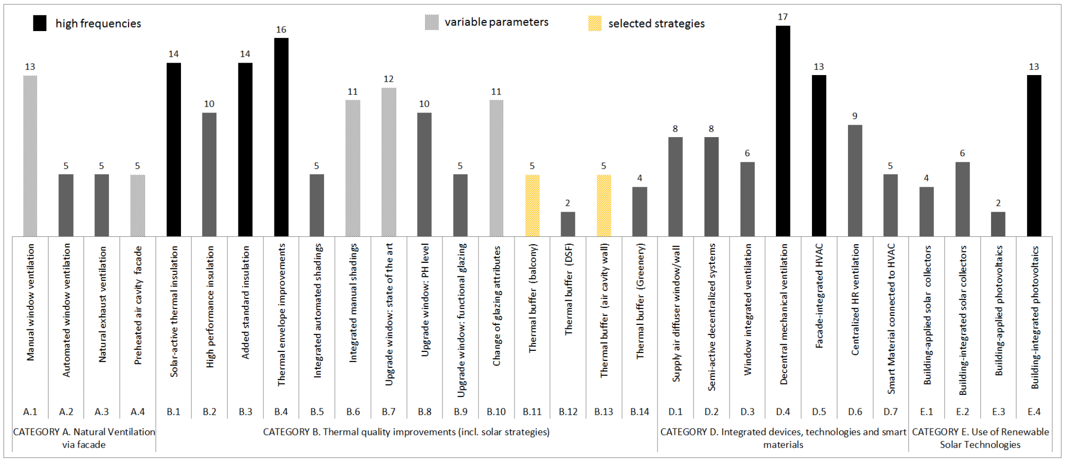


FIG. 1 List of some key measures for facade renovation (numbers display the application frequency). Selected strategies and variable parameters (orange/light grey) and often applied measures (dark, threshold >10) are highlighted.

3.2 SELECTED PASSIVE RENOVATION STRATEGIES

The intention is to develop a facade carrier that fulfils (a) multi-active façade criteria defined by the activation of façade components, (b) economic criteria defined by standardized prefabrication and customization, (c) social requirements defined by increase of living standard, and (d) architectural and constructive criteria defined by modularity and design flexibility of the system. Possible wishes to conserve the existing wall appearance need to be addressed as well. These target criteria result in the following concept: A second skin system with varying depths up to balcony width, providing a thermal buffer zone (useable for preheating of fresh air intake and/or winter garden), but allow high adaptation and transparency. The facade carrier is a lightweight frame system with infills allowing various exchangeable components (e.g. photovoltaics, solar thermal collectors, adaptive or translucent insulation, ventilation, etc.). The system components shall be standardized and follow the "plug and play" approach, whilst being architectural flexible. Fig. 2 shows two passive facade strategies (well-established systems, such as a closed balcony (S1) and a ventilated curtain wall (S2)), which promise suitable solutions for this purpose. The development of these strategies is based on the outcome of the key measures evaluation. To understand how these passive systems contribute to the performance and how they can be activated, initial performance analyses are conducted. The potential for energy saving, increased thermal comfort, and contribution towards upgraded living standard goals, are subject to the analysis and parametric studies that shall lead to the design of a multi-active façade (draft S3).

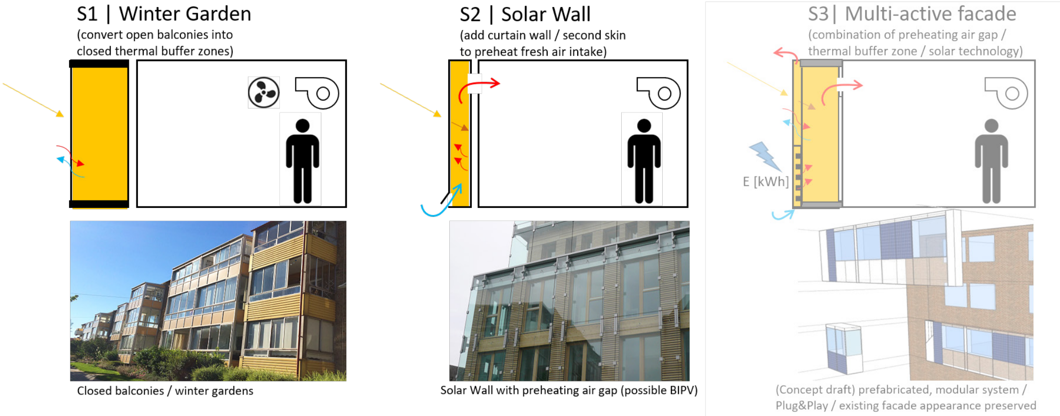


FIG. 2 Passive renovation strategies for walls / facades (from left to right): S1 | Winter Garden – converting open balconies into closed thermal buffer zone, S2 | Solar Wall – adding a second skin (possibly solar active skin) for preheating fresh air, S3 | Multi-active facade – combination of passive and active components (not presented in this paper – future work).

In the **winter garden strategy (S1)**, open balconies are converted into a closed thermal buffer (Fig. 3). A lightweight frame construction with glazing applied on the southern façade and the prolongation of the existing balcony along the apartment length, as shown in Fig. 3, is proposed. The U-value of the added single clear glazing in the winter garden is 5.8 W/(m^2·K) with a g-value of 0.65 [-]. The balcony slab (0.15 m concrete) has a U-value of 2.39 W/(m^2·K), the roof (0.14 m and 0.15 m lightweight insulation) has 0.23 W/(m^2·K). The inner double-glazed windows towards the apartment are not changed. No shading is applied in the base case and the thermal zone is "closed" (no natural ventilation through outer windows or into the apartment). The infiltration is set to 0.02 l/(s·m^2).

Following values are defined for the parametric studies in order to estimate their impact on the heat balance (It is important to mention that these analyses are focusing only on the thermal transmission behaviour):

- Various U-values for the added glazing: 1.2 W/(m^2·K) according to recommendations in the building regulation (BBR, 2015); 0.8 W/(m^2·K) according to Passive House standard (FEBY 12, 2012),
- Various shading types (interior blinds; external louvres),
- Natural ventilation when operative temperature in the thermal buffer zone exceeds 25°C: 10% of open glazing (window); 20% of open glazing (window),
- Existing windows replacement: New windows with Uw-value = 1.2 W/(m^2·K) and g-value = 0.5 [-]; Uw-value = 0.8 W/(m^2·K) and g-value = 0.5 [-].

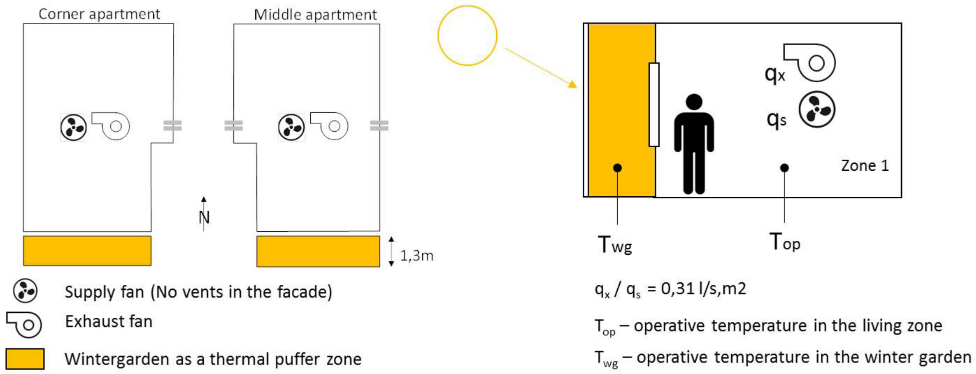


FIG. 3 S1 | Winter garden strategy and specification for analysis.

The **solar wall strategy (S2)** is a second skin system that enables preheating of fresh air (Fig. 4). It combines an external 3 mm glazed pane with a highly absorptive inner layer separated by an air gap. This structure is a ventilated curtain wall system mounted on the existing opaque walls. The system is applied on the southern and western façade. The U-value of the added outer glazing is $5.8\ W/(m^2 \cdot K)$ with a g-value of 0.88 [-]. For this scenario, natural ventilation is applied via the existing vents at the windows. The positioning of the vent and its size towards the apartments, and the air gap width (0.04 m) is set to get a comparable air flow as for the reference case (which is $0.31\ l/(s \cdot m^2)$). Again, the inner windows towards the apartments are not changed. No shading is applied in the base case and no natural ventilation into the apartment occurs.

For the parametric studies, following has been defined to estimate their impact on the heat balance:

- Various U-values for the outer glazing: same as for scenario S1,
- Various air gap depths in solar wall system: 300, 400, 500, 600, 700 and 1300 mm,

Existing windows replacement: same as for scenario S1.

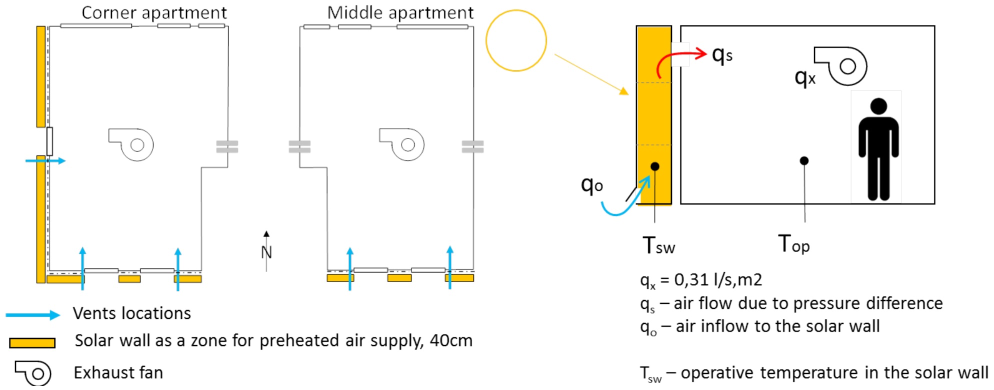


FIG. 4 S2 | Solar Wall strategy and specification for analysis.

3.3 REFERENCE BUILDING AND EXEMPLARY REFERENCE CASES

Sweden is divided into four climate zones, which require different specific energy use set points and average heat transfer coefficients of the total building envelope (Um) according to the Swedish building regulation (BBR, 2015). For the simulation, the building is located in South Sweden, in climate zone IV. The average thermal transmission coefficient requirement (Um) is 0.4 W/(m^2·K). Thus, thermal quality is assessed via the entire building envelope. If the Um requirement cannot be fulfilled, the building envelope must at least reach minimum U-values for roofs (0.13), exterior walls (0.18), basements (0.15), and windows/doors (1.2). The required ventilation flow is 0.35 l/(s·m^2) in average for the heated floor area. Infiltration and air tightness are not defined.

As shown in Fig. 5, a three-story building has been chosen that is representative for the million homes programme: It consists of 18 apartments with 81.5 m^2 each and has a gross heated floor area of 2.148 m^2. The window/wall ratio (WWR) of the building envelope is approx. 40%. The building has an average Um-value of approx. 0.55 W/(m^2·K) and an average space heating demand of 62 kWh/(m^2·yr) (BeBo, 2014). The existing heating system is a district heating system, the heat distribution is provided via water-based radiators. The ventilation is a central exhaust air ventilation system, using vents at the windows for the fresh air intake; their exact location is assumed (see arrows in Fig. 5). Air is exhausted from bathrooms and kitchens. The yearly average temperature is 7.6°C (Climate-Data, 2016). From this building, two exemplary apartments - a regular (middle) and a corner apartment – have been chosen for the parametric studies of the passive strategies on the façade's thermal behaviour.

The 'middle apartment' is on the second floor with two external walls and adjacent walls, floor and ceiling. Its calculated space heating demand is about 61 kWh/(m^2·yr). The 'corner apartment' is on the third (last) floor with four external surfaces (three walls, roof) and an adjacent floor. The calculated space heating demand is about 119 kWh/(m^2·yr).

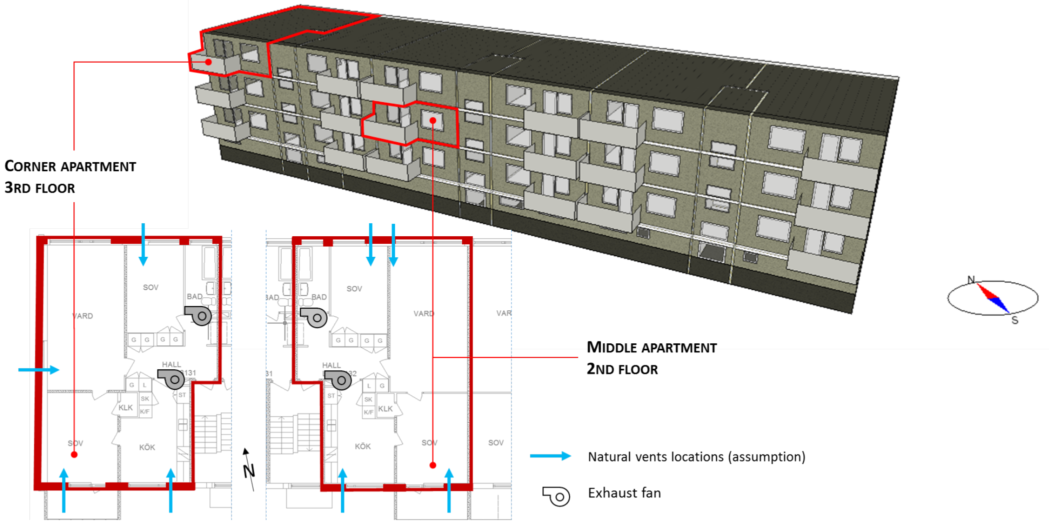


FIG. 5 Reference building – typical geometry of a three storey multi-family home, Million Home Programme, Sweden.

The exterior walls have a U-value of 0.31 $W/(m^2 \cdot K)$. The large newer windows of the living rooms have an U-value of 1.60 $W/(m^2 \cdot K)$, the U-value of the smaller windows is 2.0 $W/(m^2 \cdot K)$, and of the balcony doors 2.70 $W/(m^2 \cdot K)$, with a common g-value of 0.68 [-]. The windows are closed in the base case calculations. A shading factor of 0.5 is assumed, as well as a U-value of the floor slab with 2.39 $W/(m^2 \cdot K)$ and of the roof with 0.23 $W/(m^2 \cdot K)$. The balconies are thermally separated by 0.03 m mineral wool insulation at the attachment base. The ventilation is set by 0.31 $l/(m^2 \cdot s)$ as an average air flow. Thermal losses caused by thermal bridges have been assumed with 23% of the total UA-value according to national guidelines (Boverket, 2012). Additional infiltration has been set as 0.02 $l/(m^2 \cdot s)$. Heating and cooling has been set ideal with indoor temperature defined as 20°C for the heating set point and 25°C for the cooling set point. The internal gains are set as 3.6 units with 100 W/unit, and constant operation.

The energy performance set points, which shall be compared in the parametric studies, are defined by the national building regulation (BBR, 2015) and by the Swedish Passive House recommendation (FEBY 12, 2012): The BBR demands a max. specific energy demand (energy for space heating, domestic hot water and property-used electricity) of 75 $kWh/(m^2 \cdot A_{temp} \cdot yr)$. For the parameter studies, focusing only on space heating demand, this value is adapted to be able to compare the results with the reference case while applying the façade renovation strategies: Thus, the set point for the space heating demand is 48 $kWh/(m^2 \cdot A_{temp} \cdot yr)$ in order to reach the BBR requirements. Since the energy demand for domestic hot water (DHW) exceeds the required FEBY value of 22.5 [$kWh/(m^2 \cdot A_{temp} \cdot yr)$], the goal to reach FEBY passive house requirements is not possible without reducing the DHW energy demand (and/or auxiliary energy). Thus, the FEBY requirements are not applied for the initial analyses, but will be considered later.

The objective of the energy performance analysis and the parametric studies is to investigate the proposed passive façade renovation strategies in regards to their energy saving potential (heat balance) and their impact on the thermal comfort (change in operative temperature of adjacent rooms). Following questions are applied:

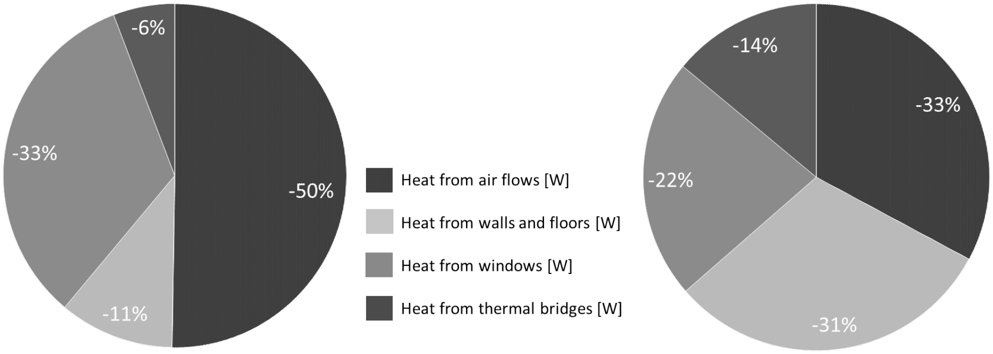
- How large is the heat loss through the walls when the proposed strategies are applied?
- How large is the effect of the proposed strategies on the heating demand?
- How do the variable parameters influence the thermal behaviour of the strategies?

Fixed parameters for the parametric studies are the climate zone, location and orientation, the apartment construction and geometry, the WWR, and the building services technology, respectively, the energy system (heating, ventilation, lighting, user profile and equipment). Furthermore, for comparability reasons in the various scenarios, it has been defined that all windows are closed and no ventilation strategy unless the defined one is applied. Infiltration and thermal bridges are assumed. Moisture is not investigated. The temperature behaviour analyses are done in free running mode without active ventilation to the apartment. The analyses are conducted in the dynamic simulation software 'IDA Indoor Climate and Energy' (IDA ICE, EQUA, 2016).

4 RESULTS

4.1 BASIS ANALYSES (REFERENCE CASE)

Fig. 6 shows how the individual elements of the existing facade contribute to the heat transmission losses. For both apartments, the highest heat losses are due to air flow, respectively, the supply of cold fresh air to apartments. Heat losses through walls are low compared to losses through windows and air flows in the middle apartment; it is even increased for the corner apartment due to the high fraction of external surfaces. Thus, a limited potential for energy savings is, in general, expected by applying passive facade renovation strategies.



February	Heat from air flows [W]	Heat from walls and floors [W]	Heat from lighting [W]	Heat from solar - direct and diffuse [W]	Heat from heating and/or cooling room units [W]	Heat from windows (incl. absorbed solar) [W]	Heat from thermal bridges [W]
Middle apartment	**-762.3**	**-164.4**	**215.6**	**81.12**	**1220**	**-502.2**	**-87.96**
Corner apartment	**-827.6**	**-775.9**	**216.4**	**87.38**	**2217.3**	**-565.3**	**-352.4**

FIG. 6 Heat balances of building envelope from middle apartment (left) and corner apartment (right) during the heating season in the coldest month February, base case.

4.2 PASSIVE FAÇADE STRATEGIES – TEMPERATURE AND ENERGY IMPACT (S1 AND S2)

Fig. 7 displays the thermal effects of the 'winter garden' on the operative temperatures T_{op} in the rooms adjacent to the winter garden and in the winter garden itself, compared to the reference case without this renovation strategy: T_{op} increases by approx. 2°C in comparison to the "old" indoor temperature $T_{op, r}$. The temperature T_{wg} in the winter garden is fluctuating largely according to the direct solar irradiation.

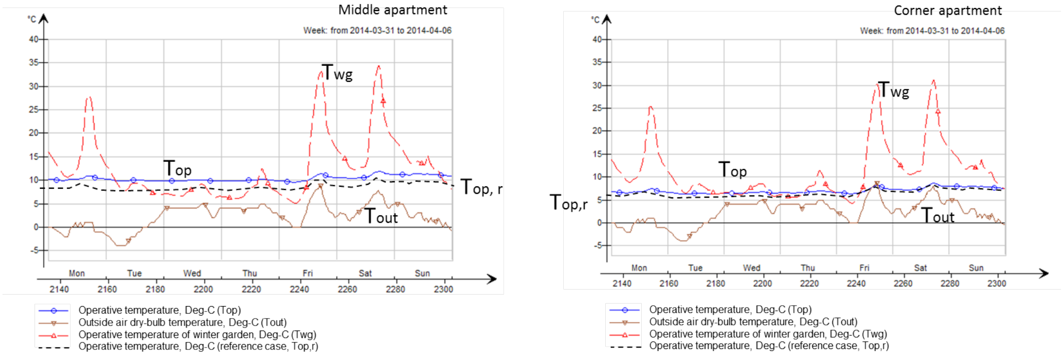


FIG. 7 Temperature profiles, winter garden, week 14 (Mar, 31 to Apr, 06) for the middle apartment (left) and corner apartment (right): Operative temperature T_{op} in adjacent apartment rooms, T_{wg} in winter garden, compared to outdoor temperature Tout and 'base case' indoor temperature $T_{op,r}$.

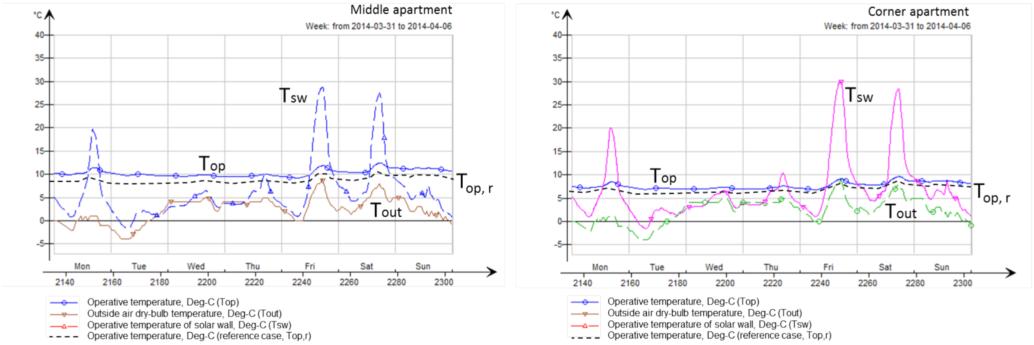


FIG. 8 Temperature profiles, solar wall, week 14 (Mar, 31 to Apr, 06) for the middle apartment (left) and corner apartment (right): Operative temperature T_{op} in adjacent apartment rooms, T_{sw} in solar wall, compared to outdoor temperature Tout and old indoor temperature $T_{op,r}$.

Fig 8 shows the effects on the 'solar wall' on the operative temperatures T_{op} in the rooms adjacent to the second skin system. T_{op} increases as well by approx. 2°C in comparison to the indoor temperature $T_{op,\ r}$.

As in Table 1 summarized, the space heating demand reduction of the 'winter garden' for the middle apartment is approx. 30% (heat losses through walls are reduced by ~48%, heat gains from solar gains into the apartment are reduced slightly, thermal bridges are reduced by ~54%) and thus, could meet the BBR requirements. The corner apartment cannot reach the set point due to the large surface area that is not upgraded for these analyses.

For the 'solar wall', the energy saving potential is opposite: The reduction is bigger for the corner apartment (24%) due to the higher share of external surfaces preheating the inlet air. In both scenarios, no roof renovation or other non-façade related measures are done. Would this be included, the middle apartment would meet the BBR requirement in both cases.

WINTER GARDEN STRATEGY (S1)	SPECIFIC HEATING DEMAND [W/(M^2·K)]	CHANGE, RELATIVE TO BASE CASE [%]
Middle apartment	43.2 (heat from walls/floors: -164.4; heat from windows: -502.2)	-30 (e.g.: heat from walls/floors: -79.41 W/(m^2·K); heat from windows: -399.3 W/(m^2·K))
Corner apartment	97.9 (e.g.: heat from walls/floors: -775.9; heat from windows: -565.3)	-18 (e.g.: heat from walls/floors: -748.9 W/(m^2·K); heat from windows: -469.7 W/(m^2·K))
Solar wall strategy (S2)		
Middle apartment	50.1 (e.g.: heat from air flow: -762.3)	-18 (e.g.: heat from air flow: -656.3 W/(m^2·K))
Corner apartment	90.1 (e.g.: heat from air flow: -827.6)	-24 (e.g.: heat from air flow: -711.2 W/(m^2·K))
Required space heating energy demand accord. to BBR12: < 75 kWh/(m^2·yr), which is adapted to the analyses: 48 kWh/(m^2·yr)		

TABLE 1 Specific energy demand for the two passive façade measures, compared to base cases and heat balance values.

4.3 PASSIVE FAÇADE STRATEGIES – PARAMETRIC STUDY RESULTS (S1 AND S2)

The results of the parametric studies (see Fig. 9) regarding the winter garden demonstrate higher effects for the middle apartment due to the higher ratio of the closed balcony to façade surface: The change of the glazing quality from 5.8 to 1.2 W/(m^2·K) seems to be sufficient; an upgrade to Passive House glazing quality (0.8 W/(m^2·K)) is not beneficial to the energy saving potential as more cooling energy is required. Shading options do not substantially change the energy balance of the indoor temperatures. It is expected that they contribute to the use of the winter garden itself. Natural ventilation for the winter garden does also not influence the energy balance of the apartment, although it must be mentioned that the windows to the apartments are kept closed in the analyses. New windows in the façade would increase the efficiency enormously and shall always be considered together with the strategy.

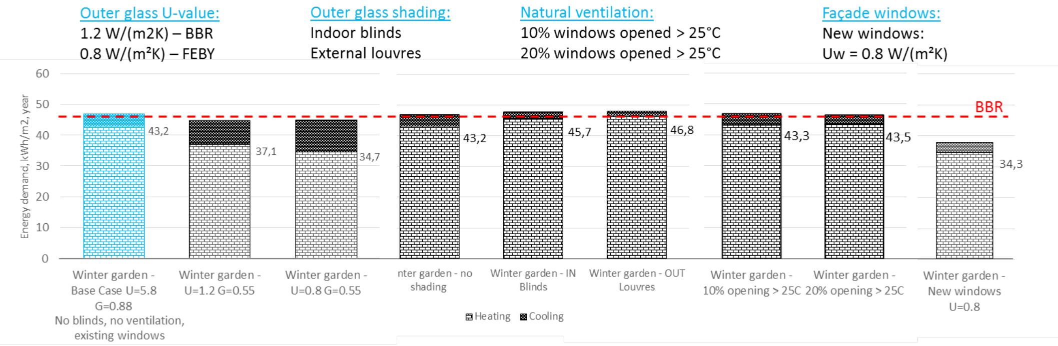


FIG. 9 Impact on energy balance through parametric variations in “winter garden” (S1), middle apartment.

The results of parametric studies for the solar wall show a constant decrease of the heating energy demand with an increase of the air gap (with 130 cm reaching the BBR requirements for heating), assumedly due to the air flow speed. As the solar wall strategy has a constant air flow in the air gap with two openings to the apartment allowing air exchange between the two zones, the positioning of the opening assumedly influences the air flow speed and air temperature development. This effect must be analysed at a next stage. The change of glazing quality of the outer glazing from the second skin has the similar effect as for the winter garden (from 5.8 to

1.2 W/(m^2·K) seems to be sufficient, no further thermal optimization with passive house glazing quality). New windows in the façade would also increase the efficiency and seems the only strategy to reach the BBR set point in both, heating and cooling energy demand (see Fig. 10).

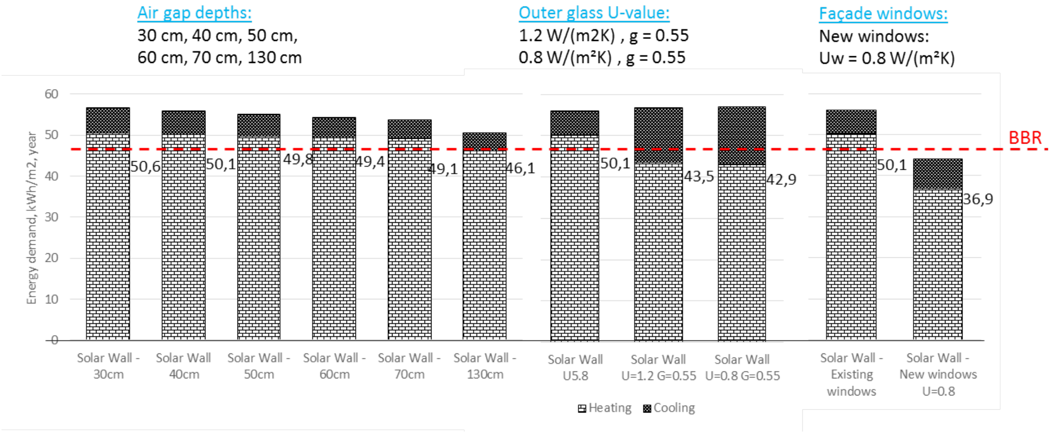


FIG. 10 Impact on energy balance through parametric variations in "solar wall" (S2), middle apartment.

5 CONCLUSIONS

The analyses of the reference cases (heat balances of the apartments) show that heat losses through walls are less significant than heat losses from air flow and low quality windows. However, it has to be noted that these results are depending on the apartment geometry and external surface area. The results may differ if these factors change: Air exchange (ventilation) holds the biggest share in heat losses for both reference cases. Hereby, it is neglectable whether the apartment has two external surfaces (two vertical wall sections at the middle apartment) or four external surfaces (roof, three vertical wall sections at the corner apartment). In contradiction, the variations in heat losses from walls and floors, thermal bridges and windows are high and thus depend strongly on the surface area of the exposed envelope. This allows the assumption that if scaling up the energy performance calculation to the whole building, the roof and basement may play a stronger role in the energy saving strategy, depending on their surface area share. Furthermore, it is assumed that thermal façade qualities impact units (apartment level) differently depending on the location on the building surface. A differentiated view on façades, such a critical corner situations, may be worth considering in regards to apply various passive measures. A detailed study of this aspect will follow.

The thermal buffer zone or "winter garden" strategy on the southern facade reduces the space heating demand by 30% (middle apartment) and 18% (corner apartment), assuming the door between the apartment and the winter garden is always closed. This is probably not the case in a real apartment, and thus, must be considered in follow-up assessments. Adding new windows to the strategy reduces the space heating energy demand by 44% and 27% respectively. Thus, a combination is recommended. A specific benefit of winter gardens is seen in the gained living space that provides a longer usage as thermally comfortable zone without extra heating or cooling. The "solar wall" strategy reduces the space heating energy demand by 18% (middle apartment) and 24% (corner apartment). Combining the solar wall with upgraded windows promises as well higher energy savings. The solar wall may contribute to preservation requirements as it can be transparent and thus, keeps the original appearance. The application of either strategy depends on the exposed surface area – in cases where balconies cover a substantial part of the facade surface, the necessarity of solar walls should be evaluated.

The assessments show that the required energy standard and thermal quality can be achieved by passive measures under certain circumstances (cp. middle apartment). This outcome will be used for further development of the multi-active façade by considering gained heat energy (preheated air) for heat recovery in mechanical ventilation or directly for thermal indoor comfort. Apart from the performance potential, the passive measures also offer the potential of embedding active systems and turn the façade into a multi-active system. The best combinations will be assessed, because it is assumed that an integration of active solar technologies will again influence the performance behavior of the passive strategy.

The presented results are part of initial assessments for the concept development of the multi-active façade. The goal was to investigate the performance potential of passive, well-known façade constructions. Knowing the influencing design parameters better now, they can be considered more effectively for the concept development. However, further analyses must be carried out at a more detailed level, such as thermal comfort effects, moisture and thermal bridges calculations, and the total energy savings potential for the building. The next step is to merge the results from the "active measures" simulations within the study that is focusing on ventilation ducts integration into the façade (Bernardo, et al., 2016) and develop a joint design. The design concept will be also optimized in regards to economic usability and added value benefits.

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