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JANUARY 19TH 2017 – MUNICH

POWERSKIN CONFERENCE

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The Building Skin has evolved enormously over the past decades. Energy performance and environmental quality of buildings are significantly determined by the building envelope. The façade has experienced a change in its role as an adaptive climate control system that leverages the synergies between form, material, mechanical and energy systems in an integrated design.

The PowerSkin Conference aims to address the role of building skins to accomplish a carbon neutral building stock. Topics such as building operation, embodied energy, energy generation and storage in context of façades, structure and environment are considered.

Three main themes will be showcased in presentations of recent scientific research and developments as well as projects related to building skins from the perspectives of material, technology and design:

Environment – Façades or elements of façades which aim for the provision of highly comfortable surroundings where environmental control strategies as well as energy generation and/or storage are integral part of an active skin.

Façade Design – The building envelope as an interface for the interaction between indoor and outdoor environment. This topic is focused on function and energy performance, technical development and material properties.

Façade Engineering – New concepts, accomplished projects, and visions for the interaction between building structure, envelope and energy technologies.

TU München, Prof. Dipl.-Ing. Thomas Auer, **TU Darmstadt**, Prof. Dr. Ing. Jens Schneider and **TU Delft**, Prof. Dr.-Ing. Ulrich Knaack are organizing the PowerSkin Conference in collaboration with BAU 2017. It is the first event of a biennial series. On January 19th, 2017 architects, engineers and scientists present their latest developments and research projects for public discussion.

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A zero-energy refurbishment solution for residential apartment buildings by applying an integrated, prefabricated façade module

Thaleia Konstantinou¹, Olivia Guerra-Santin², Juan Azcarate-Aguerre¹, Tillmann Klein¹, Sacha Silvester²

- 1 Department of Architectural Engineering and Technology/ Faculty of Architecture and the Built Environment / Delft University of Technology, Julianalaan 134, 2628 BL, Delft, the Netherlands, Email: t.konstantinou@tudelft.nl*, J.F.AzcarateAguerre@tudelft.nl, t.klein@tudelft.nl
- 2 Department of Industrial Design / Faculty of Industrial Design Engineering / Delft University of Technology, Landbergstraat 15, 2628 CE Delft, the Netherlands, Email: O.GuerraSantin@tudelft.nl, S.Silvester@tudelft.nl

Abstract

The ambition to renovate the post-war building stock to an energy-neutral quality is getting a lot of attention in social housing association and other institutional owners, financial institutions and users. The Energy Agreement for Sustainable Growth indicates that 300.000 dwellings have to be renovated in the Netherlands annually. An effective renovation plan has to be long-term, target the deep transformation of the existing building stock, and to significantly improve its actual energy performance towards nearly zero energy levels. This level of energy saving typically requires a holistic approach, viewing the renovation as a package of measures working together.

Even though the need for refurbishment is urgent, the rate of renovation and the resulting energy savings are relatively low. Main barriers identified are related to the available investment funds, awareness, advice and skills and the separation of expenditure and benefit.

To address these issues, the paper presents a prefabricated and integrated façade module that gives the possibility to improve the current energy performance up to zero energy, while ensuring minimum disturbance for the occupants, during and after the renovation. Given that the design and installation take this constrain into consideration, it is possible to reach zero energy by adding more efficient installations and energy generation, as well as taking possible behavioural changes into account. Moreover, the paper evaluates such a zero-energy refurbishment in terms of financial feasibility. The proposed approach results in a feasible solution, which achieves high energy savings and addresses the complex issue of integrated refurbishment.

Keywords

refurbishment, residential building, zero-energy, prefabrication, façade module

1 INTRODUCTION

The ambition to renovate the post-war building stock to an energy-neutral quality is getting a lot of attention of social housing corporations and other institutional owners, financial institutions and users. Studies have reported huge potential for energy savings, improved health and comfort of the occupants, elimination of fuel poverty and job creation lay in the upgrade of existing buildings. The Energy Agreement for Sustainable Growth (SER, 2013) (in accordance with the Energy Performance of Buildings Directive adopted by the European Union (DIRECTIVE, 2010/31/EU) to improve the Dutch building stock to energy neutral) indicates that 300.000 dwellings have to be renovated in the Netherlands annually.

The post-war building stock, which represents 33% of residential buildings (CBS, 2015), is particularly relevant for refurbishment. Despite its varied mix of construction types, from traditional to modern, from low rise to high-rise, it has as a common characteristic that the buildings were generally poorly insulated at the time of construction and that there is a need for renovation (Itard & Meijer, 2008). Due to the circumstances of its development, the post-war housing stock has specific characteristics in terms of neighbourhood design, construction and problems. Moreover, being 50 years old, the building envelope has reached end of life while structure is in general sound (Andeweg et al., 2007). A number of facade solutions have been developed in recent years to solve the problem of large-scale renovation of housing (Sijpheer et al., 2016). In the Netherlands, front-running housing associations have the ambition to achieve an energy-neutral renovation approach, and so, some facade solutions aim at energy neutrality, such as the Stroomversnelling (2013). However, few address the complexity of multi-family rental dwellings and more importantly, the complexity of user behaviour in the actual performance of the buildings. To reach the ambition of the Dutch government for energy savings, it is necessary to develop products and processes for renovating the multi-family apartment blocks within the existing housing stock. Previous experiences showed that there is still an enormous challenge to fulfil the ambition to make the porch apartment energy neutral for an affordable price and in an acceptable way for the residents (Silvester, 1996; Winter, 1993).

In this context, the "2ndSkin" project brings together different stakeholders of the building industry, aiming at integrating their expertise and objectives into an innovative building retrofitting concept that achieves zero energy use of a dwelling, while offering up-scaling possibilities. The hypothesis of the project is that zero-energy refurbishment can be promoted and its rate can increase if the application of prefabricated facade modules, which increase the installation speed and minimise disturbance for the occupants. Moreover, the objective is not only to find a successful refurbishment strategy for a specific building type, but also to determine the framework within which the proposed solution can be adjusted. The focus of the 2ndSkin project is the low-rise, multi-family residential buildings, accessed by separate stairwells per 6-8 apartments. This type of building represents about 300.000 houses. Nevertheless, the concept of the renovation can be applicable in apartment blocks of other than the post-war period, increasing significantly the impact of the solution with a potential target of 875.000 apartment blocks in the Netherlands (Voorbeeldwoningen, 2011).

To address these issues, the paper presents a prefabricated and integrated facade module that gives the possibility to improve the current energy performance up to zero energy, while ensuring minimum disturbance for the occupants, during and after the renovation. Given that the design and installation take this constrain into consideration, it is possible to reach zero energy by adding more efficient installations and energy generation, as well as taking possible behavioural changes into account. The technical upgrade of the proposed refurbishment solution is explained. Moreover, energy calculations to determine the energy generated needed to reach zero-energy are presented. Finally, the paper evaluates such a zero-energy refurbishment in terms of financial feasibility.

2 THE 2NDSKIN REFURBISHMENT CONCEPT

The design of the renovation solution focuses on a reference building that has been identified as a type which, given the poor thermal quality of the construction and the number of units in the Netherlands, offers the best market and carbon emission reduction opportunities. To define the reference building, literature research and an on-site investigation was carried out in the area of Rotterdam-Zuid. Systematic documentation of the building characteristics was conducted during on-site visits. A reference building type was determined, which is considered the most common type in the area of investigation while having typical characteristics found in the building stock analysis. The reference building, as shown in fig.1, is a mid-rise apartment block with central staircase, accessible in the front façade, leading to two apartments per floor. Its construction characteristics are massive concrete wall and brick cladding with an intervening, non-insulated cavity, reinforced concrete slabs, continuous to the balconies, and large windows, incorporating lightweight parapet.

The 2ndSkin design principle to reach zero-energy dwellings is based on preventing the use of energy, then use sustainable energy sources as widely as possible (renewable) and, finally, if the use of finite (fossil) energy sources is inevitable, they must be used efficiently and compensated with 100% renewable energy (AgentschapNL, 2013). The concept needs to combine the building envelope upgrade, the use of efficient building systems and the generation of energy. Moreover, both physical condition and performance of the building need to be upgraded with the minimum disturbance to the interior, so that the occupants do not have to be relocated during the construction. As part of the approach, requirement for the performance, such as building envelope thermal conductivity, ventilation rates etc., as well as standards for the occupant role, position and disturbance during and after renovation were developed (Konstantinou et al., 2015).

To meet the requirement of zero-energy consumption, the solution consists of three basic elements: Increase the thermal resistance of the building envelope, including walls, windows and roof, installing heat recovery ventilation, to reduce energy demand for heating while providing adequate indoor air quality (IAQ), and use photovoltaic (PV) panels to generate energy. The proposed renovation solution results in the required thermal characteristics of the envelope, in terms of thermal resistance and infiltration, as well as providing an updated the building services' performance, as summarised in Table 1. These benchmark values were also used in the energy simulation, explained in evaluation section of the paper.



FIG. 1 The reference building

ELEMENT	SPECIFICATIONS
Roof	Rc 4.5
Facade elements	Rc 6.5
Ground floor	Rc 3.5
Window frames	Rc 0.8
Double glazing	U 0.8 (1.135) g _g 0.8
Infiltration	0.4 dm ³ /s.m ²
Ventilation system	Balanced ventilation efficiency 0.75

TABLE 1 Input for building simulation software after renovation of building

Next to minimising the energy use, the renovation needs to address the issues of occupants' position during and after renovation. The 2ndSkin refurbishment approach aims at eliminating the energy demand, while minimising construction time and occupants' disturbance and the owner needs to acquire the acceptance of at least 70% tenants, which is needed legally in the Netherlands for the renovation to proceed. To this end, the suggested construction process differs from conventional renovation process in the fact that the technology is seen as independent from the underlying structure of the building, and integrated into the facade. The system integrates heating and ventilation into the skin (fig. 2) so it can be easily accessible from the outside of the building, therefore facilitating the maintenance. Heat recovery ventilation units are placed on the rooftop, while the ventilation pipes are integrated in an insulation board, attached to the sandwich panel that covers the opaque part of the existing façade. Regarding heating, the concept includes an all-electric decentral heat pump system for heating and DHW, with a 200litre buffer tank, per apartment. One of the possible locations in the façade of the staircase. The flexibility of the system and the accessibility from the outside the dwellings allows maintenance and upgrading the installations in further phases of the development during the lifetime of the building, thus increasing the time-span of the initial investment.

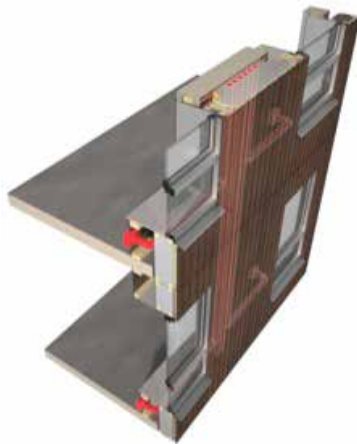


FIG. 2 Detailed 3d section, showing the ventilation pipes integration.

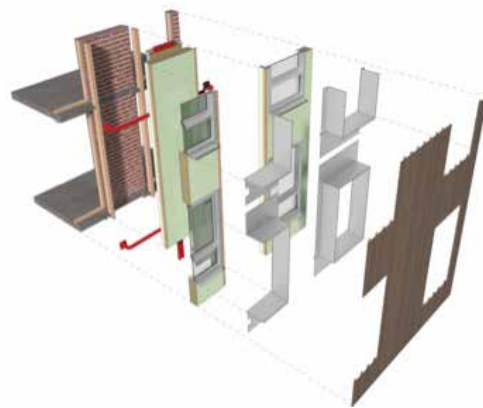


FIG. 3 The sequence of the prefabricated elements installation (from the left to the right).






SCENARIO	ORIENTATION	TYPE OF ROOF	PRODUCTION IN ROOF (KWH/YEAR/APARTMENT)		TOTAL ENERGY PRODUCTION INCLUDING FACADES / APARTMENT	
			PORCH 6 UNITS	PORCH 8 UNITS	PORCH 6 UNITS	PORCH 8 UNITS
EW_flat	East-West		1738.4	1303.8	2553.37	1915.03
NS_flat	North-South		1299.2	974.4	1739.87	1110.41
NS_flat_b	North-South		3257.4	2443.1	3698.07	2579.11
EW_pitch	East-West		1738.4	1303.8	2553.37	1915.03
NS_pitch	North-South		869.2	651.9	1309.87	787.91

TABLE 2 Total energy production per apartment in kWh/year per building/roof scenario

To achieve minimum disturbance, a starting point of the design was for the facade module to be prefabricated. During the renovation process, firstly the building envelope is insulated with prefabricated sandwich panels. Moreover, existing windows are replaced. The prefabricated, floor-height, sandwich panels, featuring new windows and integrated services pipes, are attached to the substructure that consists of wooden posts connected to external facet of the existing structures through steel U profiles. PV panels are installed on the roof, while installations to improve ventilation are also integrated in the rooftop. The ventilation pipes are integrated in an insulation board, attached to the sandwich panel that covers the opaque part of the existing façade. This panel is installed first and it comes to the building site as one piece, in order to minimise the connections between the pipes. The panels containing the windows are connected to the wooden posts subsequently.

Finally, photovoltaic panels are also integrated in the skin in order to reach the zero energy targets. Energy generation was calculated for five scenarios, taking into account the orientation of the building, the type of roof, and the possibility to provide an attic for installations. The five scenarios are: North-South orientation with flat roof, North-South orientation with pitched roof, North-West orientation with flat roof with an attic for installations, East-West orientation with flat roof, and East-West orientation with pitched roof.

Calculations were made assuming the use of a CSun255-60P solar panel (CSUN, 2014). Results of the calculations are shown in Table 2. The energy generated in the roof of the building is divided by the number of apartments in the buildings. Such building types are usually either three or four-floor high. Given that the 2ndSkin strategy could be applied to both possibilities, we studied the results of the calculations considering both scenarios. The energy generated per apartment can be seen in the right-side columns of Table 2. The total energy production takes into account the potential of energy generation using the opaque parts of the façade.

3 EVALUATION OF ENERGY PERFORMANCE AND FINANCIAL FEASIBILITY

After the refurbishment concept was developed, it needed to be evaluated. The evaluation is based, firstly, on simulating the reduced energy performance, after the renovation and defines the scenario in which this demand can be compensated with the energy generation. Furthermore, the payback time of the initial investment is calculated.

3.1 ENERGY PERFORMANCE

In this section, the energy calculations are presented. The simulation takes into account both building-related (heating, ventilation, lighting) and user-related (domestic hot water, appliances) energy consumption, as it was defined in the requirements (Konstantinou et al., 2015). The building related energy is mostly The dynamic building simulations were carried out with Bink software (BINKSoftware, 2015). Each room is modelled as one thermal zone, as we wish to investigate the effect of the room temperatures and spaces heated have on energy demand. Natural ventilation is only considered for the summer period, when external temperature reaches 18°C or internal temperature exceeds 25oC. Thus, natural ventilation does not have an effect on heating demand in the simulations.

For inputs regarding heating demand, two behavioural scenarios were used. In the first scenario, the occupants continue their pre-renovation state-of-the-art behaviour, based on the statistical analysis of the WoON dataset (WoON2012, 2013), reflecting the lifestyle and preferences of Dutch households. In the second post-renovation scenario, we assumed an adapted behaviour, based on a better control on the heating system, by heating only occupied spaces and using a setback in the thermostat during unoccupied hours and night-time.

The internal heat gains are integrated into the simulation model in two ways. Artificial lighting is defined as specific artificial use patterns. Internal heat gains for appliances and electric equipment are calculated based on statistical data on electricity consumption per household type in reference dwellings (WoON dataset).

A second set of simulations were carried out assuming a change on behaviour after the renovation. In this scenario, we consider behavioural changes to the current situation, namely increasing the indoor temperature, and assuming a better control on the heating system, by heating only occupied spaces and using a setback in the thermostat during the night and during absent hours.

The energy demand for domestic hot water was calculated, assuming five minutes showers per person per day, one and a half minutes using the sink per person per day, and using the kitchen sink for one minute per household per day. In addition, a scenario considering the use of a heat recovery shower was also calculated. According to specifications, these systems can save up to 100 m³ gas /year per household (ISO7730, 2005) or 30% of the energy use. In order to take into account the household size, we use the value of 30% reduction.

Fig. 4 shows a comparison between the energy (gas and electricity) consumed in the reference dwellings (based on WoON statistical (WoON2012, 2013)), and calculated energy demand (for heating, domestic hot water and electricity) based on the two scenarios for behaviour and electric appliances explained above:

- Scenario 1: inefficient appliances and unchanged behaviour, and
- Scenario 2: efficient appliances and adapted behaviour.

Inefficient appliances and behaviours is based on the electricity demand calculated using the energy consumption of inefficient appliances, and the pre-renovation behaviour and they are average for different household types (Guerra-Santin et al., 2016). Efficient appliances and behaviours scenario is based on the electricity demand calculated using the energy consumption of efficient appliances, and the post-renovation behaviour. The figure shows that the energy demand of the 2ndSkin technical solution (i.e. only renovation without behavioural change or change for more efficient appliances) is reduced by 66%. If we also consider a scenario with improved appliances and behaviours, we reach a reduction on energy demand of 78%. If considering the heating demand alone, which accounts for the largest percentage of energy consumption in the building stock (BPIE, 2011), it is minimised, with a reduction of 93% after the refurbishment solution.

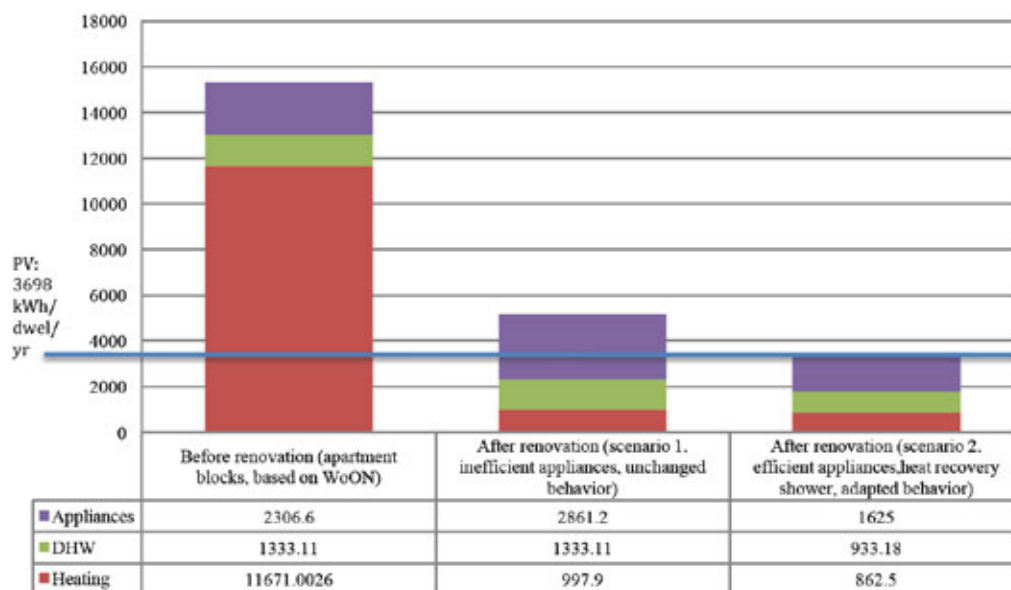


FIG. 4 Energy demand in kWh/dwelling/ year, calculated based on inefficient and efficient appliances and behaviours in comparison to the statistical energy consumption in reference dwellings. This explains the difference in the energy use for appliances between statistical and assumed appliances use. The blue line indicates the maximum electricity production in kWh/dwelling/year.

3.2 ZERO-ENERGY POTENTIAL

The comparison of shows that only in the best case scenario for energy generation using PV panels on the roof (Table 2), which is a porch building with 6 apartments, and with the possibility to build an attic structure to support the PV panels, the energy generated barely covers the energy demand when domestic hot water and electricity are considered, considering the energy efficient scenario. Considering the inefficient scenario, the best-case energy generated covers half of the demand. For an east-west orientation, the total energy demand can be almost met with the energy production on-site for buildings with three levels (six housing units). To cover the energy demand of north-south orientations without attic provision, and apartment buildings with four levels, an extra surface of 12-20m² of panels is needed. Moreover, in all other roof scenarios, the energy generated only covers the heating demand in all cases, except in four-storey buildings with North-South orientation and pitched roof.

3.3 FINANCIAL ASSESSMENT

For the financial assessment of the solution, first the initial investment was calculated. The costs included the façade module production and construction, roof insulation, building services units and PV panels, as well as preoperational works on the building site, such as removal of the components to be replaced and new foundations for the façade module. The façade module and its installation accounted approximately for 40% of the initial investment.

In order to determine the financial payback time of a full 2ndskin renovation, a comparison has been made between the benchmark energetic consumption of a typical case-study dwelling, and the simulated consumption of the unit after renovation. According to previous studies (Guerra Santin et al., 2015), the current energy use of a model dwelling under average occupancy is approximately 1.200m³ of gas (or nearly 12.000 kWh of thermal energy) and 2.300kWh of electric energy. Using energy price values for the Netherlands in 2015, according to data from the European Committee (Eurostat, 2016), this adds up to estimated yearly costs of 1.340 euros. Considering energy prices in the last two decades have been subject to an upward trend which averages 4.5% per year (CBS, 2012) the total cost of energy per dwelling in the coming 25 years could add up to nearly €60.000.

A simple payback analysis, balancing only the initial investment required for the renovation against the potential energy savings resulting from it, shows that a complete 2ndSkin renovation would have a payback time of just over 25 years, or a simple average rate of return of 4% per year. This takes into account the best scenario, for the energy production through PV, when zero-energy consumption is achieved. Partial renovations, which include only certain steps in the 2ndSkin renovation strategy, are shown to be unfeasible in their current form, as their payback time exceeds the 40 year period. While the current low cost of energy renders short-term returns unattractive, the performance of the investment is most likely to experience significant gains over time due to the high compound increase in energy prices. The 4% RoI value for a complete renovation is also most likely to improve if we consider additional financial parameters such as the resulting increase in the rent price and market value of the property, resilience against fluctuations in energy costs, and access to green subsidies or other forms of low-cost financing, even after taking into account negative factors such as general inflation rate and the client's cost of capital.

4 CONCLUSION

Within the framework of the research project 2ndSkin, which aims at the development of a refurbishment approach for zero energy renovation of apartments, the paper discussed the technical solution, the construction process and evaluated the energy performance after renovation and the financial aspects. The project's main requirements are zero-energy demand and minimum disturbance for the occupants during the renovation. The proposed solution consists of prefabricated modules, in order to reduce the construction time, that integrate high insulation for wall and windows, together with ventilation pipes. In this way, both the envelope and the building services are upgraded. Furthermore, energy generation is necessary to reach the zero-energy target, energy is generated with PV cells on the roof and potentially the façade.

Taking into account the resulting energy demand after renovation (Fig. 4) and the possibilities for energy generation, using PV panels on the roof (Table 2), we conclude that the zero-energy target can indeed be met, under specific conditions. The results show that the total energy demand can only be covered by energy production with the provision of an attic (north-south orientation) on up to three levels porch buildings. Therefore, extra surface of photovoltaic panels would be necessary to achieve the zero-on-the-meter solution only with photovoltaic panels. Façade surfaces could potentially be used to cover the rest of the energy generation required, depending on the orientation of the building. Nevertheless, the building-related energy consumption for heating can be easily covered, as proposed solution significantly reduced the demand.

The overall solution can, hence, be an answer to the need for upgrade the building stock to provide comfort and low energy demand, with minimum occupants disturbance. The construction system is based on prefabrication, maintaining still some degree of flexibility, such as different type and size of windows or different cladding material. In this way, the concept aims at higher acceptability and, thus, applicability.

Further research will include the specific design and prototyping for different buildings. Moreover, the design adaptations can be extrapolated for buildings in a European level that have similarities in the key characteristics determined by the study, providing an answer to the necessary energy upgrade of the European building stock. The proven applicability of the concept for different building types is important, because the uptake of the zero-energy refurbishment determines the CO₂ mitigation and the potential of reaching the decarbonisation targets.

Most importantly, the market intake of such renovation is currently very slow, as housing associations are reluctant to invest the increased cost of a zero-energy refurbishment, despite the energy savings and the benefits for the occupants. A more complete financial breakdown of this case-study concept, as well as options to lower the initial investment, such as subsidies or alternative business models, need to be further elaborated, in order to provide insights for a more attractive business case.

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