

AWARD WINNING FIRST HUNGARIAN ACTIVE HOUSE REFURBISHMENT

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Abstract: The First Hungarian Active House refurbishment won the Active House Award and the Energy Globe Hungary prize in 2017. This paper provides insight into the renewal design process of the typical home from the 70's under disadvantageous site conditions. Dynamic thermal simulations helped to gain insight into space organization and building envelope concepts and their effects on comfort and energy performance. The Active House Standard was applied to evaluate the calculation results. The most advantageous concept was selected for final design elaboration and construction. The implemented building proved that in the refurbishment process it is possible to achieve highest level of efficiency in operation energy consumption with positive yearly balance by simultaneously being able to rearrange the complete interior space and as a consequence the building shape and envelope into a competitive design at international level.

Keywords: Active house, Simulation, Thermal comfort, Daylight, Air quality, Energy-positive

1. Background

Globally, heating, cooling and electricity in buildings account for 40% of all energy used [1], hence the building sector is considered as one of the main improvement target to address EU's 2020 sustainability aims [2]. Further, ambitious legislations regulate buildings' Green-House Gas (GHG) emissions being reduced by 80% until 2050 [3] and prescribe the achievement of Net Zero Energy Buildings (NZEBS). For this goal, the development of building energy efficiency is widely investigated, by reducing demand,

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applying efficient Heating, Ventilating and Air Conditioning (HVAC) systems and using renewables [4]-[6]. The ground-breaking passive-house standard was elaborated in the 'LänderDreiEck' of Germany, Switzerland and Austria to address the fossil energy supply insecurity, heating energy demand reduction issues and construction industry challenges, which tried to implement energy ordinances first. However, passive-house, due to its systemic rudiments, has constant, invariant physical properties (e.g. in the building envelope); hence, reaction on external climate impacts, as well as reaction on changes from inside is very limited [7]. Consequently, the four-season aspect, meaning the time dependent assessment of physical processes is missing. In addition, energy issues are not the only key factor in reaching the desired sustainability level: several studies deal at gradually deepened level with thermal and further comfort parameters (e.g. visual comfort) [8]. Regrettably, regulations only focus on winter energy requirements in residential building structures and components, creating the 'thermos jug' effect in buildings. This often leads to increased cooling demand for instance in office buildings. Regarding the international green building standards, mostly measurable comfort and energy parameter based evaluations and labels are provided, without considering further socio-cultural, user behavioral [9] and environmental parameters [10]. This is important to mention that proliferation of quantification in sustainability values (e.g. energy usage, indoor comfort, settlement scaled energy and grid modeling) is primarily based on social processes [11]. Current certification systems of Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM) and German Green Building Council (DGNB) assessments include for instance already extended scopes of environmental and constructional aspects, yet these evaluations were developed with large-scaled buildings in mind. Therefore, these certifications are not practical for small-scaled projects (e.g. family houses, small offices, industrial or commercial facilities) due to their cost-intensity.

To overcome these shortcomings, the Active House Standard (AHS) is elaborated [12], using the knowledge of passive-house, while making further development at the same time. AHS is the further development of previous building energy standards [13] and places its gravity point at the users, today's indoor generation. It proposes a gap-filling framework, capable to incorporate comfort, energy and environmental aspects of a building in a transparent and multidimensional way. This particular paper demonstrates the first Hungarian refurbishment as an Active House (AH), and provides answers to following questions: How efficiently can the AH radar tool support the early design stages? How far can the limits of a typical Hungarian family house refurbishment pushed with the goal to develop an energy-positive building by employing maximum possible efficiency, comfort and health strengthening design measures under disadvantageous site conditions (orientation, neighborhood, solar radiation distribution, etc.), while also meeting the functional and design requirements of today's age? How great are the energy performance improvements after renovation? What are the main challenges and 'tuning-limits' in design and construction for one of the most characteristic Hungarian family house from the 70's?

2. Definition of active house

The Active House Association provides specifications and guidelines [12] for the AHS, including a post-processing-tool in form of a radar graph calculator with multiple results. It serves as a design guide, as well as a decision-support and evaluation tool for design-proposals, further, implemented buildings can be assessed and certified as well.

The radar tool helps picturing performance of design-solutions by simultaneously displaying the ‘design Code’ in the field of comfort-energy-environment. The evaluation is done in the following sub-categories: thermal (operative temperature) and visual comfort (daylight factor), air quality (CO₂-concentration), energy demand, origin of energy supply and primary energy performance, as well as freshwater consumption, environmental loads and sustainable structures. The evaluation of an active house is based on the nine quantitative sub-criteria parameters mentioned, each split into four levels (categories) of performance, where one represents the highest performance and four the minimum requirement to be an AH. Each parameter is calculated in accordance with the AH specifications. The radar method enables balancing between the contradictory operational energy consumption and the embodied energies and their impact on the environment during the use-phase and the construction phase, respectively Life Cycle Assessment (LCA approach). This means a conversion from energy-efficiency to environment-efficiency [14].

3. The ‘reborn home’ project

Composed from the most widely applied structures and materials in the 60s - 70s with a simple ashlar-shape and a saddle roof, it was conceived as a demonstrative residential retrofitting example of an energy-positive AH home for Middle-European climate. Erected in 1974, the common building type (*Fig. 1*) possesses 30 cm thick brick walls, box-type wood framework windows with multiple structural thermal bridges [15] and prefabricated concrete beams and slag filled slabs.



Fig. 1. The single-family housing before retrofitting, street view (left, middle),

Accredited Environment Protection Laboratory tests [16] revealed that the slag had 225% higher activity concentration index than the maximum threshold according to EU-112 directive. Radium content accounted approx. 10-times and thorium content approx. 4-times higher concentration than in the case of the earth crust. The statically weak roof truss was covered with asbestos panels. An electric boiler generated Domestic Hot

Water (DHW) and an approx. 30 years old gas boiler and water radiators ensured low thermal comfort. The roof structures, slab filling and the inefficient, fossil driven services systems had to be removed. The old room layout could not meet the contractor's requirements.

The planning phase is one of the most critical phases in realizing a building. Based on the complexity of determining boundary conditions and influencing factors, there can be more versions of design solutions, aiming the optimal solution from different viewpoints. In order to find the most optimal solution in form of a combination compromise, it is recommended to compose multiple building cases to examine and narrow the boundaries of the optimal AH concept. The Energia Design[®] (ED) method was applied to create the possible optimal solutions. Firstly, a basic model is created based on given conditions, secondly, four model variations were developed as shown in Fig. 2, according to different passive climate strategies and simplified energy balance calculations.



Fig. 2. 3D blueprint plan models: 'basic refurbishment', 'semi-detached', 'reborn home', 'zebra'

The 'basic refurbishment' model retained the existing room organization; external thermal insulation in roof, wall and floor structures and applied window renewal. Garage (G), attic (A) and HVAC central are unconditioned. The 'semi-detached' house divides the interior into two identical apartments in ground and first floor with an unconditioned staircase (S), attic and double garage. The version of 'reborn home' has an integrated solar chimney gallery at the SouthEast (SE) oriented façade and a central concrete staircase, which divide the interior into a SouthWest (SW) and a NorthEast (NE) oriented partition. SW section contains kitchen (K) on ground floor and office (O)

on first floor, and the NE section integrates living room (L) on ground floor and bedroom-bath (Be, Ba) on first floor. The roof is specifically shaped to become a N- and S-faced surface with optimal inclination for crystalline PhotoVoltaic (PV) modules. The attic is indirectly tempered through the gallery, while the garage is unconditioned. The ‘zebra’ model’s east and west façades and roof consist of alternating transparent and opaque stripes to ensure high level of daylight all year long. The staircase is similar to the ‘basic refurbishment’ model’s solution. The attic is indirectly tempered through the staircase-gallery, while the garage is unconditioned.

4. Results

Through sketch plan stage thermal simulations, the model versions have undergone a comparative analysis to detect the most advantageous performance. Spaces and building body geometry with according opaque and transparent structures were modeled and calculated in 3D, via simulation framework of IDA ICE Code. The building envelope was retrofitted with thermal insulation at the level of the minimum requirement pursuant to the national regulation [17]. A thermally untreated supply and exhaust air volume flow of 2 l/sm² ensured appropriate Air CHange (ACH) in each room. The models were operated without passive ventilation, specified heat transfer, as well as heat generation systems, since HVAC system performance is not relevant in this stage of design investigation (COP 1, EER 1). Standard 0.1 occupant metabolic rate (1.0 Met and 0.85 ± 0.25 clothing (clo)), light (100 W/piece internal heat production) and equipment (100 W/piece internal heat production) per m² net floor space were set. Using these modeling technique and settings, crucial differences between sketch plan concept versions can be adequately assessed, without sacrificing calculation and modeling time. The comfort evaluation is detailed in *Fig. 3* according to AH radar assessment method with classification scores. Visual comfort is based on Daylight Factor (DF) calculations under mixed sky conditions [18] in the main spaces.

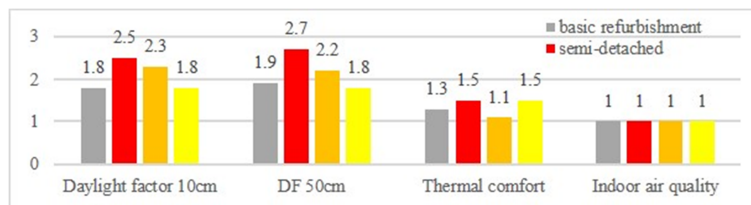


Fig. 3. Comfort evaluation of sketch plan concepts

The end score is achieved by calculating the area-weighted mean score of DF in the rooms. The four main spaces (living room, kitchen and children’s rooms) were analyzed pursuant to AHS. The visual comfort results delivered the largest deviation between the models. Two different settings in DF simulations were calculated: areas in a distance of 10 cm from the enclosing walls to assess the complete area and 50 cm distance to keep the AHS prerequisite, respectively. The more homogenous window arrangement is planned, the higher average DF can be achieved, as it is shown in the ‘basic

refurbishment' and the 'zebra' models (*Fig. 4*). The Window-to-Wall Ratio (WWR) has less effect on the DF performance than the arrangement and form ratio of the glazing.

The simulated operative temperatures (thermal comfort) and CO₂-concentration Indoor Air Quality (IAQ) end scores are occupancy rated hourly mean values in all calculated rooms. The highest temperature limits apply when outdoor temperature is more than 12 °C, while minimum limits are considered under this level. Thermal comfort values must meet the requirements during greater than 95% of the occupied time. Best thermal comfort is given in the 'reborn home' model but all models perform at a very good level (1.1 - 1.5). Reason for that is the same use and size of the different rooms in the versions with identical heating-cooling set-points (21-25 °C) and capacity. All models performed the same high level of indoor air quality thanks to the appropriate level of mechanical ACH.

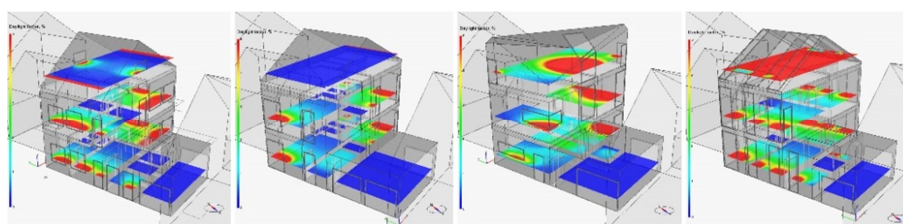


Fig. 4. DF distribution in the sketch plan models: 'basic refurbishment', 'semi-detached', 'reborn home', 'zebra'

Since the various sketch plan concepts comprise significantly different heated-cooled and ventilated spaces (see section 3.2), the energy assessment is calculated in area-specific values (*Fig. 5*). The heated floor space in reborn home and zebra models is 25-50% higher than it is the case of the other models, since they include direct heated (kitchen, bath, living room, office) and indirect heated (attic, staircase) spaces due to large openings between the zones (*Fig. 6*). These differences are the consequences of the space arrangement alterations in the concepts. In addition, the glazed façade partition changes accordingly, resulting in different wall-window ratio (WWR) and architectural appearance in the models. Consequently, the energy demand and heat balance values are calculated with the according specific floor space dimension: for instance heating demand is divided by the floor space of the heated zones, etc.

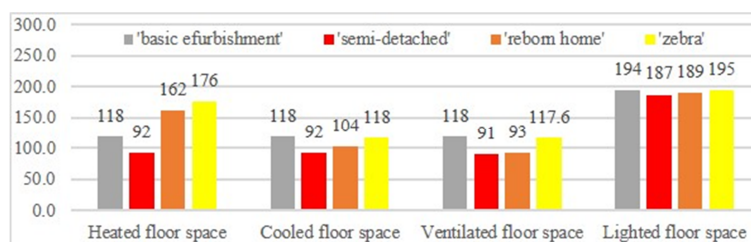


Fig. 5. Conditioned floor space distribution of sketch plan concepts [m²]

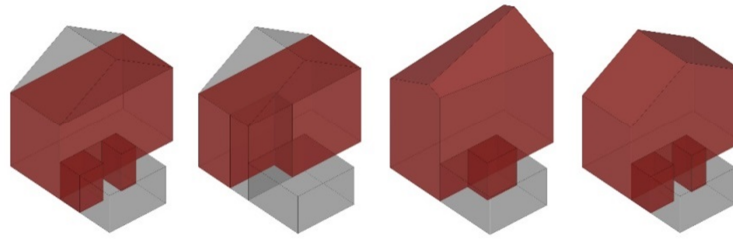


Fig. 6. Heated areas in the sketch plan models: 'basic refurbishment', 'semi-detached', 'reborn home', 'zebra'

Fig. 7 assesses the used energy demand of the models. Taking the 'basic refurbishment' version as a reference, the 'reborn home' and 'zebra' models perform 37% and 27.7% less heating demand. The cooling energy requirement of the models changes only marginally (within a 12% range), while ventilation and lighting demand remains the same, since summer solar loads and internal gains are relatively similar in the models.

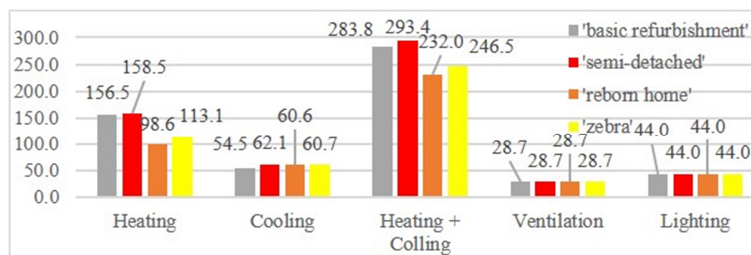


Fig. 7. Final energy evaluation of sketch plan concepts [kWh/m²a]

The heating performance is proportional to the heat loss through the envelope and thermal bridges as shown in the heat balance evaluation in Fig. 8. Significantly lower specific losses evolved due to the greater conditioned zone partitions in 'reborn home' and 'zebra' models. Similar differences are to observe in infiltration losses due to the larger heated zone sections. While the heat losses via glazed envelope surfaces are neutralized by solar gains - and hence relatively similar cooling demand in the models) - the heat losses from ventilation airflow are nearly similar in the models due to identical floor space specific ventilation rates (l/sm²). Lighting (as well as occupants and equipment) generated the same internal gains, because the total lighted and occupied spaces and the operation schedules are nearly similar in all models.

The WWR values in the models give the only information about the LCA level of the envelope structures: the 'zebra' model (20.1%) has approx. 100% more glazing than in the rest of the models (basic refurbishment 8.7%; semi-detached 7.6%; reborn home 11.6%), with according higher LCA-equivalents.

Based on the evaluation, the 'reborn home' model possess the best IAQ and thermal comfort, moreover it achieved second place in visual comfort, as well as best energy efficiency performance. In addition, the concept of 'reborn home' was the most

applicable to the user preferences in terms of functionality and architectural appearance, therefore this sketch plan model version was selected for processing approval and final plans.



Fig. 8. Heat balance of the 4 sketch plan models [kWh/m²a]

5. Construction of the prototype building – passive and active measures

The main goal during the approval and final planning was the application of as many as possible, reasonable, the building's situation matching passive design elements (Fig. 9, top) for minimizing heat losses and summer solar loads and maximizing winter solar gains.

Climate zoning divides the unconditioned garage (buffer zone) from the conditioned housing section, and a complete functional conversion sets all rooms around an internal staircase with a southern oriented, fully glazed gallery in order to ensure solar gains as a winter garden and maximum daylight level in the central, darker section of the building. A Finnish-Russian masonry heater combination is built of recycled bricks serves as a reserve-heating and kitchen oven. This heater and the thermal activated mass of the concrete staircase temperate the interior from the center. Approx. seven months can be naturally ventilated and night cooled by ventilation, specifically through the solar chimney gallery. The reuse of almost all existing thermal mass of walls and slabs is enhanced by eight tons of healthy inner adobe plaster, controlling thermal and moisture balance for improved thermal comfort and energy saving. Anti-smog and anti-electric radiation protection is guaranteed.

The thermal envelope was developed with a series of thermal simulations applying diverse natural insulation materials in different thicknesses (Fig. 10). With energy-positive balance and low environmental impact in mind, the 30 cm brick walls and roof were equipped with 36 cm external wood fiber insulation - as an upper limit of cost-efficiency rate - and ventilated timber planking. 25 cm Extruded PolyStyrene (XPS) protects the floor structure against heat loss.

Table I details the excellent thermal properties of the envelope. The window refurbishment includes 3-pane 'passive house'-glazing with PolyVinyl Chloride (PVC) and aluminum frames and external aluminum louver shading to prevent overheating. Subsequent sealing problems were solved by innovative biotechnology, a crystalline capillary-channel filling plaster (Kerakoll Biocalce). A new roof geometry provides a

27° sloped south oriented, optimal surface for a 3.5 kWp PV-system with maximized summer overproduction efficiency. A 27 m³ water cleaner cistern collects rainwater from the roof.

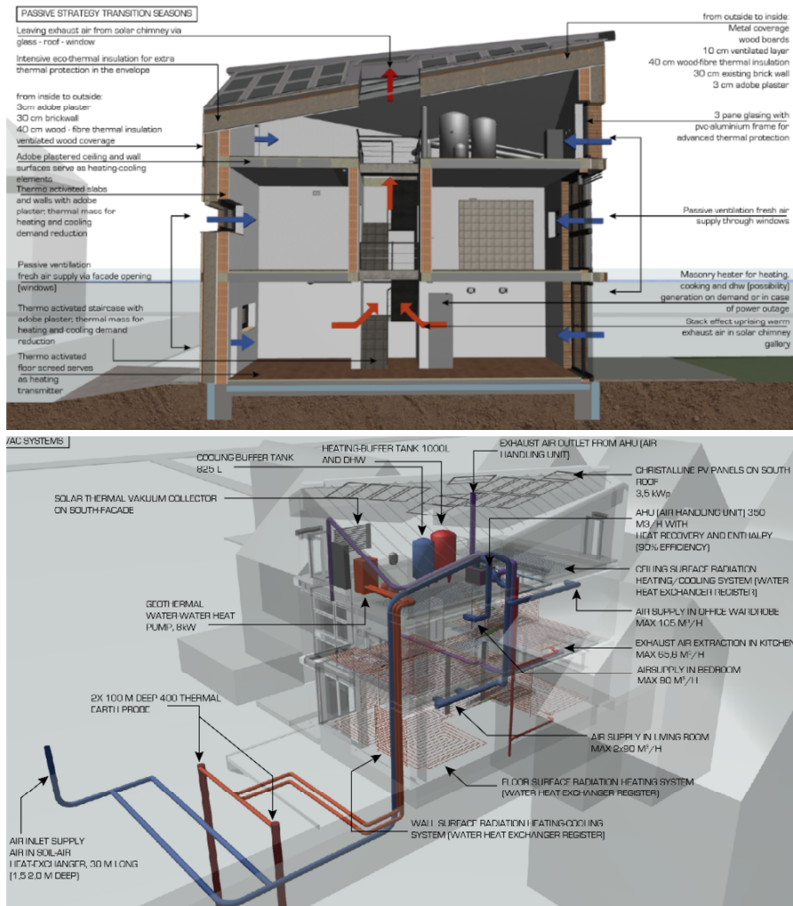


Fig. 9. Passive design strategy (top); active design strategy and components (bottom)

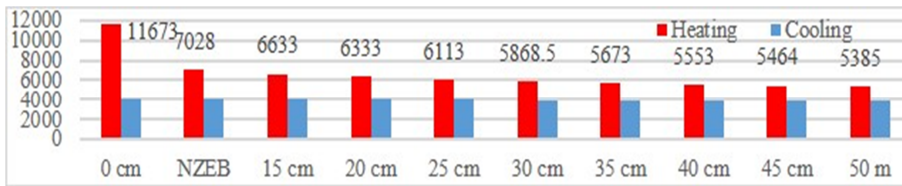


Fig. 10. Thermal insulation versions in the final plan model - used heating energy demand [kWh/a]

Table I

Thermal properties of the building envelope

U-value	glazing	frame	win	wall	attic	roof	slab on ground	garage	mean
[W/m ² K]	0.80	1.00	0.87	0.09	0.08	0.08	0.14	0.09	0.37

After the passive work package is absolved, the active design strategies follow. According to the ED policy, most possible energy conservation should be ensured by all passive measures. Thereafter, the building service system, consisting of the most efficient components available in the market should cover the remaining comfort and energy demand by using renewables. The heat transfer systems are low-temperature floor, wall and ceiling surface heating and high-temperature wall and ceiling surface cooling in all rooms, despite the sanitary rooms (only floor heating). The thermo-activated floating screed and adobe plaster are supplied with heating and cooling energy by two 100 m deep earth probes, combined with a 8 kW geothermal water-water heat pump (COP 4.5) and 1000 l hot water tank and 875 l cool water storage. In summer the approx. 15 °C brine water cools the interior passively (summer EER approx. 20) or the heat pump's active cooling mode (EER 6.91). The concrete staircase surface heating-cooling serves as a 'lukewarm stove' in the middle of the house. DHW is generated by a vacuum thermal collector with 1.51 m² absorber surface in approx. 6 months; otherwise the heat pump produces DHW in the remaining time.

The Air Handling Unit (AHU) is responsible for the ACH with max. 350 m³/h and a cross flow plate heat recovery (efficiency up to 90%). The fresh air intake is preheated/precooled in a 30 m long soil-air heat exchanger collector with industry silver anti-bacterial inner coating (Rehau Awadukt). A Building Management System (BMS) controls and monitors mechanical ventilation upon Volatile Organic Compound (VOC) and relative humidity levels, heating and cooling with Individual Room Controlling (IRC), natural ventilation (windows of the solar chimney), DHW and vacuum collector.

The construction of the building was absolved in 2015 (*Fig. 11 left*), with a substantial energy demand reduction. To compensate the LCA impact of the complex HVAC system and window structures, reuse of almost 100% of solid structures and application of natural and recycled materials are employed, for instance wooden thermal insulation and façade coverage, adobe plaster, bio-plaster for sealing, partly recycled tile flooring. The project won 2017 the Active House Award and the E.ON. Energy Globe Hungary prize. *Fig. 11 right* analyses measured and invoiced final energy consumption and production balances. The yearly energy balance is really zero by considering the roof integrated PV system. Calculating the originally designed (not yet installed) PV-canopy for firewood at the garden façade with an extra 3.5 kWp inverter, the positive energy balance of 8427 kWh/a and hence a 'payback station' is provided.

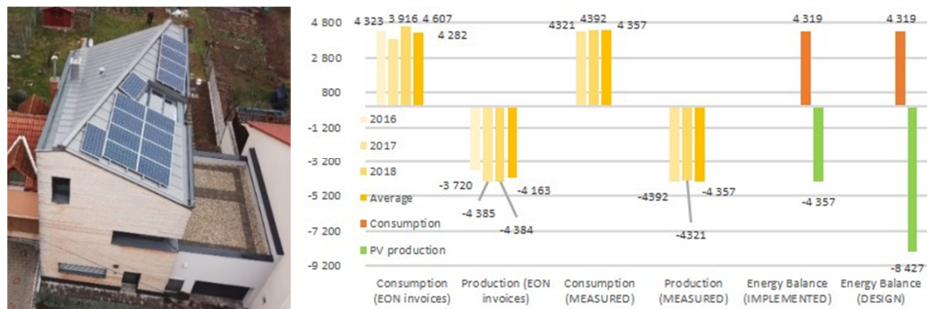


Fig. 11. Photo of the implemented building (left); final energy balances according to supplier invoices (E.ON) and in situ measurements (right)

6. Conclusion

The AH evaluation tool enabled a detailed and effective evaluation of different blueprint concept plan versions, considering thermal, visual and IAQ performance, based on dynamic simulations. At this design stage, the energy and environmental analysis is not possible with the AH tool, since the plans only include passive design measures, without finally defining the structures and the HVAC system. Hence, energy performance is evaluated directly via simulated energy demand comparison. Since the AH tool is well applicable for comfort, energy and environmental performance analysis in further design stages, in a next step, the AH certification should be carried out to qualify the building in the complete comfort-energy-environment evaluation framework. Due to direct neighbor border, complicated internal thermal insulation was needed at the north façade. Further difficulties evolved due to dense neighborhood and the fixed existing structures, acting as limitations in space organization, building body shaping, number of stories, envelope design, orientation of rooms, solar gains in winter (neighbor's shading), selection of structures and materials, as well as impossible use of natural straw ball insulation and thermal insulation at the footing. Moreover, complex modifications in the load bearing structure and subsequent sealing caused further challenges. On contrary, shaping of the new roof geometry was free of prerequisites and the HVAC system design could be set relatively freely. Despite the problems, a complete rearrangement of the spaces and the building envelope could meet the requirements of the user preferred modern home with award winning external appearance. An excellent energy performance could be achieved with approx. two times greater final energy production than consumption.

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