Investigating passive strategies in a cold climate – teaching EDDA in architectural education

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Abstract. This paper describes the results of an architectural teaching module investigating passive building strategies in cold climatic conditions on the case study of Iceland. Focusing on thermal comfort in buildings, usual case study tasks are located in cooling-dominated climates as vernacular design for hot climate zones offers more passive strategies than for cold climates. As part of the architectural education programme at Jade University of Applied Sciences, students investigated the impact of passive strategies in a building design concept for a hotel in Iceland by applying numerical simulation within the initial design phase. The aim was to develop a holistic energy efficiency strategy and to optimize their initial design propositions exploiting its full potential for high thermal comfort in the guest rooms. Although each student started with an individual research question for a specific passive strategy, i.e., investigating varying construction materials, buffer zones, window-wall-ratio, Trombe walls, etc., all design concepts finally included multi-storey glazed buffer zones contributing to comfortable room temperatures by high solar gains from April to September resulting in a significantly reduced heating load. Furthermore, the study identified several design metrics for passive solar buffer zones to ensure the positive impact throughout the months with varying solar intensity. The teaching module called EDDA (Environmental Digital Design Analysis) is based on simplified 3D models in McNeels Rhinoceros 3D undergoing thermal simulation with a Grasshopper–Ladybug–Honeybee workflow. This allowed the students to iterate their building designs for maximum thermal comfort before adding HVAC systems. Ultimately, EDDA fostered to design climate-sensitive buildings by identifying a suitable set of passive strategies for the predominant climatic conditions as a first – but essential - step towards climate-neutral buildings. At the same time, prospective architects are empowered leading the building sectors towards a carbon-neutral future.

Keywords: passive building design strategies, building energy simulation, cold climate, Iceland, architectural teaching

1. Introduction

Within the discourse of climate change and the new European Green Deal, passive strategies to keep buildings comfortable with minimized energy demand seem to experience a revival in architectural building design [1, 2]. Widely published case studies such as the 2226 concept or the increasing research
activities on so called “natural buildings” or “simple buildings” raise awareness for the long-forgotten traditions of passive measurements in architecture for heating dominated climates [3, 4].

In architectural education passive strategies are taught comprehensively and throughout the varying climate zones and more often building energy simulation tools are used in this context to verify the impact of passive measurements of design proposals by evaluating indoor thermal comfort and/or energy demand for heating and cooling [5]. At Jade University of Applied Sciences students explore passive architectural design by evaluating their design proposals applying the Environmental Digital Design Analysis (EDDA) workflow. EDDA combines simplified geometric 3D models made in Rhinoceros software with visual scripting in Grasshopper and the Ladybug Tools to carry out a thermal simulation in Energy Plus. Participants learn how a) to optimize the thermal performance of a design proposal and b) to explore the architectural impact of passive strategies by investigating specific material and construction options, geometric variation, buffer zones, ventilation strategies, and shading/solar radiation. Evaluating the resulting indoor thermal comfort and the heating or cooling load of the building respectively, students are enhanced to adapt, iterate and optimize their initial design proposal to achieve maximum thermal comfort by passive means only. Depending on the given task and the given location or climate zone the defined maximum of thermal comfort varies. The key learning goals are the application of passive building design strategies according to the predominant climate to design climate-sensitive and low energy demand buildings with high thermal user comfort. Within this learning context, the combination of different passive strategies and their architectural implementation can be counterproductive to its initial intention. Thus, the numerical simulation supports not only the design idea but also design decisions throughout the holistic process.

The impact becomes significantly apparent in cold climates such as Iceland. Vernacular architecture always has applied passive solar gains, high thermal mass and geothermal heat. However, using a five storey hotel building on Iceland as case study task for the teaching module, required comprehensive investigations of the architectural implementation of passive strategies to an acceptable level of thermal comfort in guest room sections [6, 7].

2. Methods

The methods of the elective course (carried out in winter semester 2020/2021) followed the Blooms taxonomy of six learning levels: from simple to complex [8]. The first two learning goals were raising awareness of passive strategies in architecture and an understanding of applicable passive strategies in a heating dominated climate such as Iceland. After a detailed climatic analysis by applying the Ladybug Tools, students developed their own specific sustainability strategy for a design proposal of a five-storey hotel in Iceland implementing passive measurements to aim for maximum thermal comfort in the guest rooms of the hotel. As such, each student proposed an individual research question to be answered by the energy simulation with EnergyPlus.

After evaluating the simulation results in terms of adaptive comfort levels and indoor temperatures, students iterated their initial design proposals - adding or changing the set-up of passive strategies - until the building designs reached maximum indoor thermal comfort. With this teaching method the learning goals for following design studios/design tasks have successfully been addressed: Firstly, to understand and clarify the purpose of the simulation within the design process and secondly, to characterize valid assessment tasks and design strategies to ensure that the simulation instructions are aligned with the objective. By establishing this holistic approach students evaluated passive strategies based on adaptive thermal comfort as a holistic score. To simulate and analyse the results, various factors and factor levels were identified based on factorial design [9]. These factors were approached holistically to simplify the simulation, and to ease the process of identifying favourable factors [10]. The results were evaluated and iteratively included in the following design proposal decisions. Thus, each factorial simulation is based on a different case study depending on its initial design proposal and the following optimization process. However, every design proposal is based in Iceland and has the same boundary conditions. To run the simulation, typical meteorological years (TMY) from Climate.oneBuilding data sets in the EPW
file format [11] were used according to the chosen site locations. The students simulated representative floors, dividing the whole building into sections to explore the overall thermal comfort.

The teaching method included an inverted classroom concept by means of software teaching videos, weekly seminar meetings with one-to-one discussions on the design development as well as software support and an interim and a final presentation in front of the students group acting as plenum for feedback. Each week, the teaching part included another knowledge content followed by the corresponding simulation exercise executed on their own building design proposal. Due to the Covid-19-pandemic lock-down of the university buildings in 2020, all teaching took place online via Cisco Webex Training which enabled the students to perform all simulations on the university lab computers remote from home while being connected to the module leader and student tutor in the virtual seminar room. In addition, a Padlet board was provided for collecting questions, information on Iceland and its climatic conditions, vernacular architecture, and passive strategies etc. among the students offering a continuously growing knowledge storage. Learning goals, teaching mode and assessments followed the constructive alignment concept by Biggs [12].

3. Case Study

In winter semester 2020/21 Iceland served as a case study site offering a heating dominated climate and - depending on the chosen location on the island - being even limited in solar radiation availability over the winter months. In return, Iceland offers tremendous geothermal potential, being very close to the ground surface. Thus, the island serves as the ideal case study challenging the students to thoroughly investigate passive building strategies and their underlying basic physical principles as it is not possible to simply transfer common passive strategies from subtropical climates, where they are more popular and widely-used, to Tundra and Subpolar oceanic climatic conditions with varying availability of ambient heat sources (Figure 4).

Iceland lies in the North Atlantic between latitudes 63°23'N and 66°32'N and longitudes 13°30'W and 24°32'W, close to the Arctic Circle. The Köppen-Geiger climate classification indicates that Iceland has tundra climatic conditions (ET) that overlap slightly with subpolar oceanic (Cfc). Therefore, Iceland has both a subpolar oceanic and in most parts Tundra climate. Iceland has a wide variety of volcanism because it is situated over a rift between continental plates. Its mountains form a barrier against the maritime air, thereby protecting the inland [16]. According to these factors, Iceland weather can be defined into a short warm season from June to the start of September as shown in Figure 5; a longer cold season occurs from November till the end of March (Figure 4). The temperature is rather temperate to cold. The solar radiation, thus the overall daylight time is significantly lower in the cold months. The hours of daylight range from twenty-one hours in June and four hours in December (Figure 3). The warm months are characterized by a low precipitation, higher clear cloud covers and lower wind speeds [16].
Figure 4. Mean January temp. in Iceland [17]  

Figure 5. Mean July temp. in Iceland [17]  

The task of a five-story hotel design proposal accommodating guest rooms, reception, breakfast rooms, a small office, staff rooms, and a storage room was artificial; the location on the island of Iceland could be chosen by the students according to their climatic analysis and the chosen set of initial passive strategies as displayed. Students participating in the elective course had basic knowledge in architectural design development, construction and HVAC systems. None of them had had any simulation experience before. Most students were master students, some bachelor students in fifth semester. They had no previous experiences with Rhinoceros and Grasshopper, nor the Ladybug Tools. However, all participants had basic to advanced knowledge of several other computer-aided design software like Autodesk Revit, AutoCAD or Graphisoft Archicad (CAD/BIM).

4. Simulation Results

Resulting from a collectively undertaken climatic analysis with the Ladybug Tools in terms of solar radiation, mean radiant temperatures, precipitation, air temperatures, wind direction and wind speed as well as ground temperatures, each student chose a specific site for his/her design proposal of the five-storey hotel (Figure 2). In combination with the first design proposals by the students, the following passive strategies were simulated (the analysis period is given in bracket behind):

1. Division of glazed buffer zones and adapted ventilation (adjusted inter-zone airflow buffer zone, guest room for winter/summer) for passive solar gains (April - Sept)
2. Buffer zone dimensions on southwest facade for passive solar gains (April-Sept)
3. Impact of Trombe walls (April - Sept)
4. Window-wall-ratio on south facades for passive solar gains (Jan - Dec)
5. Window construction on south facade for passive solar gains (Jan - Dec)
6. Window-wall-ratio for passive solar gains (building enclosed by buffer zone) (April - Sept)
7. Impact of concrete/ steel/ wooden construction for a cantilevering design on thermal indoor comfort (Jan - Dec)

Figure 6. Resulting thermal comfort range of passive strategies for the individual design proposals
As shown in Figure 6, the simulation results clearly indicate that glazed strategies (1), (2) and (6) or buffer zones respectively offer the highest optimization potential of adaptive thermal comfort in the guest rooms from April to September when solar radiation is available. The Trombe wall (3) holds a higher comfort range compared to the former glazing-only strategies. Varying the window-wall ration in strategy (6) resulted in an illustrated learning experience as the comfort rises significantly by a reduced glazed area in cold climates. Strategy (7) cannot be compared to the other student simulation strategies as boundary temperatures for natural ventilation were adapted when the construction type was changed to improve the resulting adaptive comfort.

These first results were presented to the seminar group in an interim presentation following a collaborative learning approach. Subsequently, all groups proactively re-designed their proposals integrating architectural features to harvest solar gains for the guest rooms.

The following sections show three different exemplary students projects and, most importantly, how the design proposals developed according to the simulation results:

4.1. Design Proposal 1

The first design proposal was situated in the central area of Iceland within the Tundra climate of Hveravellir (Figure 2) primarily focusing on how the building behaves, when it is enclosed by a continuous buffer zone. Hveravellir is not only a geothermal high temperature field but at the same time includes a volcanic system.

Due to the limited solar radiation in winter months, the student analysed only the results from April to September. The proposal stated that the glazing of the outer skin greatly effects the thermal comfort of the internal zones. Therefore, the window-wall ratio (WWR), buffer zone size (BZS) and the window construction (WCO) were examined as impact factors for the simulation. The WCO defines the U-value, the solar heat gain coefficient (SHGC) and the visible transmittance (VT) within reasonable bounds, to evaluate double glazing, triple glazing, and the effects of sun protective glass as shown in table 1. To analyse the zones, the adaptive comfort for all internal zones, the buffer zone and the average of all zones were determined. The internal zones were simplified and therefore were modelled as one thermal zone per storey. The status quo was a lightweight construction, using a stack ventilation to aerate the buffer zone with a 20% WWR. The internal zones used natural ventilation.

As clearly visible in the simulation results in Figure 9, thermal comfort in the guest rooms (internal zone) increased significantly by doubling the depth of the buffer zone from 1.5 metres to 3 metres. This could be even enhanced if the glazing ratio was reduced to 20% whereas a raised glazing ratio of 80% led to reduced thermal comfort in guest rooms as well as the buffer zone itself. Overall, designing a surrounding thermal buffer zone with 20% glazing resulted in more than 90% adaptive thermal comfort between March and October (Figure 10). Figure 11 shows the final design proposal.
Figure 9. Adaptive thermal comfort results from the first initial design proposal to optimized design versions by varying individual factors (table 1).

Figure 10. Adaptive thermal comfort final design proposal between April and September.

Figure 11. Final design proposal with 20% window to wall ratio and a 3m buffer zone.

4.2. Design Proposal 2

The second design proposal investigated the effects of horizontally split buffer zones and its glazing ratio (WWR) in Keflavik, Iceland (Figure 2), which was located in the southwest area with a sub-polar climate showing slightly warmer temperatures throughout the year. The simulated iterations were analysed for the whole year; apart from the final design only considering the months from April until September. The initial proposal, shown in Figure 12 stated that the south orientation of the buffer zone, as well as the glazing percentage contributed to improved thermal comfort. In addition, a better result for one buffer zone with a stack ventilation was anticipated. The window wall ratio (WWR), the building orientation (BO), façade angle (FA) and the floor division (FD) were identified as the varying factors for the simulation as shown in table 2. To evaluate the results, the building was simplified and only the

### Table 1. Factor variations from the first initial design proposal to optimized design versions.

| WWR (%) | U-value (W/m²K) | SHGC (%) | VT (%) | BZS (m) |
|---------|-----------------|----------|--------|--------|
| 1.1     | 20              | 1.1      | 80     | 80     | 3.00   |
| 1.2     | 40              | 1.1      | 80     | 80     | 3.00   |
| 1.3     | 60              | 1.1      | 80     | 80     | 3.00   |
| 1.4     | 80              | 0.5      | 40     | 40     | 3.00   |
| 1.5     | 20              | 0.5      | 40     | 40     | 3.00   |
| 1.6     | 40              | 0.5      | 40     | 40     | 3.00   |
| 1.7     | 60              | 0.5      | 40     | 40     | 3.00   |
| 1.8     | 80              | 0.5      | 40     | 40     | 3.00   |
| 1.9     | 60              | 1.1      | 30     | 30     | 3.00   |
| 1.10    | 80              | 1.1      | 30     | 30     | 3.00   |
| 1.11    | 60              | 0.5      | 30     | 30     | 3.00   |
| 1.12    | 80              | 0.5      | 30     | 30     | 3.00   |
| 1.13    | 80              | 0.5      | 40     | 40     | 1.25   |
| 1.14    | 60              | 0.5      | 40     | 40     | 3.00   |
| 1.15    | 20              | 0.5      | 40     | 40     | 3.00   |
| 1.16    | 80              | 0.5      | 40     | 40     | 3.00   |

*Limiting the natural ventilation only operating when a minimum of 18°C is reached to reduce heat loss.
bottom, middle and the top floor, including the roof were simulated. The results were combined into an average.

![Figure 12. Ground floor plan of the initial design proposal](image)

**Figure 12.** Ground floor plan of the initial design proposal

**Figure 13.** Axonometric projection of the initial design and the thermal zone configuration

Simulation results in Figure 14 displayed the highest adaptive comfort in the guest rooms combining a 3m wide south oriented buffer zone that was horizontally split by each floor. The initial proposal contained a slightly angled south façade to maximize solar gains. This effect was verified by the simulation results. The student kept the angled south façade for design reasons averaging the optimal 3m depth of the buffer zone from 1 metre on top floor to 4.5 metres on bottom floor.

![Figure 14. Adaptive thermal comfort results from the second initial design proposal to optimized design versions by varying individual factors (table 2)](image)

**Figure 14.** Adaptive thermal comfort results from the second initial design proposal to optimized design versions by varying individual factors (table 2)

| Building orientation | WWR (%) | Glazing construction | Facade angle (in °) | BZS (m) | No. of floors |
|----------------------|---------|----------------------|--------------------|---------|--------------|
| 2.1 south            | 50      | Triple glazing       | 80                 | 0       | 0            |
| 2.2 east             | 50      | Triple glazing       | 80                 | 0       | 0            |
| 2.3 west             | 50      | Double glazing       | 80                 | 0       | 0            |
| 2.4 south            | 30      | Triple glazing       | 80                 | 0       | 0            |
| 2.5 south            | 90      | Double glazing       | 80                 | 4.5 to 1| 0            |
| 2.6 south            | 50      | Double glazing       | 80                 | 4.5 to 1| 0            |
| 2.8 south            | 50      | Triple glazing       | 80                 | 0       | 6            |
| 2.9 south            | 50      | Triple glazing       | 80                 | 0       | 6            |
| 2.10 south           | 50      | Triple glazing       | 80                 | 0       | 6            |
| 2.11 south           | 50      | Triple glazing       | 80                 | 0       | 6            |
| 2.12 south           | 50      | Triple glazing       | 80                 | 0       | 6            |
| 2.13 south           | 50      | Triple glazing       | 80                 | 0       | 6            |
| 2.14 south           | 50      | Triple glazing       | 80                 | 0       | 6            |
| 2.15 south           | 50      | Triple glazing       | 80                 | 0       | 6            |

In combination with triple glazing, a moderate window-wall ratio of 50% and the horizontal splits the adaptive comfort range could be doubled to nearly 70% compared to the initial design proposal (Figure 15). The final design proposal is displayed in Figure 16. Construction and ventilation schedule were predefined and not altered throughout the simulation variations. An inter-zone airflow was introduced in-between the buffer zones and the guest rooms, the stack ventilation defined with minimum
indoor temperatures only ventilating at 22°C in the summer to create an air flow and allowing temperatures of the different zones to balance. In the winter, the inter-zone airflow was reduced to create a thermal buffer.

**Figure 15.** Adaptive thermal comfort of the final design proposal between April and September

**Figure 16.** Axonometric view of the final design proposal

### 4.3. Design Proposal 3

The third case study proposal investigated the effect of Trombe walls in combination with buffer zones being located at the same climatic conditions in Hveravellir in central Iceland as the first design proposal. Therefore, the design includes a high thermal mass construction, double glazed windows and a fully glazed South façade in front of the Trombe walls as shown in Figure 17. The analysis period was set to April to September.

**Figure 17.** Section of the middle floor from the initial design proposal

**Figure 18.** Perspective view of the initial design proposal and the thermal zone configuration

**Table 3.** Factor variations from the second initial design proposal to optimized design versions.

| Table 3          | Construction | Ventilation       | Trombe wall    |
|------------------|--------------|-------------------|----------------|
| 3.1              | Thermal mass | n.a.              | No Trombe wall |
| 3.2              | Thermal mass | Stack flow        | Two small walls; total area 6m² |
| 3.3              | Thermal mass | Stack flow        | One centred wall; total area 6m² |

**Figure 19.** Adaptive thermal comfort results of optimized design versions (table 3)
Introducing a Trombe wall serving as thermal storage and zone-dividing as well as zone-connecting element nearly doubles the thermal comfort in the guest rooms immediately as shown in Figure 19. In detail, the impact of the wall properties was researched identifying the shares of the storage volume do not alter the comfort range showing comfortable indoor temperatures (Figure 20). The final design proposal suggests a Trombe wall of 6 m² for each guest room; an exemplary design is displayed in Figure 21.

Figure 20. Adaptive thermal comfort of the final design proposal (April-September)

Figure 21. Axonometric perspective of the final design proposal and architectural configuration

5. Discussion

Varying analysis periods (including or excluding the dark winter months) as well as altering several parameters simultaneously in the student simulations made comparing the results difficult, i.e., strategy (7) cannot be compared to other student simulation strategies as boundary temperatures for natural ventilation were adapted when the construction type was changed to improve the resulting adaptive comfort. These simulation methodology shortcomings are mainly the result of a short-term change from classroom teaching to solely online teaching EDDA following the global Corona pandemic. Remote online teaching was often difficult as the university computers were switched off without notice or screen resolution and data transfer rates via Webex Training were insufficient. As Rhinoceros is a licensed software, most of the students did not install the software workflow on their laptops. The Ladybug Tools offer a visual understanding of the interactive parameters influencing indoor thermal comfort that can be intentionally designed by architects, which helps to explain the interdependence of passive strategies. However, European standards especially for construction are not available within the tool set.

The holistic approach to thermal dynamic simulation significantly eased the simulation process for the students. However, this generalization does not consider all design possibilities and constraints and limits the user. Using Monte Carlo simulations to investigate a large number of design iterations represents a possible solution to analyse passive strategies in greater depth [10]. Passive strategies can be very effective in reducing the energy demand, and thereby the contribution of the building sector to climate change. However, Iceland’s unique topography with its considerable geothermal capacity [18], minimizes the requirement of using passive heating strategies. Furthermore, Iceland’s future climatic condition has not been considered. It is predicted to change in the upcoming centuries, representing warmer weather conditions, due to climate change [19].

Additionally, we offered thermal simulation for passive building design evaluation and iteration for the interdisciplinary teaching module Inselkita Spiekeroog [20] in 2021. The student groups consisted in early childhood education, architectural, civil engineering and geoinformation. Because the students did not have previous knowledge of thermal simulation, they used a given predefined simulation set-up. After attending the workshop lecture on thermal simulation, only the architectural students pursued simulation to improve the design proposal. However, the simulation results were not discussed further with the other disciplines to collectively redevelop the design, which might offer the conclusion that thermal simulation was perceived as a design tool.
6. **Conclusion**
Thermal simulation represents a very effective teaching method to visualize and to train the impact of passive architectural strategies on the thermal comfort of buildings and hence, its energy efficiency. The awareness of the impact of passive building design options empowers prospective architects to take a leading role in the task of creating a carbon-neutral building sector. Choosing a case study with a cold climate fostered the detailed analysis of the chosen strategy and its parameters by the students. Architecturally, south oriented, slightly angled buffer zones that are max. 50% triple glazed, ca. 3m in depth and horizontally split floor by floor in combination with high thermal mass construction result in the highest indoor thermal comfort for hotel guest rooms in Iceland. Teaching thermal simulation as a design tool for architectural students proved challenging being solely online and remote, thus a combined teaching mode, such as an inverted classroom concept is recommended.

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