ASSESSING RENOVATION INTERVENTIONS TOWARDS "ENERGY PLUS" BUILDINGS THROUGH PARAMETRIC EXPLORATION --- THE CASE OF GLAZED BUFFER SPACES

Hans-Georg Bauer[1], Julien Nembrini[1,2], Steffen Samberger[1], Christoph Gengnagel[1]
[1]Berlin University of the Arts (UdK), Berlin, Germany
[2]Swiss National Science Foundation (SNF), Switzerland

ABSTRACT

Starting from an entry in the recent German Energy Plus Renovation competition (EPA --- EnergyPlus im Altbau 2012), the paper presents the design tools used to assess the project's energy consumption at competition stage. It further elaborates on the potential of such tools to support design decisions in allowing the consistent exploration of the influence on performance of a particular design component.

The EPA competition asked participants to elaborate a renovation concept for a social housing building and to transform it into an "Energy Plus" building, a building producing more energy averaged over the year than its own consumption.

To achieve such energy standards, focus is put in design components contributing to performance as well as architectural value. The paper focuses on glazed buffer space additions on the facade providing energy gains in winter, reducing insulation needs on the existing facade and increasing usable space in summer.

By combining an open source parametric scripting engine in interaction with EnergyPlus, a full multi-zone thermal model including airflow network is easily defined, refined and transformed by the designers themselves. The use of such tools at the competition stage demonstrates the ability to support early design decision making. It allows to determine the parameters that constitute a functioning buffer space both in terms of usage and thermal efficiency. The parametric scripting approach allows an order of magnitude in simulation runs supporting broader exploration of the design space without sacrificing modeling accuracy.

This research is part of a general effort in developing, in parallel, a set of design tools and a catalogue of design components addressing the energy spending of the existing building fabric, with the prospect to apply it to new projects.

INTRODUCTION

In the context of generating comfortable climatic indoor conditions, one can distinguish two main strategies for achieving the adjustments between exterior factors and interior requirements. On the one hand primarily through passive architectural and constructional properties, such as material, zoning-layouts, orientation and surface to volume ratio (low-tech), on the other hand through active conditioning with the aid of additional building technology (high tech) (Gauzin-Müller 2012).

While focusing on the low-tech approach, it is necessary for the described architectural and constructional properties to respond to specific climate conditions. In contrast to building technologies, the strong impact of those properties on the overall performance and thermal behaviour of a building is quite complex to understand and hard to predict. Extensive building performance simulations (BPS) become necessary. With the progress of the design phase and the consolidation of design ideas, it is increasingly difficult to include identified improvements regarding thermal behaviour in the project. This requires considering BPS very early in the design phase – when essential geometrical or material decisions are not made yet and can still be adapted to simulation insights. As frequently acknowledged (Hensen 2004, McElroy 2009), decisions taken during the early design phase can dramatically influence the performance of the building projected.

The EPA Competition Proposal

The goal of the EPA competition was the development of a renovation concept for a 1930s two-floor social row housing building in Neu-Ulm (Germany), with the aim to transform it into a building that produces in average over the year more energy than it consumes (figure 1).

To increase usable space, the attic was transformed into a third apartment floor, enlarging the total heated living space to 390 square meters. Raising parts of the roof provided supplementary living space,

Figure 1 Street view of existing building (left) and competition proposal (right)

improved the natural lighting condition and enabled the use of the roof surface for solar energy gains through photovoltaic cells and solar heat. An additional glazed unheated buffer space on the north façade to the backyard, also containing the new staircase, provides energy gains during winter, reduces insulation needs and increases the usable space in summer (figure 2, figure 7).

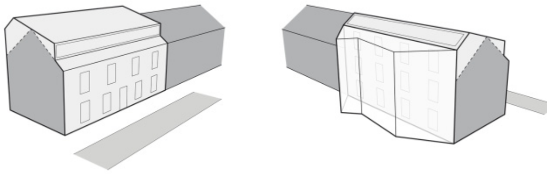


Figure 2 Architectural strategies included changes to the roof and additional buffer space (right)

In the competition, the context did not allow to increase building volume on the south side. Being not evident at first thought, the advantage of a buffer space on the north side was quantitatively assessed through simulations. Exploring parameter space through Sensitivity Analysis techniques during competition phase displayed consistent advantage. The paper will explore the limits of these findings.

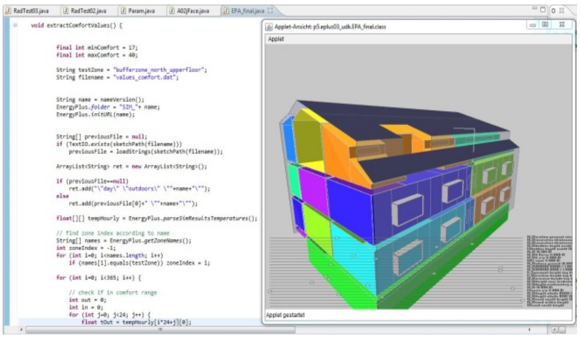
METHODS

In order to implement the efforts towards a performance-based exploration of early design alternatives and non-standard climatic strategies, an approach based on generating form through code instructions is used. Designers can create geometry and parametrically modify it in real-time. Design Variations and alternative solutions can easily be explored and their performance tested, as this context allows the use of code instructions for the definition of material properties and in-depth input needed by expert-level BPS. These tools can be used from the earliest design steps and can provide performance feedback throughout the entire design process, enabling to detect key parameters and instantly react to it.

Anar +

To achieve the desired characteristics, the proposed method makes use of the prototype framework part of ANAR+, an open source parametric scripting tool used in architectural design studios (LaBelle et al. 2009, 2010). Implemented as a library extension to the popular coding framework Processing.org, the framework allows geometry definition through JAVA object-oriented language instructions. The graphical user interface allows continuous alteration of parameters through sliders (as in Lagios et al. 2010), whereas topological transformations must happen through code modifications.

This geometric framework is extended by defining sets of higher level functions (e.g. an Application Programming Interface (API)) that provide interfaces to several expert-level BPS software.



```
void extractComfortValues() {


        final int minComfort = 17;
        final int maxComfort = 40;

        String testZone = "bufferzone_north_upperfloor";
        String filename = "values_comfort.dat";


        String name = nameVersion();
        EnergyPlus.folder = "SIM_"+ name;
        EnergyPlus.initURL(name);


        String[] previousFile = null;
        if (TextIO.exists(sketchPath(filename)))
            previousFile = loadStrings(sketchPath(filename));

        ArrayList<String> ret = new ArrayList<String>();

        if (previousFile==null)
            ret.add("\"day\" \"outdoors\" \""+name+"\"");
        else
            ret.add(previousFile[0]+" \""+name+"\"");

        float[][] tempHourly = EnergyPlus.parseSimResultsTemperatures();

        // find zone index according to name
        String[] names = EnergyPlus.getZoneNames();
        int zoneIndex = -1;
        for (int i=0; i<names.length; i++)
            if (names[i].equals(testZone)) zoneIndex = i;

        for (int i=0; i<365; i++) {

            // check if in comfort range
            int out = 0;
            int in = 0;
            for (int j=0; j<24; j++) {
                float tOut = tempHourly[i*24+j][0];
```

Figure 3 Framework ANAR+ with graphical representation of multi-zone model for simulation

This combination allows one to modify parametrically the geometry and run corresponding thermal, solar gains and airflow analysis. In this way it becomes possible systematically to explore the influence of parameters on different design alternatives as often required in early design stage. This is done through automatic production of simulation input from the geometric description annotated with physical information in a fashion similar to (Lagios et al. 2010, Toth et al. 2012). Given the source code availability, such an interface can be extended to access the full capability of the underlying BPS, addressing needs from non-experts up to advanced users.

Results may either be graphically represented or fed back to the parametric script for performance-based form modification or for design-specific custom visualization, building on the strength of the Processing.org project.

Building Performance Simulation Tools

In the present paper the framework is used for its capacity to interface to EnergyPlus. This simulation software is used for thermal and airflow analysis. To avoid complex input and thus be relevant for the early design stage, it is made use of the provided ideal HVAC systems to model heating energy demands, as well as minimal outside air supply. Internal gains such as users, lighting or electrical equipment are modelled. This software also provides crude daylighting computations, which have an effect on lighting electric consumption.

To test the possibility of natural ventilation to achieve energy-free cooling, the ability of EnergyPlus to model airflow is available without additional input.

Performance Assessment

Simulation results usually are returned in form of temperature or energy demand time-series graphs, separately for each zone. This kind of detailed 'raw' data is hard to compare and analyse, especially when considering the intended large number of simulated design versions.

Within the proposed scripting environment, it is possible to process the gained results further, in order to determine and compare the performance of design alternatives. Depending on the design topology, the considered performance definition as well as optimization intentions, individual calculations have to be conducted in order to draw project-specific conclusions.

Processed results then can be visualized to support the designer in taking design decisions. Alternatively, they can be fed back to the parametric model. That way, a performance-based design adaptation can be automated.

This paper is part of a general effort to develop those methods and previous work already applies the described methodology and analyses its technical implementation and applicability [Nembrini et al. 2012]. Following the same approach, conducted case studies [Nembrini et al. 2011] have been examining design parameters like window to wall ratios and the general impact of unheated glazed buffer zones – like applied in the work of Lacaton & Vassal [Ruby 2009].

In contrast to previous, more technical examinations of the described approach, this paper emphasizes its actual application for taking architectural design decisions during early design stages. It addresses more design- and performance-related issues of possible design alternatives, such as geometric properties or orientation. A conducted case study, based on a made proposal for an actual design competition, purposefully explores detailed characteristics of an attached unheated buffer space regarding performance benefits.

EXPERIMENT

Case Study

In order to investigate the buffer space as a passive architectural building component and usable thermal insulation in a more general way, a case study is considered, using the existing competition project as starting point and constraint. With the idea of applying buffer space in other renovation project of similar typology, a series of simulations analyze the influence of the orientation of the facade where the additional buffer space is located in combination with varying depths of the buffer. As reference, simple balconies without glazing but with the same depths, providing shading, are simulated. The potential of the buffer space is to protect from outside weather fluctuations while allowing rapid heating through solar radiation in winter. Similar to a balcony, the usability of such space depends mainly on the climate conditions. To avoid overheating, it can be fully opened in summer. Aiming for passive approaches, only natural ventilation is considered.

The possibility to harvest solar energy was an important part of the EPA-competition proposal and had significant influence on the design of the changes made to the roof, which was to provide sufficient area facing south. Thus four different roof variants as strategies to deal with different building orientations are compared and the influence on the performance of the building in combination with additional buffer space is analyzed.

The case study building consists of three floors with two apartments on each floor, each apartment with windows to the street and windows to the backyard, where the buffer space can be applied. Exterior walls are made of masonry with exterior insulation (U-values front 0.14 W/(m2·K), back 0.18 W/(m2·K)), windows have triple layer glazing (U-value 0.7 W/(m2·K)), slabs and insulated roof are wood constructions (U-value roof 0.12 W/(m2·K)), the buffer glazing consists of polycarbonate twin wall sheets (U-value 2.6 W/(m2·K)).

The parametric simulation model is built entirely through code instructions and consists of 12 zones within the insulated building area (4 zones for each floor with 2 zones per apartment, one facing to the street and one to the backyard) as well as three zones for the uninsulated buffer space, one for each floor, and one zone for the uninsulated basement. With the scripting approach, building parameters like buffer depth and roof variants as well as definitions of material properties for simulation and control of BPS runs are easily refined and can be subsequently changed and analyzed (figure 4).

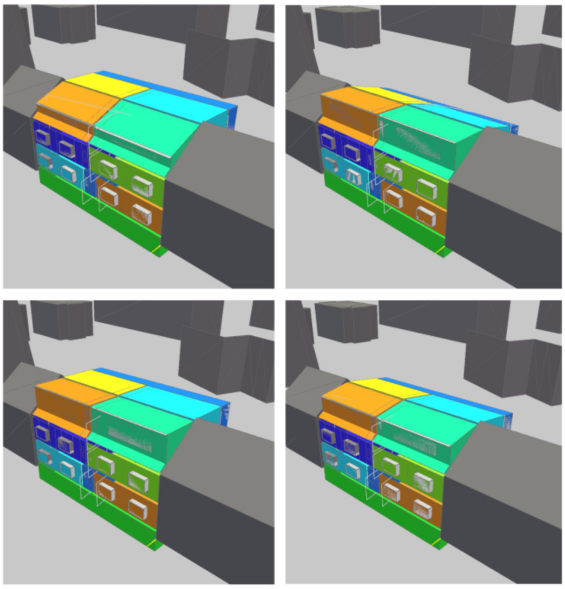


Figure 4 Zone models for simulation with roof variants top left to bottom right: Var1-front down buffer up, Var2-front up buffer down, Var3-Front and buffer up, Var4-front and buffer in middle

To investigate the benefits of the space and the amount of usable time, different variants are compared in terms of comfort frequencies and energy consumption. Following ISO standard 7730, comfort frequency is defined as the amount of hours in a yearly simulation in which the zone is within the range [−0.5;+0.5] (class B) of predicted mean vote (PMV) as defined by Fanger. This PMV is computed using the same metabolic rate and clothing adaptation for heated and non-heated spaces. The metabolic rate is ISO ”sedentary activity” (1.2 met) and clothing within [0.3, 1.0] clo, Energy consumption is computed in kWh/m2.

Experimental setup

Each simulation is run over the whole year for a set of modified parameter values to study their influence on thermal behaviour. Close-by buildings and major vegetation are modeled and considered for shading calculations onto the facade.

Weather data is provided by Deutscher Wetterdienst. The test reference year (TRY) of region 13 is used and includes Neu-Ulm, the location of the competition site. It is based on the data provided by the representing station Muehldorf (WMO number 10875, period 1988 – 2007). The data has been adapted to the elevation of Neu-Ulm.

Each zone includes users representing 4 occupants per flat, which have an activity level between 70 W (when sleeping) to 100 W in the interior zones and up to 120 W in the buffer zones. As additional internal gain a general lighting is defined with a consumption of 2 W/m2 and the luminous efficacy of fluorescent bulbs.

General electrical equipment is assumed with additional 2 W/m2 constantly throughout the year.

The provided ideal HVAC system of EnergyPlus is scheduled to heat when the temperature of the heated space drops below 20° Celsius, for the buffer space heating is scheduled below -30 °C, and therefore doesn’t occur.

As an additional level of inquiry, airflow network modeling is used to assess the potential of a given variant for passive cooling. The parametric framework automatically produces airflow network parameters and topology for thermal co-simulation with EnergyPlus (Hensen 1999).

Ventilation is scheduled to vent above 24 °C in the heated areas throughout the year. For the buffer space the venting schedule is varied. In spring and fall venting is scheduled above 24 °C. To avoid overheating, venting in summer is scheduled above -30 °C, effectively leaving the buffer space always open. In order to maximize solar gains, venting is scheduled above 55 °C in winter.

The use of movable shading elements for windows and buffer space is assumed, if outside temperatures reach 26 °C.

Simulations

For an investigation of possible effects resulting from changes in the slope of the roof, four different roof variants are considered (figure 1). Each roof variant is simulated with additional buffer space of depth 0.5m, 1.5m., 2.5m, and 3.5m for 8 orientations (N,NW,W,SW,S,SE,E,NE). As reference case, the same simulations are run with the glazing of the buffer space always open, resulting in simple balconies. An additional variant without any balconies is simulated (buffer depth = 0.1m and buffer glazing always open). In total 288 different variants are simulated.

SIMULATION RESULTS

Roof variants comparison

To reveal effects of the roof variants on the building performance, they are compared regarding the average of the yearly comfort hours of all heated zones and the additional buffer zones (figure 5), as well as their mean total yearly energy consumption per square meter (figure 6) from all the simulations. Figure 5 shows the gain of average comfort hours when buffer space is added, even if the unheated buffer zones are included in the calculation. As no significant differences are evident between roof variants, only one variant (var1) is kept for further analysis.

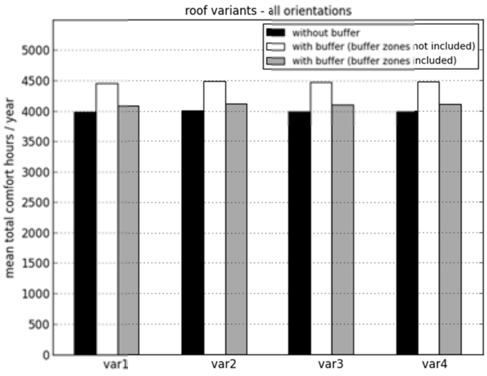


Figure 5 Total mean comfort hours for each roof variant: Without buffer (black), with buffer but hours of buffer zones not included (white), with buffer and hours of buffer zones included (grey)

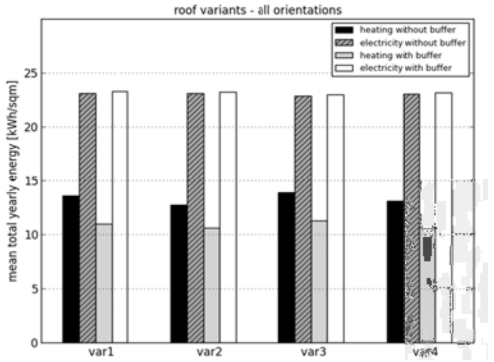


Figure 6 Energy consumption for heating and electricity without and with buffer for each roof var.

Orientation and buffer depth comparison

Performance inquiry and comparison of design variants are simplified through script based post processing of the simulation results. For comparison of multiple design parameters, values for the total amount of hours with comfortable temperatures according to ISO 7730 are generated. For the case study three zones of the first floor are chosen for evaluation (figure 7).

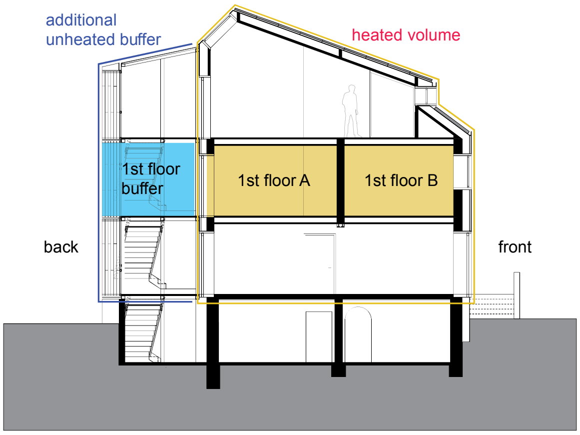


Figure 7 Section showing heated Volume, location of buffer space and analyzed Zones (1st floor buffer, 1st floor A, 1st floor B)

In order to visualize the influence of the buffer within the whole parameter space, the total amount of comfort hours are compared. Figure 8 shows the amount of comfort hours (starting at 1800h/year) as the radius of concentric circles for different zones and optional additional buffer in relation to orientation and buffer depth. In that way it is possible to have an overview of all variants and to compare their behavior regarding design parameters. It is clearly visible that additional buffer space increases the total amount of hours in the zone "1st floor A" for all variants within the defined comfort range. The biggest impact exists when buffer space is oriented toward south, with the impact decreasing with the orientation changing towards north. Regarding buffer depth, the biggest gain of comfort hours is observable for the depth of 1.5m and 2.5m. The even deeper variant of 3.5m performs slightly worse, the least gain is identifiable for the smallest depth of 0.5m. The amount of comfort hours in the zone "1st floor buffer" is obviously smaller than in the heated zone, but shows the same behavior regarding influence of orientation. Regarding the influence of buffer depth, the smallest variant of 0.5m shows bigger impact compared to its impact on "1st floor A".

Figure 9 shows a comparison of all variants regarding yearly energy consumption for heating and electricity. For all variants the additional buffer decreases the energy consumption for heating. The best results regarding design parameters are visible for buffer oriented south and with buffer depth 0.5 m.

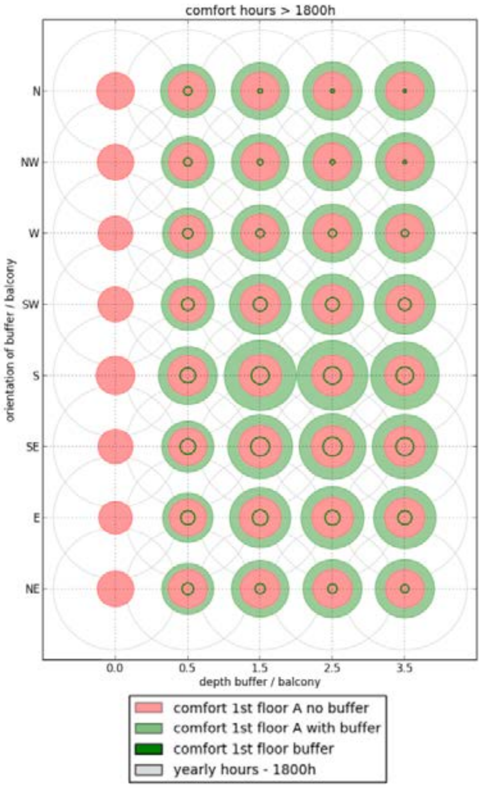


Figure 8 Total amount of comfortable hours in relation to orientation and buffer depth for 1st floor zone A without buffer, zone A with buffer, zone buffer The grey circles indicate the amount of total yearly hours (8760h), starting at 1800h (center points)

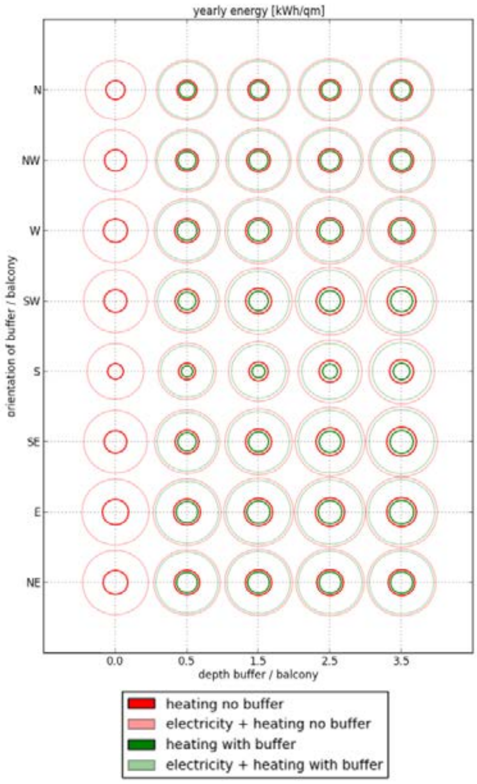


Figure 9 Yearly energy consumption in relation to orientation and buffer depth

Temperature frequencies

With the overview provided by the visualizations of larger parts of the parameter space, specific design parameter combinations can be compared and design decisions can be assisted.

Yet, more detailed information about variants of interest can be helpful to understand their performance. Temperature frequencies for any thermal zones, together with frequencies of comfortable temperatures according to ISO 7730, can be automatically created.

Figure 10 and 11 show how hours, that are within the comfortable range, increase in the zones "1st floor A" and "1st floor B" with additional buffer space.

It is recognizable how the temperature range containing comfortable hours is widened when the buffer is added. The temperature frequencies for the zone "1st floor buffer" (figure 11) are shifted towards higher temperatures with an accumulation of comfortable hours around 20-25 °C compared to the outside temperature (figure 10 zone "1st floor outside").

As it can be difficult to detect differences between variants, a subtraction of the temperature frequencies and frequencies of comfort hours helps to discover how much a variant better performs over the other and in which temperature ranges these improvements are located (figure 12).

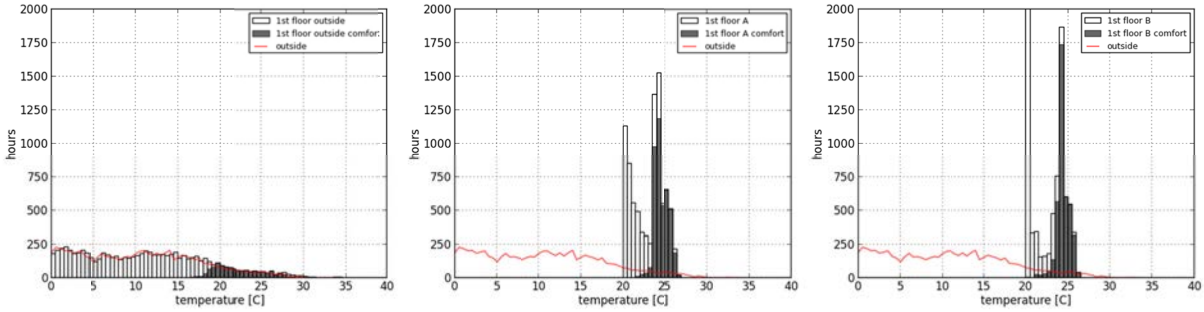


Figure 10 Temperature frequencies together with frequencies of comfortable temperatures for three zones (1st floor outside, 1st floor A, 1st floor B) – without buffer, orientation south, balcony depth 1.5m

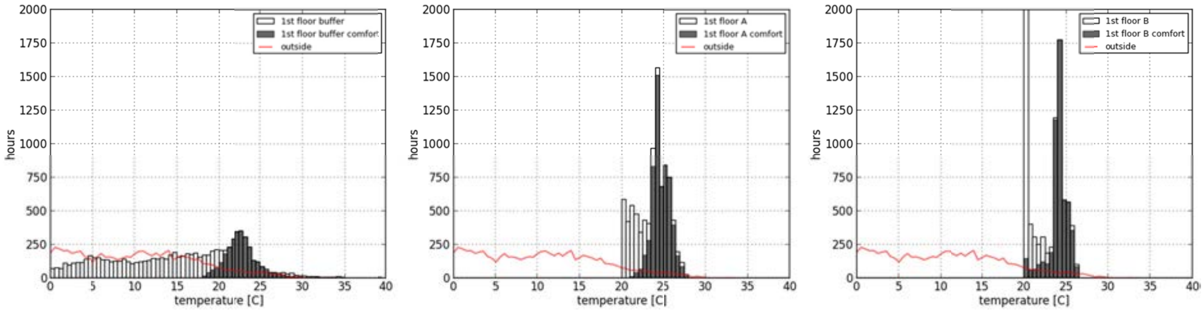


Figure 11 Temperature frequencies together with frequencies of comfortable temperatures for three zones (1st floor buffer, 1st floor A, 1st floor B) – with buffer, orientation south, balcony depth 1.5m

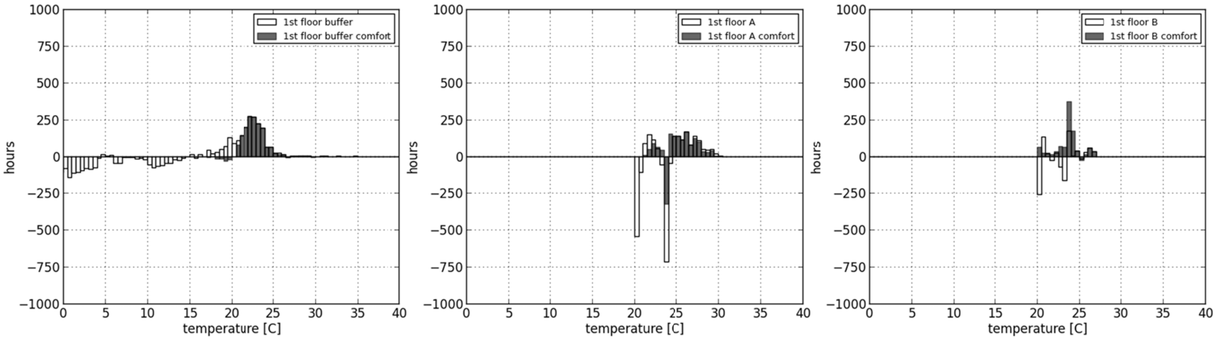


Figure 12 Comparison of figure 10 and figure 11: difference between additional buffer (positive when larger) and without buffer (negative when larger)

DISCUSSION

As this research is part of a general effort in developing, in parallel, a set of design tools and a catalogue of design components addressing the energy spending of the existing building fabric, simulation results clarify component performance as well as contributing to the assessment of deployed design tools.

Design component buffer space

The investigated design parameters of the additional buffer space (orientation and buffer depth) are, at least for existing buildings, not very flexible and might also be constricted by building law. For project-specific inquiry a number of additional and potentially more flexible parameters as materiality, variation of shape and usage should be considered. As an unheated interior space, it might for example contain shared circulation and public stairs, decreasing the heated volume of the building. Here also lies an architectonical potential for a spatial quality that is not easily quantifiable and beyond the scope of this research.

For further research, a wide range of building typologies and usage of existing and new constructions should be considered, as three story row-housing apartment buildings are a common typology, but by far not the only one.

For the comfort assessment of buffer space more flexibility for clothing and activity level for the PMV calculation might be considered, or a different and more suited comfort definition could be used.

Design tools

By providing a simplified but extensible entry point into readily available, validated and open-source BPS, requirements for non-expert users to experts are consistent within a single framework. Designers are able to explore impacts of innovative and non-standard strategies for low-energy building design, not limited by commonly established building systems.

The current role definition between BPS expert and designer is questioned as designers can take part in analyzing and using information provided by BPS tools to steer design decisions. These tools can help to raise their understanding of the physics involved in sustainable construction.

Since this research is focused on investigating design concepts, it is based solely on computer simulations. Further research could be done regarding on-site monitoring of implemented built structure.

CONCLUSION

The case study shows that an additional unheated glazed buffer space is generally beneficial in terms of energy consumption and comfort hours for the renovation concept for a 1930s two-floor social row housing building. Still the impact of such building component depends on and varies with different basic conditions such as orientation and buffer depth.

The presented framework provides an interface between parametric scripting and BPS tools and makes investigation of variants easy through parametric modifications and automatic generation of simulation input data. It demonstrates the potential of parametric scripting combined with automated visualization of simulation results to define and analyze early design variants.

REFERENCES

Gauzin-Müller D., Nachhaltig Bauen: Lowtech oder Hightech, in: Building the Future, Jovis Verlag, Berlin, 2012.

Hensen J., On the thermal interaction of building structure and heating and ventilating system, Ph.D. thesis, Technical University, Eindhoven, Netherlands, 1999.

Hensen J.L.M., Towards more effective use of building performance simulation in design, in: Developments in Design & Decision Support Systems, 2004.

LaBelle G., Nembrini J., Huang J., Programming framework for architectural design [anar+], in: CAAD Futures'09, Montreal, Canada, 2009.

Lagios K., Niemasz J., Reinhart C. F., Animated building performance simulation (abps) - linking rhinoceros/grasshopper with radiance/daysim, in: SimBuild 2010, New York, USA, 2010.

McElroy L. B., Embedding Integrated Building Performance Assessment In Design Practice, Ph.D. thesis, Energy Systems Research Unit (ESRU), Univ. of Strathclyde, UK, 2009.

Nembrini J., Samberger S., Sternitzke A., Labelle G., Combining sensitivity analysis with parametric modeling to inform early design, in: Simulation for Arch. and Urban Design, simAUD 2012.

Nembrini J., Samberger S., Sternitzke A., Labelle G. The Potential of Scripting Interfaces for Form and Performance Systemic Co-Design, in: Proceedings of Design Modelling Symposium, Berlin. Springer. 2011.

Ruby A., Lacaton & Vassal, Ed. HYX, France 2009.

Toth B., Salim F., Drogemuller R., Frazer J., Burry J., Closing the loop of design and analysis: Parametric modelling tools for early decision support, in: Proc. Int. Conf. on CAAD Research in Asia (CAADRIA), pp. 525–534, 2012.