Form follows the human?

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Abstract

In his famous phrase, Sullivan said, that form follows function. After the energy crisis in the 1970s, form followed energy. Although with recent advancement of computational design methods it is getting suspicious, these might have missed the point: it is not the building that uses energy or obeys abstract rules, it is us, the users. The way we move, behave, sweat or feel good can be simulated or assessed with methods of comfort analysis, a field of building energy modelling (BEM). Many of the input data required to run such simulations can be stored in building information models (BIM), a geometry based semantic database. BIMs generally do not describe people in much detail, which would be important to bridge the performance gap of building simulations. Our results showed, that not changing the building construction setup in a coupled comfort and energy simulation, but making the occupant model more granular can still significantly reduce the overall energy consumption of the simulated design. The driven criteria for such exercises are building physics properties of construction elements, most importantly of the thermal envelope. Designing building enclosures is one of the most complex tasks that an architect could face: the huge number of parameters that need to be tamed can easily influence the thermal- and visual comfort experienced by the users of the building, which we saw is the driving force behind the construction industry's huge energy footprint.

1. INTRODUCTION

The design chosen for the assessment was an award-winning master thesis project at the Budapest University of Technology and Economics, Faculty of Architecture. The design is located in Kaunas, Lithuania. The wooden skeleton frame construction is covered with a low U-value opaque thermal envelope and appropriate glazing: choosing the type of glazing was the question for a south facing library in the building, whether to choose low U-value triple glazing with Kr filling, or higher thermal transmittance with sun protective coating, or transmissive glazing. We chose 3 theoretical glazing type with distinctive characteristics.

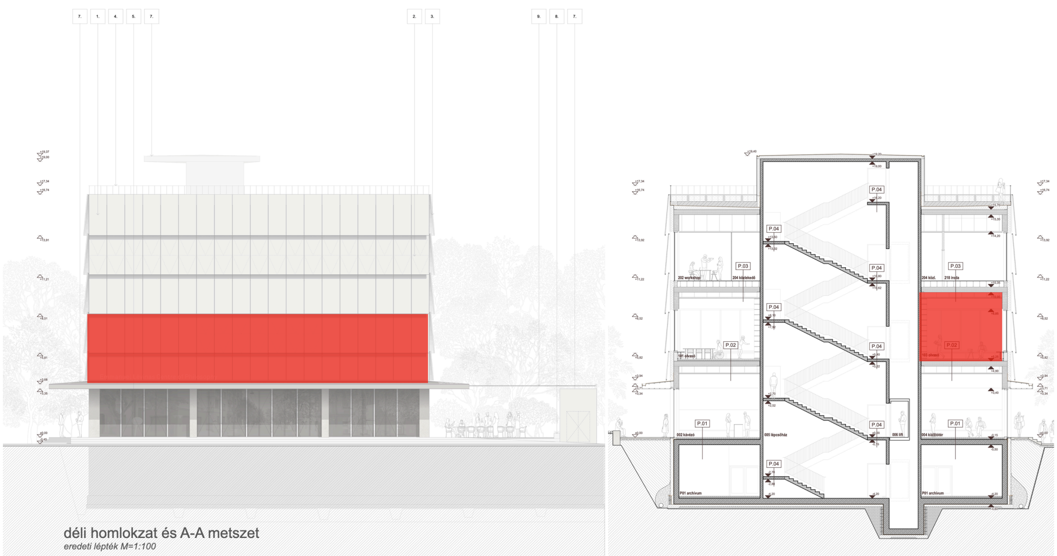


Fig. 01: *South facing facade and cross section.*

A comprehensive BIM was built that served as the sources of the whole documentation and basis of the design tasks.

With a conversion of this model to BEM we were facing common challenges [1], several workflows were tested to ensure the least amount of lost data. We opted using open-source tools mainly they provide access to their inner algorithms. This way it was possible to evaluate the model progression at every step. This proved to be useful, as significant simplifications needed to be applied, as the starting model was way too detailed to be useful in a building energy simulation. Most troubles came from the fact, that most parts of the thermal envelope were modelled by numerous disconnected elements instead of using composite profiles - a data structure that enables the definition of multi-layered skins in a building model as one element.

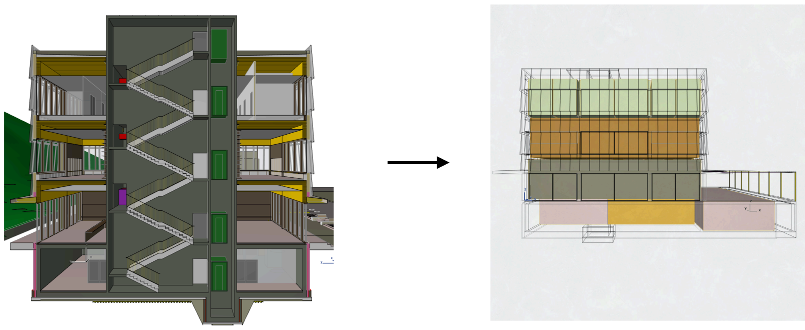


Fig. 02: *BIM (left) to BEM (right) conversion is a complex task that gets harder as LOD (especially LOG) goes higher.*

The whole building energy model is composed of 42 zones, the simulation and management of which is beyond the scope of this exercise. The selected space under study is the first floor library (room 103), south-facing. Its east, south and west facing windows make it a good study subject. The function was modelled using the *SecondarySchool::Library* occupied hours schedule described in ASHRAE 90.1:2019 [2], with the occupancy schedule modified to 07:00-19:00.

The sun protection on the exterior side and and internal glare protection was modelled in the BIM model in a simplified fashion: only the necessary structural geometry and the textile membrane was present.

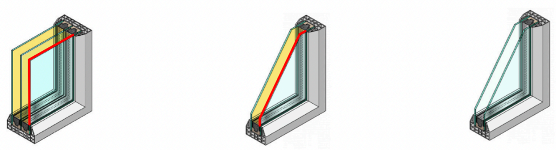
Fig. 03: *External renderings showing the possible states of the exterior shading.*

2. PROBLEM STATEMENT

The building physics parameters of the thermal envelope (especially glazed surfaces) are influencing all our senses, resulting in discomfort if not designed properly. To avoid discomfort, we use energy to heat and cool buildings. It is very important to thoroughly understand which parameters play a role in this, and choose an optimal solution that causes the least-, or no among of discomfort. The library shown in ***Fig. 01*** has opening towards each orientation to let natural light come in, but the urban scale position of the building forces it to be facing also south. It is not clear by intuition, what kind of glazing needs to be used, so we created a parametric energy model study with coupled thermal and visual comfort assessment capabilities to answer this question.

Each design option was assigned a 6 character code shown in the figure below. With the 3 windows in the assessed space, there was 3^3=27 possible scenarios - we chose discrete values for each physical property acting as input values, it would've also been a possibility to discretise the value ranges between valid extremities, it would have given a similar output in the end with much more computation spent on irrelevant options, because the possible spectrum is not fully covered with products available for purchase.

Paraméter	**0** **Kr-filled +** **Low-E coating**	**1** **Normal**	**2** **Transmissive**
U-érték (W/m^{2}K)	0,6	1,1	2
SHGC	0,2	0,6	0,8
T_{vis}	0,25	0,7	0,9



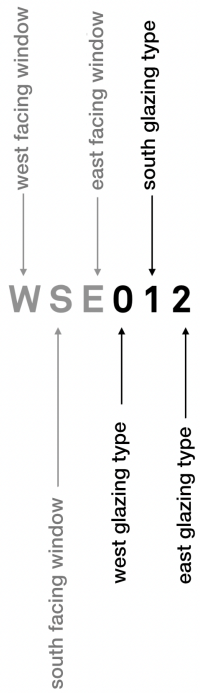


Fig. 04: *different type of glazing used to determine the appropriate one in each direction.*

Further refinement of the assessment is possible using lower-level building physics parameters, such as the thermal conductivity, reflectance, transmissivity, etc. to compute the higher level energy-related metrics (U-value, SHGC and T_{vis}). It was determined to be unfeasible to go to this level of granularity for this study, because the aim was to support architectural decision making and the design process at a higher level, which usually involves the selection of available products from the market. The most expensive option is the "Kr filled + low-E coating", which is a triple glazed structure. The "normal" option is a window with gas filling (Ar or Kr) and low-E coating, but with two glass panes. The "transmissive" option is a double glazed window (uncommon by now).

3. RESULT ASSESSMENT

The different options were compared in terms of energy use (energy use intensity - EUI), thermal comfort (predicted mean vote - PMV), and visual comfort (daylight autonomy, useful daylight illuminance and glare analysis). Since this proved to be a multidimensional analysis, we used a web based tool to analyse the different scenarios. Each column shows a criteria and each horizontal polyline is one possible glazing arrangement.
From the chart it is visible, that changing the glazing while keeping the rest of the building parameters the same can vary a lot in terms of the evaluated metrics. It is more visible if we compare the best option in terms of heating and cooling energy used to maintain occupant thermal comfort: the best option uses far less energy for both than half the options for cooling.

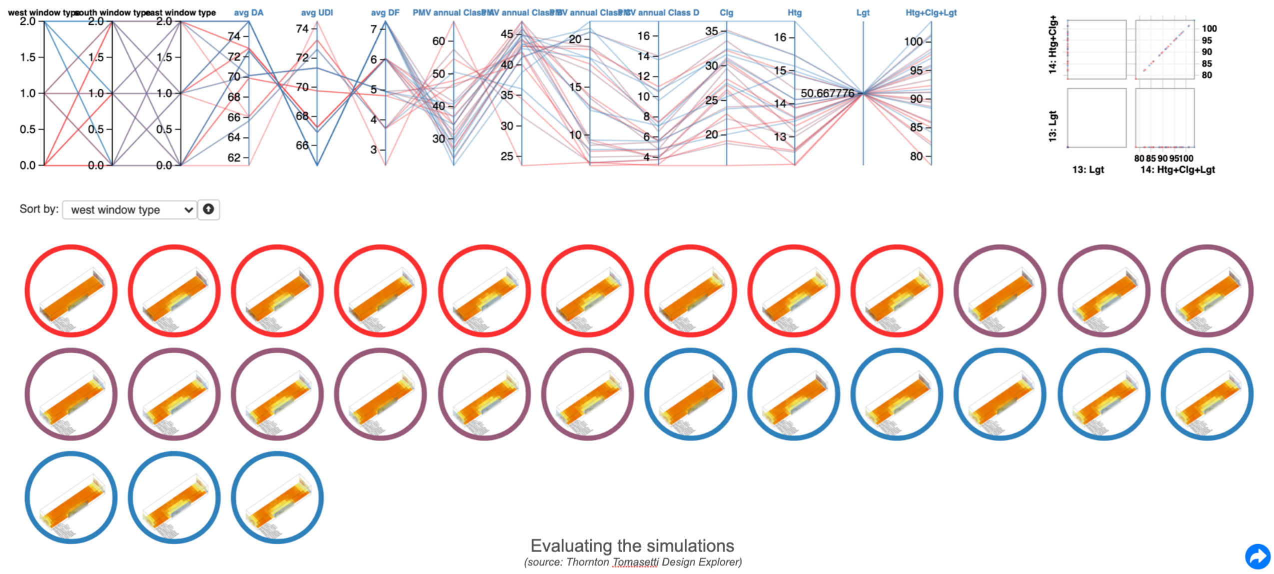


Fig. 05: *Multidimensional analysis of different scenarios.*

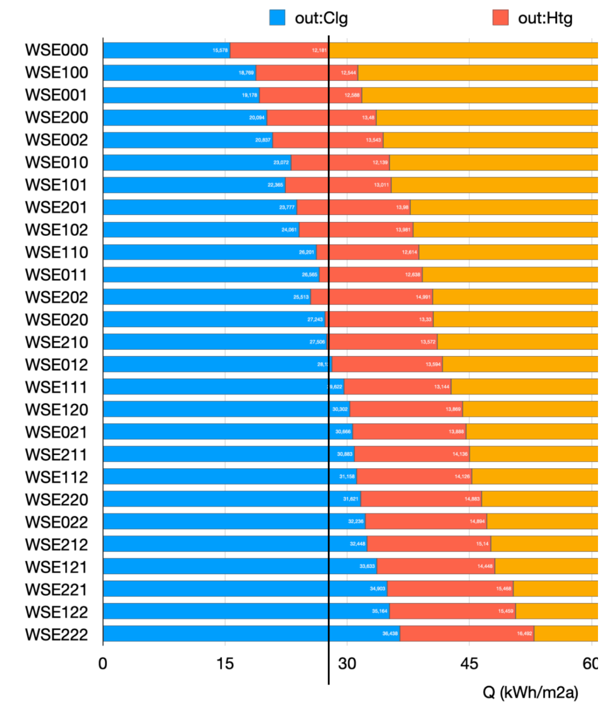


Fig. 06: *Energy consumptions for each design option, the difference is substantial.*

4. CLOTHING ADJUSTMENT BASED ON CLIMATE DATA

It is interesting to note that in terms of thermal comfort, the room does not move above class A for about 35% of the annual occupancy. This is due to a number of parameters: the fixed value of 0.7 clo assumed for the thermal insulation performance of clothing (which was calculated above) is considered to be a light clothing in Lithuanian weather, and it is unlikely that everyone will be wearing long sleeves and long trousers in winter and summer. Based on the CBE Comfort Tool's Dynamic Predictive Clothing algorithm [3], a minimum-maximum clothing thermal insulation coefficient was generated in the range of 8760 clo for the hourly simulation, taking into account the outside air temperature:

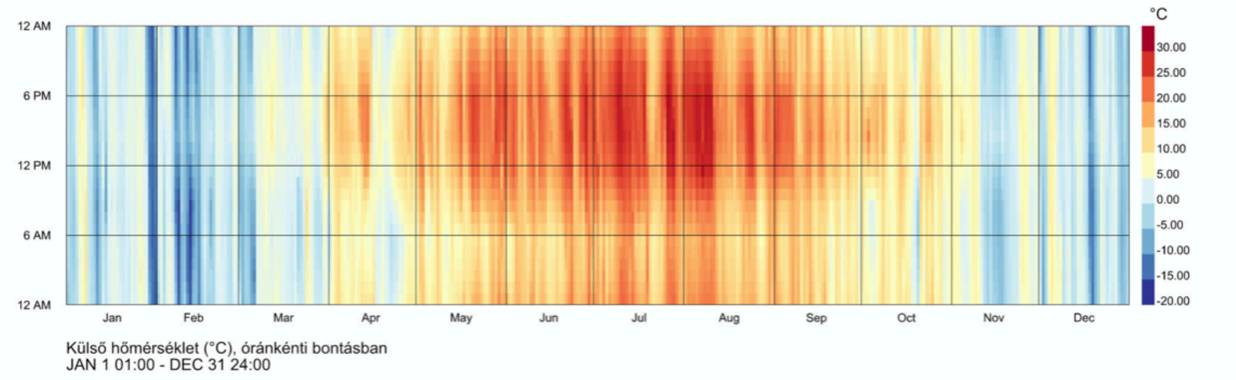


Fig. 07: *Kaunas' annual temperature distribution,*
based on the US Department of Energy's EPW weather data file.

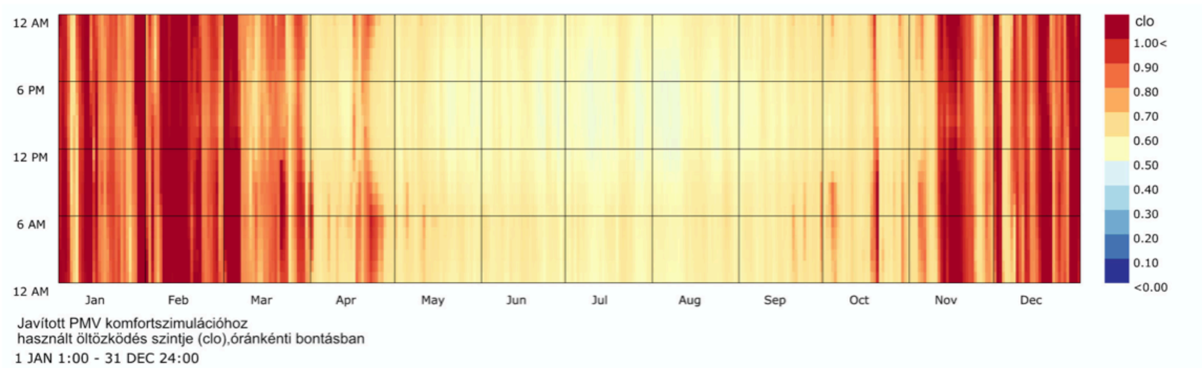


Fig. 08: *Adjusted clo values based on the external temperatures.*

Without this adjustment, we were simulating as if the occupants were overdressed during the summer or warmer periods. To address possible occupant sensation, ISO 7730 [4] comfort classes are a quick way to evaluate a space on an annual bases: it allows to classify at an hourly basis, the percentage of time that the room in question is occupied in each class is stored in a database. In the SQL database, the PMV value describing the thermal comfort is available for all rooms in the building, on an hourly basis. The classification based on PMV values can be done as follows:

- Class A if | PM V | ≤ 0.2,
- Class B if 0.2 < | PM V | ≤ 0.5,
- Class C 0.5 < | PM V | ≤ 0.7.

The metric used for the annual evaluation was calculated according to the above relationship, which gives the percentage of the year in which the tested the room is in a particular class. The ideal condition is when vA = 100 % . After doing the adjustment, the time spent in Class A almost doubles (***Fig. 09***):

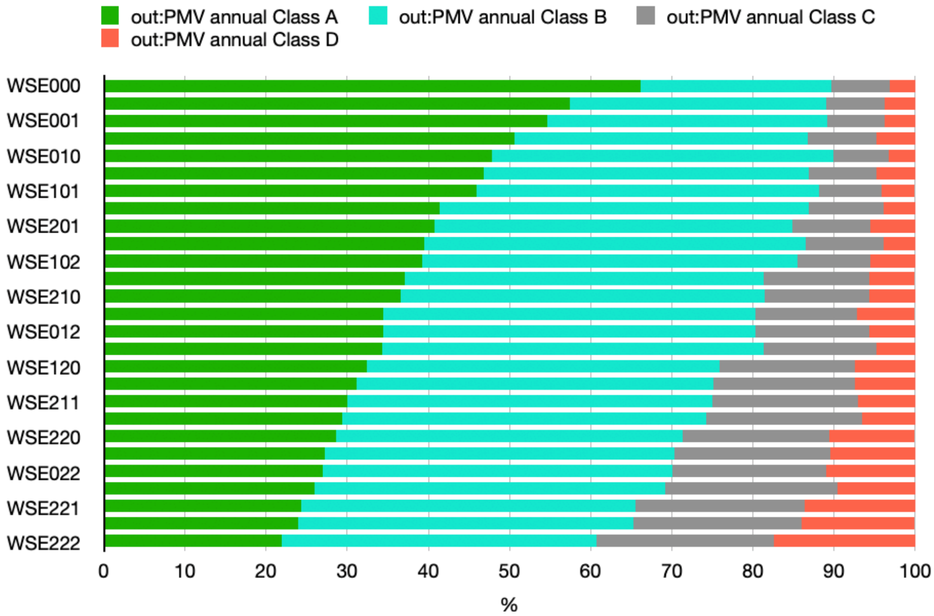


Fig. 09: ISO 7730 classification of the evaluated library space after the clothing adjustment was done.

FURTHER STUDY

The experiment presented here was based on external temperature values, a next step for more accurate simulation would be to use internal temperature values from an initial annual dynamic simulation to predict how people would behave inside the building. Combining these clo values with the clo values from the internal simulation and developing an algorithm to predict the probable level of clothing (e.g. during winter warmer hours there is a threshold until people can undress because of their warmer street clothing).

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[4] ISO 7730:2005 Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.