Multi-layered Breathing Architectural Envelope

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A multi layered breathing envelope is developed as a method of natural ventilation. The two main layers consist of mineral wool and air permeable concrete. The mineral wool works as a dynamic insulation and the permeable concrete as a heat recovery system with a high thermal mass for heat storage. The performance of the envelope is simulated and put through an optimization process. The impact of a design system on the architectural potential of Performance -based design was investigated.

Keywords: *Architectural Envelope, Performance-based architecture, Air permeable concrete*

INTRODUCTION

This study seeks to articulate an architectural envelope and investigate its capacities to regulate the indoor environment through a composition of permeable materials. In recent years the requirements for low energy consumption for buildings has increased rapidly. A lot of solutions to this issue focus on separating the indoor environment from the outdoor with more insulation and increased air tightness of the building envelope, where the envelope is often perceived as a static boundary. This study attempts to perceive the envelope as a dynamic transition between environments where one environment can benefit from the other. The goal is to create an air permeable envelope as a method for natural ventilation. From this, the work focuses on the architectural language of performance-based design while enhancing the atmospheric and thermal environment by means of modulating the form and material of the envelope.

The type of building envelope is also called a "breathing envelope", which basically is a wall orientated to the outdoor environment where air is pulled through to ventilate the building. When the air is moving through a porous media in the wall it will function as a dynamic insulator. The dynamic U-value can be calculated by a function of airflow velocity, when velocity increases the U-value decreases (Taylor, et al. 1996). The dynamic insulation works by air obtaining the heat from the conductive thermal flux and creates a contra-flux and thus preheating the inlet air; this principle is shown on Figure 1. The opposite of contra-flux is pro-flux this occurs if the airflow has the same direction as the thermal flux resulting in decreasing dynamic U-value.

Multiple field testing has been conducted in order to document the effect of breathing envelopes and dynamic insulation. In a study by Mohammed S. Imbabi (Imbabi, 2005) a breathing wall panel was tested in a "Breathing wall test cell". The dynamic insulation was shown to work as an air pollution filter besides the function as air supply source and heat exchanger. The energy saving of heating and cooling for dynamic insolation compared to conventional insulation are first demonstrated significantly when applying a heat recovery system to the exhaust air.

Most of the work regarding dynamic insulation is based on mechanical ventilation to control the air flow. This can pose challenges, in an experimental study by A. Dimoudi et al. (Dimoudi et al. 2004) a breathing envelope construction was tested under real weather conditions in a test reg. The experiment showed that the weather conditions like wind have a large impact on behavior of the air flow and thus the performance of the envelope.

Low outdoor temperatures can cause the inlet air of a breathing envelope to be well below room temperature. This doesn't seem to cause relevant problems due to relative low air flow velocity. But an increasing air flow velocity results in a drop in temperature of the interior wall surface (TAYLOR, et al. 1998). In a study of the thermal comfort in rooms with dynamic insulation by Guohui Gan (Gan. 2000) an issue with interior surface temperature well below the room temperature was demonstrated to cause thermal discomfort.

The envelope is a multi-layered breathing envelope, which means that all the layers are air permeable to some extent. The external layer is a perforated screen which purpose is to shield the insolation layer from exposure to external damages like rain and physical interaction. The insolation is a fiber-based media like rock wool and functions as the main dynamic insulator. The final layer consists of air permeable concrete and is the interior layer, which means it is also the interior visible material. This will also function as a dynamic insulator but the main function is heat recovery and heat storage. This is possible because air permeable concrete is a porous material, which is both highly conductive and has a high thermal mass. (Wong, et al. 2007)

From this a strategy of modulating the interior envelope surface by patterns creates a design system that articulates and enhances the thermal performance of the envelope.

METHOD

Experiments are conducted to examine both the environmental performance and the visual expression of the patterning in relation to a multi layered breathing envelope. Physical design models of different designs are casted in both scale 1:1 and 1:10. The purpose is to get an understanding of the materiality and appearance of the patterning on the interior surface created by the design system and to get a more spatial notion of the design. A computational system is developed, with the purpose to calculate the performance in order to evaluate the specific design. And to optimize towards les temperature difference between the wall surface and the room by manipulating the wall surface.

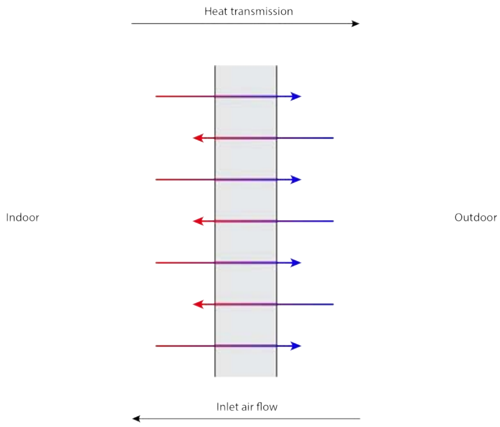


Figure 1
Principle of contra-flux. Inlet air is preheated by the heat transmitted through the wall.

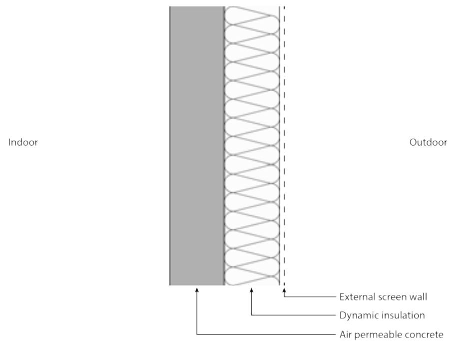


Figure 2
The order of the material layers of the envelope.

Envelope description

The tree layers of the envelope serves different functions for the performance and is arranged as illustrated in Figure 2. The protective exterior screen is in this study not detail more than being highly air permeable. The two main layers is the insolation and the concrete layers which in combination holds the possibility of achieving very low dynamic U-values by the insolation layer and grate heat recovery and thermal storages by the air permeable concrete.

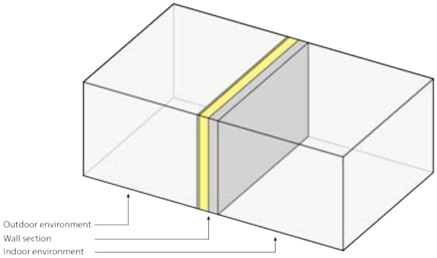


Figure 3
Theoretical setup for the investigation.

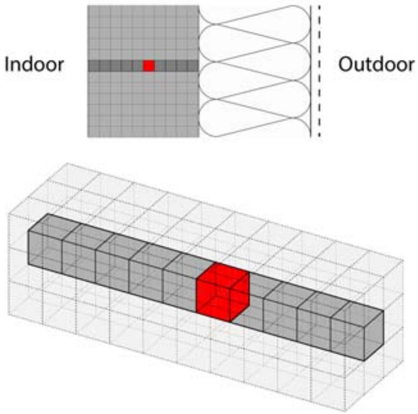


Figure 4
Arrangement of the segment for the thermal simolation of the envelope.

The setup used for the development of the envelope is as illustrated on Figure 3 consisting of three zones; an internal environment, an external environment and a wall section between the two. The external environment is defined by wind direction, wind speed and temperature, all other weather conditions is discarded. The weather data is DRY Copenhagen reference year for the period 07/01 - 11/01. For the internal environment the heat gains and the CO_2 pollution from people is calculated for at situation with 0,04 persons per cubic meters room and a metabolic rate of 1,2. In the usage time 08.00 - 16.00 the internal loads is 100% of the calculated and 10% at any other time.

To make concrete air permeable the void fraction between the aggregates is utilized to the formation of interconnected air channels through the material. Rounded aggregates bound together by cement bridges, leaving free air channels. The recipe and procedure used in this study is developed by Daniels et al. (Daniels et al. 2011).

Computational system

The computational system is based on the "Schematic of an integrated performance-based/driven architectural design platform" described by Xing Shi (Shi, 2010). It consists of a looping process between simulation, evaluation, optimization and generation (refer to Figure 5). The simulation starts with inputs from the weather data and the calculated internal loads. The generated envelope surface geometry is put through a series of operations to split it up in smaller pieces and is translated into numbers to feed into the equations of the simulation. In Figure 4 a representation of the arrangement of thes smaller pieces is shown for a section of the wall. Each cube is a volume fraction of the envelope. The segments is used to calculate the temperature change through the envelope by calculating the transmition between each segment for each time step.

The simulation outputs the CO_2 concentration and the room temperature in a graph as a function of time. A simulation will simulate for a period of 5 days for a winter situation. The results will then be analyzed and converted to a fitness number to feed into the evolutionary algorithmic software Rhinoceros Grasshopper plugin Galapagos de-

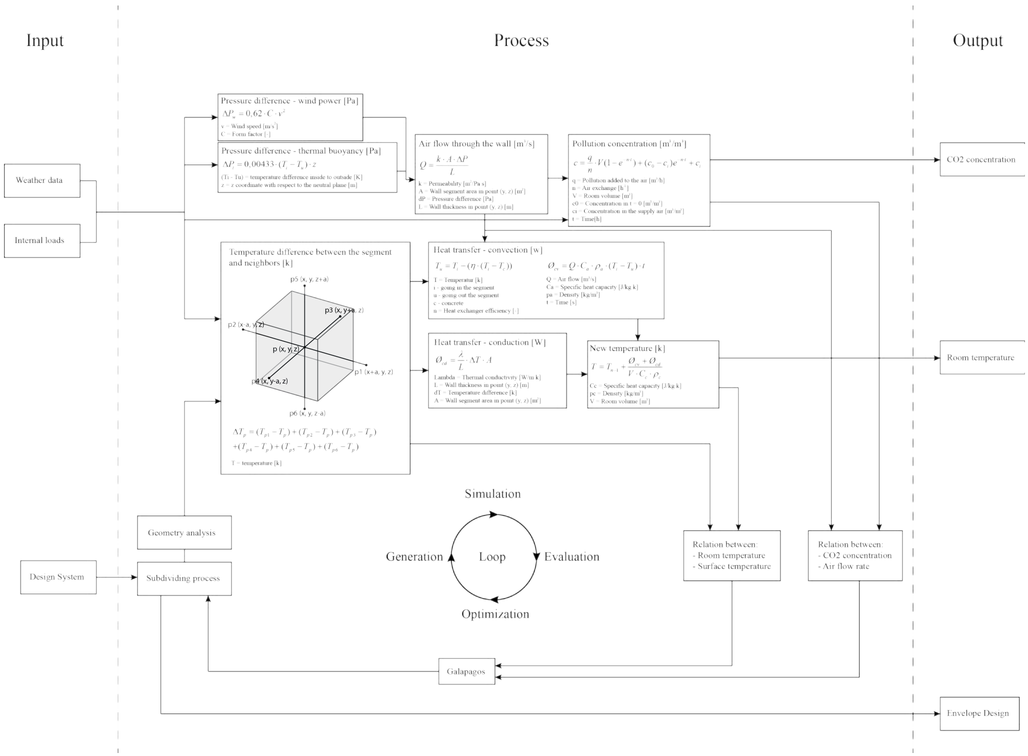


Figure 5
Flow chart for the simulation and the optimization process

veloped by McNeel, in order to generate a new design to be analyzed. The generation is based on a design system input outlining the boundaries for the design. The final output is then a design with corresponding performance simulation results.

Design system

The design system is based on a simple set of rules. A rectangular surface is split into two. A division on the center of the longest edge does this. These two new surfaces return as new inputs to be subdivided. Creating a pattern of fragments as the rectangles gets smaller as illustrated on Figure 6. The pattern can be varied by not returning some of the rectangles causing them to stop subdividing. The patterning can be controlled by different methods selecting which rectangles are returned. It can be towards a point or a curve as illustrated on Figure 7. The patterning is determining where on the wall there is a potential for enlargement of the surface area. It is the degree of subdivisions and the oscillation in depth of the pattern that determine the area and the subsequent performance of the envelope segment. Moving each face of the subdivided surface perpendicular with a distance defined by a function of sinus and thus oscillating the wall surface create the depth of the patterning.

RESULTS

It can be seen that giving different inputs to the design system outputs designs of different character-

Figure 6
Logic of the subdivision for the design system.

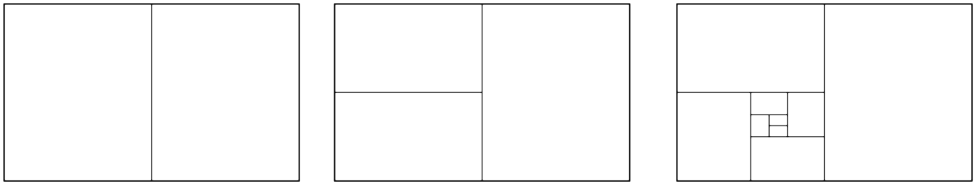
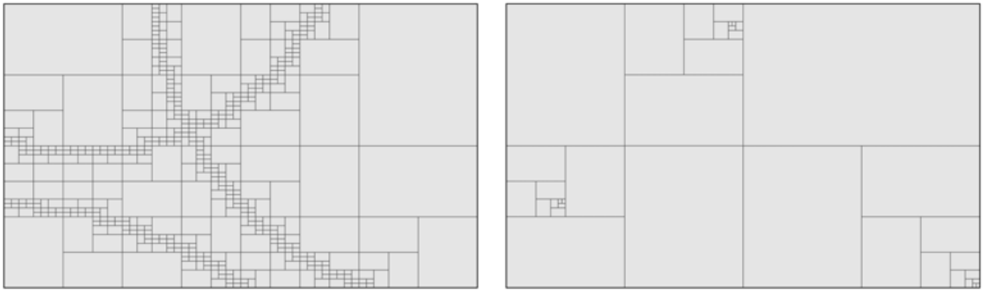


Figure 7
Example of designs for two different selection methods.



istics. The transparency in the selection of subdivision is largely affected by the method. The selection method with curves, see Figure 9, almost draws the curves on the wall with the patenting and thus the system of selection becomes easy readable. For comparison the point selection method, see Figure 8, appears more random and without a visible geometric logic. Still, if looking thoroughly on the pattern and understanding the design system, the point distribution can be read. This clear relation between inputs and appearance of the design gives the designer a large amount of control of the end resultant.

The simulation indicated a good possibility for using a multi layered breathing envelope as a method for natural ventilation, thereby reducing the need for mechanical ventilation systems. Furthermore, the optimisation process of the interior envelope surface showed only minor change in the thermal performance and primarily in the relation between the surface temperature and the room temperature. As the performance of the envelope is linked explicitly to the patterns created, a merge between architectural surface articulation and ventilation modification is evident. This allows for an architectural method where a designer has rich opportunities to express both visual and thermal perceptions simultaneously as an integrative design approach.

DISCUSSION

A multilayered breathing envelope with a light weight dynamic insulator and a heavy layer for heat recovery seems to be a promising source to energy efficient natural ventilation. The optimisation of the patterning showed only small improvements. To achieve improved results a local variation of the concrete layer thickness could be introduced, as the simulation indicates this to be a determining factors. Some aspects like vapor diffusion in the construction and solar gains were discarded to simplify the study.

This may reveal some challenges and benefits. Further studies must be carried out in order to identify the possible challenges related to above-mentioned alterations of the studies performed. Xing Shi suggests that performance-based architecture leads to "a paradigm shift from focusing on form and aesthetics to emphasizing the balance between traditional concerns of architectural design and the building's quantifiable and physical performances." (Shi, 2010) This study suggests that the aesthetics is as large a factor in performance-based architecture as it is today, but approached in a new way. The architect's role is to construct and guide the algorithm by means of designing the inputs and the framework for the computational process.

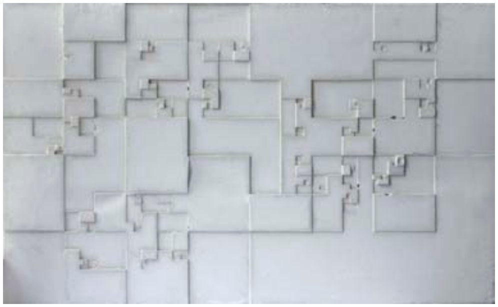


Figure 8
1:10 scale model of a patterning design towards points.

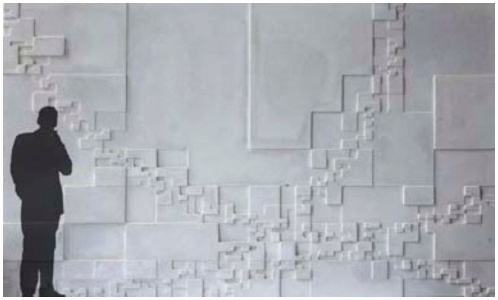


Figure 9
1:10 scale model of a patterning design towards curves.

Figure 10
1:1 model of a section of a envelope design.

ACKNOWLEDGMENTS

The execution of the physical experiments in the present study was only possible thanks to the material sponsors: DanSand A/S, Aalborg Portland and BASF.

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