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Paper: **Energy consumption as design principle re-investigated**

Topic: Architecture

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Abstract:
After WO-II in the Netherland the “Leitmotiv” in Dutch building industry was mass housing production. There were after the war far too few houses for the Dutch population, so the building industry sought ways to build houses in less time, mass production of dwellings. This resulted in the development of the so-called “doorzonwoning”. It was an easy and fast to build dwelling type, till to today this is still the most build housing type. To reduce the heat loss the cavity layer was partial filled with an insulation material.

It is our expectation that increasing the energy reduction of buildings cannot continue without changing the layout of the building and/or the layout of the neighborhood.

We start our experiment with a normal heat resistance (= 2.5 W/k) for the envelope and let the GA generate shapes that meet the energy performance coefficient given the spatial conditions. This experiment will consist of several runs of the application. For each run the EPC value will be decreased by 0.25. The application has to find values for the other parameters, as there are: building shape, heat resistance of the walls, number of floor levels, windows area in the walls, to fulfill the EPC constrain. Each of this set values are decoded into a building shape. In this way we can see what typical solutions are for a specific EPC value.

We expect to prove:

- That by decreasing the EPC-constrain there will be a turning point in the ‘shape’ development;
- That the shape will slowly grow into a cube. However it won’t be a perfect cube because of the fact that the ground floor has a better heat resistance then walls. To gain as much as possible positive influence of the sunlight, the windows will be located mainly in the south façade.

After several runs and plotting the results we noticed some contradictions to our beliefs in the behavior of the overall building shape. There was a turning point, after a certain value of the heat resistance there was an ‘explosion’ in the height of the building which resulted in narrow high-rise buildings. This outcome contradicted all our beliefs and hopes. In our paper we will discus our findings of this strange behavior and explain why it happened. We are aware that this phenomenon is a typical Dutch problem, but it shows building codes “as are” can’t be taken for granted as constraints in future low energy building decisions.
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Energy comsumption as design principle re-investigated

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Abstract. The goal of this research is to see what the influence is of reducing the energy consumption on the building layout. It is our expectation that increasing the energy reduction of buildings cannot continues without changing the layout of the building and/ or the layout f the neighborhood. During our experiments we noticed a strange phenomenon which contradicts our assumption. This paper is about the strange phenomenon we encounter and why it happened.

Keywords. Generic design; low energy housing; building code.

Introduction

After WO-II in the Netherland the “Leitmotiv” in Dutch building industry was mass housing production. There were after the war far too few houses for the Dutch population, so the building industry sought ways to build houses in less time, mass production of dwellings. This resulted in the development of the so-called “doorzonwoning”. It was an easy and fast to build dwelling type, till to today this is still the most build housing type. To reduce the heat loss the cavity layer was partial filled with an insulation material.

Because of the changing climate, energy consumption reduction has now become a hot topic in building industry. Early in the 1994 the Dutch government made a new building code to reduce the energy transmission for buildings and dwellings. The total energy performance of a building is expressed in an energy-performance-coefficient. This coefficient has to be less then 1.0 (for dwellings), the lower the better the energy performance will be. During the following years this index is decreased till 0.75 nowadays. In the future this index will be further decreased. However, up to now this has not lead to dramatic changes in the architectural layout of buildings.

There is tendency in the building industry first increases the insulation (more insulation or newly development insulation materials) in the building envelope as an easy way to fulfill the energy reduction constraint. However there will come a point at which further increasing of the insulation layer will gain less reduction against substantial extra costs. In cavity walls there is a max thickens of insulation, beyond that point the cavity isn’t working as one wall but as two walls which has an decrease in structural performance.

Our approach to Generative Design takes the Dutch building codes and regulations as a starting point. It is our expectation that increasing the energy reduction of buildings cannot continue without changing the layout of the building and/or the layout of the neighborhood. In our research we tried to backup this expectation. In order to validate our assumption we use a simple test design housing project, consisting of 8 rooms, each with a minimum and maximum area. This simple client’s brief is a typical requirement for a Dutch one-family house. The relations and areas of the rooms are presented table 1.

Rooms	Relationship between rooms											
Name	Min.	Max.		V1	V2	V3	V4	V5	V6	V7	V8	B
Circ.room space	2	10	V1									
Entree	2	10	V2	■								
Living	15	40	V3		■							
Kitchen	10	15	V4									
Bedroom 1	20	25	V5		■	■	■					
Bedroom 2	12	15	V6		■	■	■	■				
Bedroom 3	12	15	V7		■	■	■	■	■			
Bathroom	5	10	V8		■	■	■		■	■		
Environment	-	-	B	■				■	■	■	■	
Total area	78	140										

Table 1
Clients brief

In our search for new dwelling types which are better suited for low energy housing (Zee and Vries 2003), we use a simple genetic algorithm to generate alternative solutions.

The project consists of two experiments:

1. -The first experiment was to investigate if the GD system can find an optimal overall shape. In the next paragraph we will explain the experiment in more detail;
2. -In a second experiment we will investigate if the genome can be extended in a way to see what the influence of the separate rooms is on the overall shape.

Constrains

Energy consumption reduction is implemented by the government in the Netherlands and many other countries by gradually reducing the energy performance coefficient over the past years. Designers and engineers have adjusted their design and materials such that could meet the new standard. However, up to now this hasn't lead to dramatic changes in the architectural layout of buildings. Our aim in this experiment is to find this point through the generation of design alternatives for housing as a function of decreasing energy consumption. We start with a normal heat resistance (= 2.5 W/k) for the envelope and let the GD generate shapes that meet the energy performance coefficient given the spatial conditions. Subsequently, the energy performance coefficient will be reduced to study the changes in spatial layout.

In order to generate alternatives, which can be tested against the energy performance constraint and spatial conformances, the design is parameterized. We depict housing, as parameterized apartments, corridors and envelopes. Each of the parameters represents physical, geometrical and topological properties. By systematically changing these variables, the GA (Goldberg, 1989; Holland 1992) is able to generate alternative spatial configurations and envelope sections (Vries, Zee and Carp, 2004).

In our first experiment we use the GD from earlier experiments (Zee and Vries, 2003) with a few minor adaptations to the new problem. First of all we had to adjust the genotype to the new problem and secondly we used less constrains. For this experiment we only used a few basic parameters concerning:

Shape of the building;

Heat resistance of the walls;
Area of windows in walls;
Energy performance of the building (EPC).

In the next sections we will briefly discuss the constraints, the "Energy performance of the building" constraint we will discuss in more detail.

Building shape

Each dwelling is considered as a shape with a constant volume but different measurements. The overall shape of the building is a summation of different volumes (= dwelling). The form for the building will be parameterized, into 3 variables namely the width, length, and number of floors. These properties will affect all other constrains.

For our experiments we use a building block consisting of 30 dwellings. Each dwelling has max area of 140 m2, see table 1. According to Dutch regulation the minimum ceiling height is 2.70m, for the height of the ground floor and "roof" for used 0.30 m, so the resulting gross height of a dwelling is 3.30m. By keeping the volume constant we can change the overall building shape, two possible extreme forms are shown in figure 1. The left building represents a high rise building and the right one a regular small town street building block.

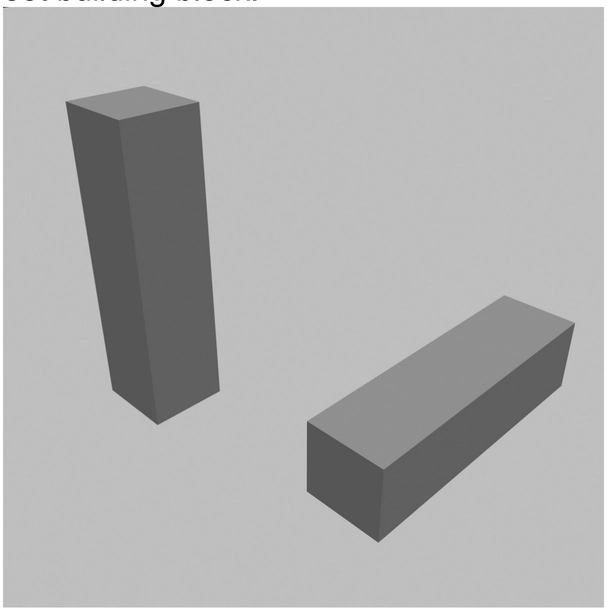

Figure 1
Extreme solutions

Heat resistance of the walls

In the Dutch building regulation the minimum heat resistance for outside walls is 2.5 K/W. If the wall consists of 40 cm fiber wool with a lambda of 0.025 W/(m.K) the heat resistance would be 16 W/k, so if we choose a maximum value 20 instead of ∞ we get a bandwidth for the solution will be is 2.5< Rc <= 20.

Area of windows

In order to translate a grid from the genotype we translate the genotype-number back into ‘1’ and ‘0’. A ‘0’ corresponds to a closed wall and a ‘1’ correspond to a window.

This array is a 1 dimensional representation of a 2 dimension grid, see figure 2. In this way there is flexibility in window size, shape and location.

Figure 2
Window grid

The number of possible windows solutions is controlled by the grid dimensions. For a draft design a grid of 3 x 8 is adequate. Each grid size has it own maximum number, $2^{(i+j)} + 1$, where I en j are the grid dimensions. The maximum number corresponds with a wall made entirely out of glass.

Energy consumption code

In the Netherlands the energy performance of a building is calculated according to a national norm (NEN, 1998). The current building code has some extensions, it also take in account the heat loss through the cracks in windows and doors. This norm provides the terminology and calculation methods of the energy performance of dwellings.

The energy performance (Qpres_tot) is a function of the total outside area of the building enclosures, the heat resistance of the used materials, window orientations and 'living'-area, used heating installation etc. The total energy performance of a building is expressed in the energy-performance-coefficient (EPC). The objective is that this coefficient is less then 1.0, the smaller the better the energy performance will be. We will discuss the energy-performance-coefficient briefly, it will show that the method is more then the calculation of the heat loss through the building envelope, as is a mostly used calculation method especially in the HVAC industry.

The EPC is calculated according to equation 1 (NEN, 1998).

$$EPC = Qpres\_tot / (330.0 * Ag\_verw + 65.0 * Averlies) \quad (1)$$

Where:

EPC	Energy performance coefficient	Ag_verw	Total ‘living’ area of the heated spaces
Qpres_tot	Characteristic energy consumption of a building	Averlies	Total heat loss area of a building

These parameters will be explained briefly for a better understanding of the complete EPN calculation.

By summation of the all the areas of the heated spaces we get the total ‘living’ area of the heated spaces (Ag_verw);

The total heat loss area of a building (Averlies) is the summation of all the projected areas of the building envelope (Ai) multiplied with a reduction factor (di).

Characteristic energy consumption of a building is a summation of different energy consumption artifacts making the total building HVAC system:

$$Qpres\_tot = Qprim\_verw + Qprim\_tap + Qprim\_vent + Qprim\_vl \quad (2)$$

Where: -

Qpres_tot	Characteristic energy consumption of a building	Qprim_vent	Primary Energy consumption due to ventilation
Qprim_verw	Primary Energy consumption due to heating	Qprim_vl	Primary Energy consumption due to lighting
Qprim_tap	Primary Energy consumption due to heating drink water		

The energy lost by ventilators (Qprime_vent) is a summation over all used ventilators for ventilation and /or air heating.

The energy lost by lighting (Qprim_vl) is depended of the total heated area of the building.

For the energy lost of heating tap water (Qprim_tap) we used the simplified method which is depended of the total heating area and the efficiency of the system.

The energy lost due the heating is a more complex calculation.

$$Qprim\_verw = (((Qwb;verw / \eta sys;verw) - Qze;verw) / \eta opw;verw) + Qhulp;verw \quad (3)$$

Where:

Qwb;verw	The net heat-requirements for space-heating	ηopw;verw	generation-efficiency of the heating system
Qze;verw	Annual energy gain by a solar energy system -	Qhulp;verw	Energy consumption of the heating system, when not used for heating the building
ηsys;verw	System-efficiency of the heating system		

The ηsys;verw, ηopw;verw and Qhulp;verw are system depended variables in some case constants. The Qze;verw is depended of system efficiency, orientation and a shading reduction factor. We won't go into further detail of these variables.

The net-heating requirement for a building is a complex calculation and we will only discuss it briefly.

$$Qwb;verw = Qverlies - \eta b \cdot Qwinst \quad (4)$$

Where:

Qverlies	Heat loss due to heating and ventilation of a building	Qwinst	Heat gain by solar energy and internal heat production
ηb	Heat gain utilization coefficient		

The heat gain utilization coefficient (ηb) is depended of the ratio between the heat loss and heat gain of a building.

The total heat loss is a summation of the heat loss due to transmission (Htr) and to the heat loss due to ventilation (Hvent). The Htr is the actual heat loss calculation, and is the multiplication of envelope areas; reciprocate of the heat resistance and a constant. The heat lose by ventilation is depended of the airflow-volumes of the used ventilation systems.

The total heat gain is a summation of the heat gain through all windows and is depended of the window area, orientation, rotation and a shading reduction factor.

First Experiment and conclusions

After a few test runs we decided to simplify the model more and leave the "windows area" constrain out. This simplified the calculations because the energy gain due to the solar energy and the orientation of the building is omitted. For some variables, in the EPC calculations, we use the suggested fixed values.

	R_c [W/k.m]	EPC [-]	L [m]	W [m]	H [m]	Floors [-]	A0/V [m^{-1}]	Ag [m^2]
1	2.0	1.04	24	25	18.9	7	0.27	4200
2	2.5	1.00	21	25	21.6	8	0.27	4200
3	3.0	0.98	20	19	29.7	11	0.27	4180
4	3.25	0.97	19	18	32.4	12	0.28	4104
5	3.5	0.96	20	15	37.8	14	0.29	4200
6	3.625	0.95	17	16	40.5	15	0.29	4080
7	3.6875	0.95	11	7	145.8	54	0.48	4158
8	3.75	0.95	9	8	156.6	58	0.48	4176
9	4.0	0.93	9	7	178.2	66	0.52	4159
10	4.5	0.65	31.0	1.0	348	129	2.07	4003
11	10.0	0.65	31.0	1.0	348	129	2.07	4003

Table 2
Results

We did a number of runs, each with an increased heat resistance value for the walls, see table 2. Between an Rc-value of 3.5 and 4 we noticed a strange behavior of the building shape. In order to investigate it further we decreased the step size between the consecutive heat resistances. In the plotted curve, see figure 3, discontinuance between 3.5 and 4 can be noticed, there is an unexpected increase in the height of the building shape while the length and width of the building decreases.

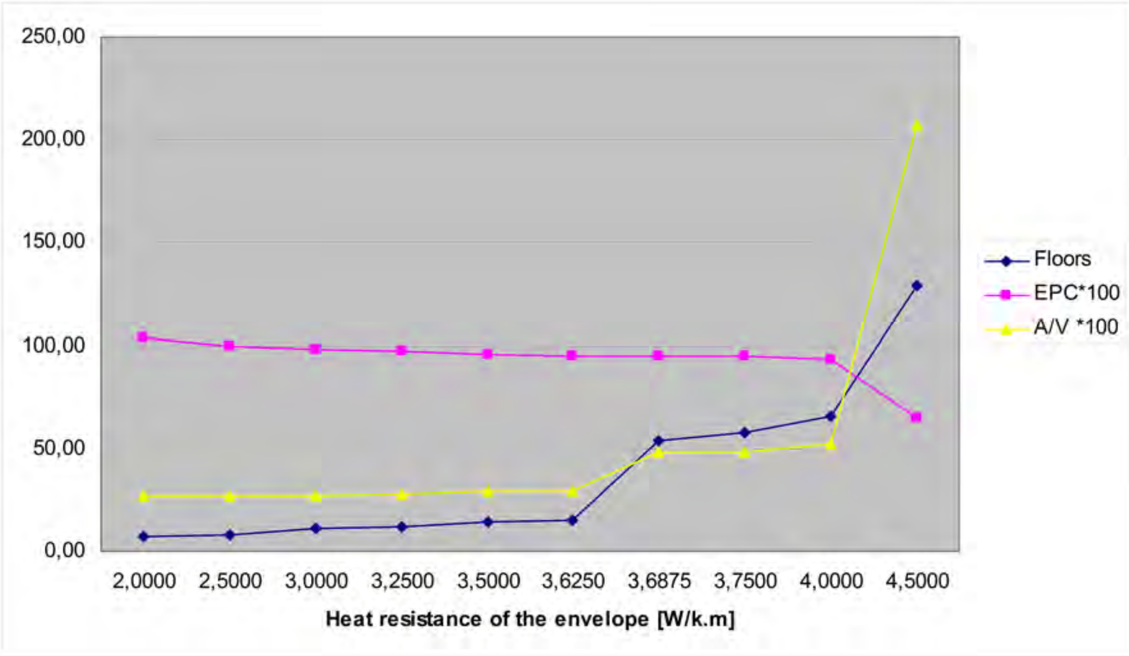

Figure 3
Plotted results

As we mentioned earlier in the discussion of the EPC calculation method, some parameters are more or less solely depended of the heated area, while the heat loss (Htr) is solely depended of the building envelope area and heat resistance. A decrease in heat loss due to an increase in the insulation has no effect on the energy consumption of for instance the heating of drinking water (see Qprim_tap). The later is more or less a "constant" in the EPC calculation of a building with a constant floor area. There is a mathematical turning point in the EPC calculation, where the energy consumption due to heat loss through the envelope, is getting less then the energy consumption of the "constant energy consumers". The turning point is where:

Htr == Qprim_tap+Qprim_vent+Qprim_vl (5)

Beyond this point the energy consumption is "slowed" down, increase in insulation thickness results in a relative minor decrease in the total energy consumption. The fraction of the "heatloss through wall" becomes relative small in the total energy consumption of the building.

The genetic algorithm is trying to minimize the EPC constrain. As we mentioned the EPC is depended of Qpres_tot, Ag_verw and Averlies (see eq 1). Beyond the turning point, increase in the insulation thickness results in a relative small decrease of the total energy consumption. Even an increase in the building envelope area has a small effect on the total heat loss because of the heavy insulation of the envelope of the whole building, thus the only parameter left to change is the Averlies (= heat loss area of the building). The genetic algorithm makes the tradeoff between increasing the Averlies against a relative small increase in Qpres_tot in order to gain a decrease in the EPC-coefficient.

Overall conclusion

Overall we can conclude that a genetic algorithm is a great tool for generation alternative forms. These alternatives can be use for different tasks, such as performance checking. In very short time you can explore many alternative solutions. But it all depends on the constraints. As we noticed in our experiment you can't translate building code out of the box into a constraint. However by the huge amount of calculations you gain quickly insight in the code and it limitations.

Secondly the EPC-coefficient isn't a good tool in optimization of building shapes with respect to the energy consumption. As we learned form this experiment the use of a simple heat loss calculation probably do better then the complex EPC which is used in the building regulations.

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