

Comparing district designs

Screening analysis of the critical factors at the building level

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Abstract: More and more urban designs show the appliance of low-energy techniques. Unfortunately, it is difficult to determine which one of these urban designs has the best results for energy consumption and CO₂-emissions because of a lack of methods and techniques at district level. A new energy performance calculation method at district level including aspects like houses, transport and households is presented. In this paper we focus on the critical factors at the building level that should be included in a district data model. Therefore we have executed a screening analysis to indicate what the critical factors are.

1. INTRODUCTION

1.1 Energy saving is needed

Environmental issues show energy saving is needed. In the first place, our energy use is increasing while our (fossil) energy sources are decreasing. The estimated years of production for oil, gas and coal are 45, 65 and 200 years respectively (Ministerie van Economische Zaken, 1995, World Energy Council, 2004). Developing countries like China and India might even accelerate running out of these energy sources. Therefore techniques are developed to use renewable energy sources, like wind, sun and geothermal heat.

Secondly, most countries made agreements on CO₂ reduction because of the climate change. CO₂ is one of the gasses that increases the climate change. The European Union aims to reduce the CO₂ emissions with 20% in 2020 according to 1990.

The built environment is responsible for 40% of the total energy consumption in Europe (Sunikka, 2006). Which makes exploration of the possibilities to reduce energy in the built environment relevant. The amount of energy saving solutions enlarges when a district or even a whole city is considered instead of a individual building which is the daily routine.

1.2 Evaluation district plans

The need for energy saving in the built environment influences designs for buildings, district and cities. More and more designers are incorporating energy saving techniques and construction methods. One example is the Beddington Zero Energy Development project (BedZED) designed by Bill Dunster Architects and built in England. This district consists of houses and offices built close to each other. Every house receives a great amount of daylight, while the opposite applies to the offices. Materials from the area, with low impact on the environment, have been used. To generate electricity for all buildings, solar panels and combined heat and power systems are being used.

Two other designs worth mentioning called 'Masdar city' and 'Dongtan Eco-city', are actually competing with each other to become the thirist zero carbon city in the world. Masdar city, a design by Foster and Partners will be built in Abu Dhabi. The design for the Masdar city has an area of 6 km² and houses 47.500 resident's and 60.500 workers. The buildings will have a maximum of five building stories to prevent the use of elevators. Walking and public transport is encouraged through the management of the streets. And the sidewalks are overshadowed through narrow streets and solar panels

which will generate electricity for the whole city accompanied by wind farms. Probably solar collectors will be used to generate hot water.

Dongtan Eco-city, a design by Arup, is planned near Shanghai. In this even larger city 500.000 residents will be housed. The dense district consists of low rise buildings, with a maximum of six stories and narrow streets. The walking distances are limited and batteries or fuels cells will be used for transport by car. A combined heat and power system will provide heat and electricity for the whole city together with small wind turbines. Finally, residents behaviour is influenced with energy meters in buildings and energy use boundaries.

All three designs have different solutions for an low-energy or energy zero district. With the current techniques and methods, mostly applicable for individual buildings, it is hard to determine which of these urban designs has the best results for energy consumption and CO₂-emissions. Therefore new techniques and methods need to be developed for district evaluation to support designers and decision makers.

1.3 Objective

The objective is to develop a district evaluation model based on energy performance, costs and comfort. Figure 1 shows a schematization of the evaluation model.

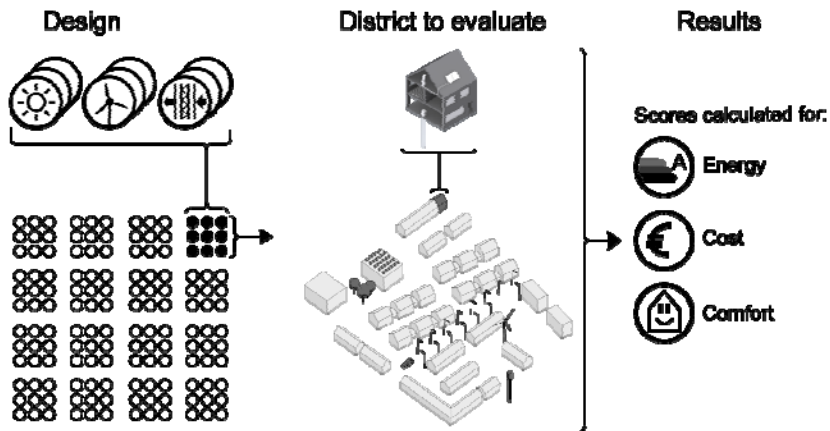


Figure 1. Schematization district evaluation model

On the left, single design solutions, like solar energy and insulation, are arranged in a solution package. These packages are applied to the district design. Next, the evaluation model will return scores for energy performance, costs and comfort. And finally an optimization technique is used to compare the results for each design package and return the user a top ten of design solutions.

1.4 Deliverables

The following methods and techniques will be used or developed and eventually implemented in a prototype evaluation model:

1. Energy and comfort performance calculation at district level, based on existing methods at building level like EPN, EPA.
2. District data model based on existing methods like IFC, Het Digitale Huis.
3. Residents' preferences measurement method for the determination of the preferred design solution, based on existing methods like semantic differentials, conjoint analysis.
4. Optimization technique for the determination of the optimal design solution.

In this paper the development of an energy performance calculation method at district level will be discussed.

2. RESEARCH METHODS

2.1 Average district energy consumption

The average energy consumption and CO₂-emissions of objects like houses, streetlights, traffic flows and households are used to develop a district energy calculation method. Table 1 shows houses have the largest contribution to the energy consumption in a district. The value shown in table 1 is the average energy use of the Dutch housing stock and considers energy needed for heating, hot water and appliances (SenterNovem, 2007b). For heating, the energy consumption strongly depends on the building period and housing type. Generally, detached and semi-detached houses have higher values for energy consumption and CO₂-emissions than row houses and apartments. The same applies for old and new houses because of moderate insulation and outdated systems.

The amount of CO₂-emissions produced by transportation strongly depends on the type of transport and the travelling distance. The CO₂-emissions produced by transport, shown in table 1, are based on an average household consisting of 2,3 persons¹. Transport by car, assuming an average travelling distance of 15.500 km per year, has the second largest contribution to the CO₂-emissions in a district.

The amount of electricity needed for streetlights, given per house (Rooijers, F., S. Moorman, et. al, 2001), is very small compared to the contribution of the houses and transportation. Therefore this aspect could be left out in the district energy performance calculation.

Table 1. Average energy consumption and CO₂-emissions in the Netherlands per year

Aspect	Object	Consumption	CO ₂ -emissions	Year
House	Electricity	3346 kWh	1,9 ton	2004
	Gas	1736 m ³	3,1 ton	2004
Transport	Car	15.500 km	3,0 ton	2008
	Public transport		0,2 ton	2008
	- Train	894 km		
	- Bus, tram, metro	409 km		
Streetlights	Airplane	1300 km	0,8 ton	2008
	Electricity	150 kW	0,085 ton	2001

2.2 Aspects to take into account

The previous paragraph concluded that houses and transportation are the most important aspects to taken into account for evaluating the energy consumption and CO₂-emissions in a district. The new district energy calculation method will evaluate the systems and building constructions in the district, the households and their transport (figure 2).

Because existing energy performance calculation methods consider mainly an average household with a certain user behaviour, the actual and calculated energy consumption can differ. The user behaviour has a large influence on the eventual energy consumption. Research shows differences in energy consumption between households living in the same houses (Soethout, Peitsman, et al 1999). Therefore the household is included in the new district energy performance calculation.

To compute the energy consumption for systems and building constructions in the district, existing Dutch calculation methods will be used. To predict the type of transport and transportation distance a Dutch simulation model will be used. This model is capable of predicting the transport activities for an household. In the next section we describe which models are used and how they are integrated into one district model.

¹ www.milieucentraal.nl

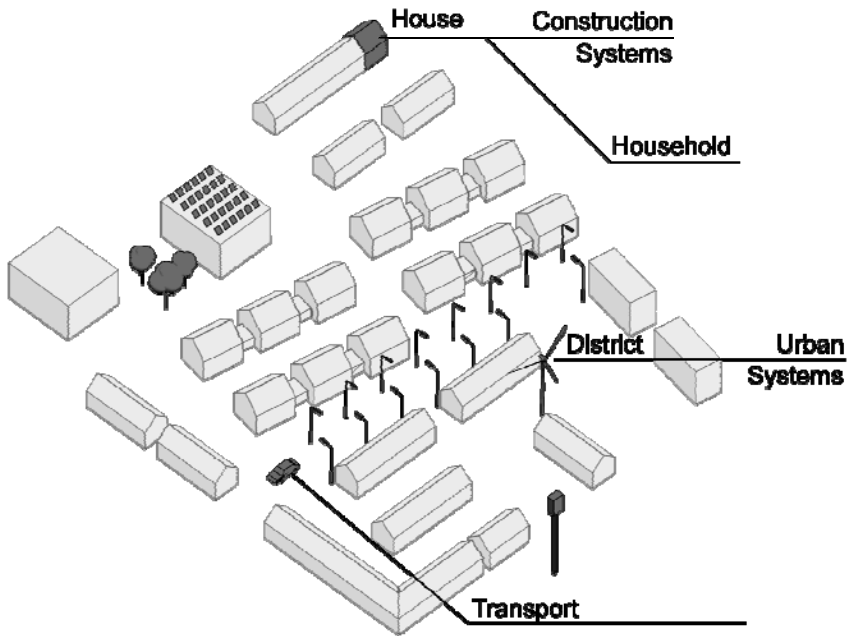


Figure 2. Aspects in new district energy performance calculation

2.3 Software structure

The first prototype of the district evaluation model will consist of the existing Dutch calculation methods EPA (Energy Performance Advice) and EPL (Energy Performance of a Location). The EPA is used in the Netherlands to compute the energy performance of a building and to create an energy label which is required when selling or renting certain house-, commercial or industrial buildings in the Netherlands. The EPL, mainly used by the government, is helpful to fix energy performance goals for a certain location and often applied to new districts or renovation projects.

The new district energy performance calculation will eventually be part of the evaluation model schematised in figure 1. The structure of the new energy calculation method is shown figure 3. Data from the district and the design solution packages are collected in a district data model. The evaluation model translates this data into input values needed for the existing

calculation methods EPA and EPL. Next the energy performance results are retrieved. And finally the evaluation model returns for each design solution package a score for energy performance to the user.

In a later stadium the remaining items household and transport will become part of the district data model.

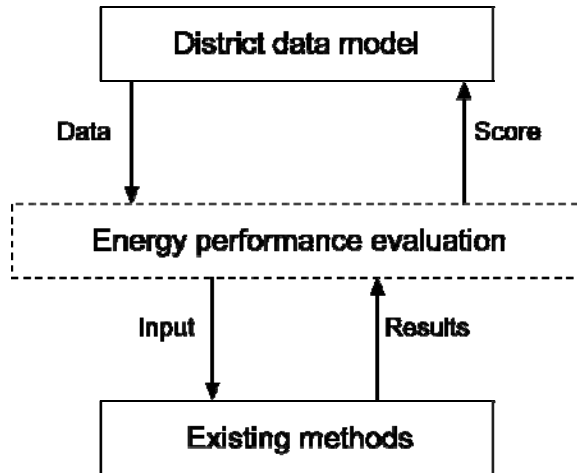


Figure 3. Software structure prototype evaluation model

2.4 Screening analysis at the building level

In total 99 input values are needed for the EPA calculation method to compute the energy performance of a house. Because of this large amount of input values, a screening analysis is performed to find the most critical factors at building level. The screening technique evaluates a single input value while the other input values are fixed. For each single input a minimum and maximum value is used to find out how large the influence on the output is.

The EPA calculation method computes among others the energy index (EI), the energy use for heating, hot water, ventilation and lighting, and the amount of CO₂-emissions. For the screening analysis the influence on the energy index, total energy use and CO₂-emissions is evaluated. The energy index describes a score for energy performance, how smaller the number, the better the energy performance.

Some of the single input values are related to others, like the usable floor area and the façade area, which makes a single input evaluation not useful. To research the influence of these input values on the output, data of reference houses is being used (SenterNovem, 2007b). This data describes average Dutch houses divided into building type, like row, detached and semi-detached houses and building period.

The dependent input values receive fixed values from the reference houses while the independent input values are varied with a minimum, maximum and intermediate value which is derived from the reference house. To find out if the dependent input values have a large influence on the output, the results of the screening analysis per building type and per building period are compared.

Table 2 shows the dependent and independent input values in the EPA calculation method. The total amount of input values shown in this table is lower than the amount mentioned earlier because for the first screening analysis the district systems are not evaluated and the input values concerning the front, back, left and right façade are combined in the table. For each dependent variable, the variables it depends upon are noted between brackets. Some input values have both dependent and independent characters. For instance, the supply temperature has an independent character when the delivery system ‘radiator’ is chosen (three options) and dependent in case of underfloor heating (one option).

Table 2. Dependent and independent variables in EPA calculation

Variable	Dependent	Independent
1. Average inside temperature		x
2. Ventilation correction factor		x
3. Internal heat production		x
4. Amount of residents		x
5. Usable floor area	x (8,12,16,19,22)	
6. House type	x (5,8,12,16,19,22)	
7. Roof type		x
8. Façade, opaque area	x (5,6)	
9. Façade, opaque thermal insulation		x
10. Façade, opaque boundary condition		x
11. Façade, transparent orientation		x
12. Façade, transparent area	x (5,6)	
13. Façade, transparent thermal insulation		x
14. Façade, transparent sun access factor		x
15. Façade, transparent boundary condition		x
16. Floor, area	x (5,6)	
17. Floor, thermal insulation		x
18. Floor, boundary condition		x
19. Roof, opaque area	x (5,6)	
20. Roof, opaque thermal insulation		x
21. Roof, transparent orientation		x

	Variable	Dependent	Independent
22.	Roof, transparent area	x (5,6)	
23.	Roof, transparent thermal insulation		x
24.	Roof, transparent sun access factor		x
25.	Airtightness		x
26.	Individual/District system		x
27.	Ind. heating system, type	x (26)	x
28.	Ind. heating system, electronic ignition	x (27)	x
29.	Ind. heating system, inside building envelope		x
30.	Ind. heating system, supply temperature	x (27)	x
31.	Ind. heating system, delivery system	x (30)	x
32.	Ind. heating system, optimal control		x
33.	Ind. heating system, individual energy bill		x
34.	Ind. heating system, pipes in unheated rooms		x
35.	Ind. heating system, insulated pipes	x (34)	
36.	Hot water system, type		x
37.	Hot water system, location		x
38.	Hot water system, kitchen boiler		x
39.	Hot water system, circulation pipe	x (36)	x
40.	Hot water system, insulated circulation pipe	x (39)	
41.	Hot water system, dishwasher		x
42.	Hot water system, shower		x
43.	Hot water system, water-saving showerhead		x
44.	Hot water system, bath		x
45.	Ventilation system		x
46.	Ventilation heat recovery efficiency	x (45)	x
47.	Fan type	x (45)	x
48.	Solar boiler, type		x
49.	Solar boiler, individual/district		x
50.	Solar boiler, area per household		x
51.	Solar boiler, contribute to heating system		x
52.	Solar boiler, contribute to hot water system		x
53.	Solar boiler, area	x (48)	
54.	Solar boiler, orientation		x
55.	Solar boiler, angle		x
56.	Solar panel, type		x
57.	Solar panel, area		x
58.	Solar panel, orientation		x
59.	Solar panel, angle		x

3. RESULTS

The single input influence on the output is computed for each independent variable and discussed in paragraph 3.1. To find out how large the influence of the dependent input values is, the output results are compared among five building types (paragraph 3.2) and among four building periods of a row house (paragraph 3.3).

3.1 Single input influence

In total nine different reference houses, consisting of five building types and four building periods for a row house, are used in the screening analysis. For each reference house the independent input values, shown in table 2, received a reference, minimum and maximum value. Per single input the energy index, total energy use and CO₂-emissions are computed for the reference, minimum and maximum value. In case of a large difference between the output results caused by the minimum and maximum input value, the input influence on the output is large.

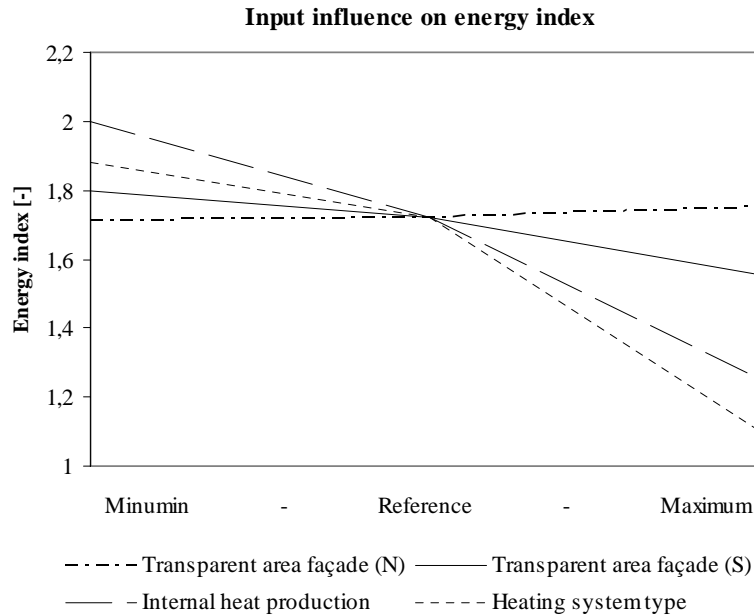


Figure 4. Comparison input influence on output

An example of input influence on the energy index is shown in figure 4. The reference house used for this graph is a row house built before 1946 with an energy index of 1,72. The input variable ‘transparent area in the façade on the north’ has a minimum value of 1 m² which gives an energy index of 1,71 and a maximum value of 28,2 m² (total façade area minus 1) with an energy index of 1,75. This shows, more glass on the north will give worse results for the energy performance. The opposite applies to the input variable ‘transparent area in the façade on the south’. A larger area of glass

on the south gives, with an energy index of 1,55, much better results for the energy performance.

The input variable ‘internal heat production’ shows also better results for the maximum value according to the minimum. This was to be expected, because larger internal heat production lowers the heat demand and therefore the use of energy. The last input variable shown in figure 4 is the ‘type of heating system’. The system with the highest efficiency (maximum) gives the best results for energy performance.

The four input variables in figure 4 show the differences between the influence on the output, in this case the energy index. When we do the same for all independent variables shown in table 2, the most important input values are related to thermal insulation, residents’ behaviour and systems. In the field of thermal insulation, the roof, façade and glass have the largest influence on the output. The input values related to the residents’ behaviour, named average inside temperature, internal heat production, amount of residents and the ventilation correction factor show a large influence on the output. The same can be said about the type of heating, hot water and ventilation system.

3.2 Housing type influence

The comparison of five different reference houses, consisting of a row house, detached house, semi-detached house, maisonette and apartment, shows the influence of the dependent input values like usable floor area, building envelope area and percentage of glass in the façades. The main differences between the reference input values for the five building types are the usable floor area, amount of residents, building envelope area and percentage of glass in the façades. To exclude differences caused by insulation, the five reference houses are all from the same building period (< 1966). The results for the energy index, total energy use and CO₂-emissions shown in table 3 differ a lot between the five different building types. This shows the input values usable floor area, building envelope area and percentage of glass in the façades have an influence on the output.

Table 3. Results EPA calculation for five different building types

Building type	Energy index	Total energy use	CO₂-emissions
	[-]	[MJ]	[kg]
Apartment	1,71	41300	2172
Maisonette	1,60	55705	2893
Row house	1,68	65266	3382
Semi-detached	2,10	108115	5560
Detached	1,98	190925	9831

Besides differences between the building types caused by the dependent variables, the independent variables appear to have different influence on the output. When we look at the input values with the largest influence on the output mentioned in the last section of paragraph 3.1, some of them have equal results for each building type, this applies to the thermal insulation of the roof. Others show an increasing influence on the output in case of a bigger house, like the average inside temperature and the heating system. But most of the input values show an increasing influence when the house is enlarged. The graph in figure 5 shows the influence of the thermal insulation of the façade on the energy index for four different building types. The apartment is left out of the graph because it had almost equal results as the row house. The minimum value for the façade insulation is $0,1 \text{ m}^2\text{K/W}$ and based on a 100 mm concrete wall. The reference value is $0,36 \text{ m}^2\text{K/W}$ and the maximum value is $8,0 \text{ m}^2\text{K/W}$, based on the passive house concept.

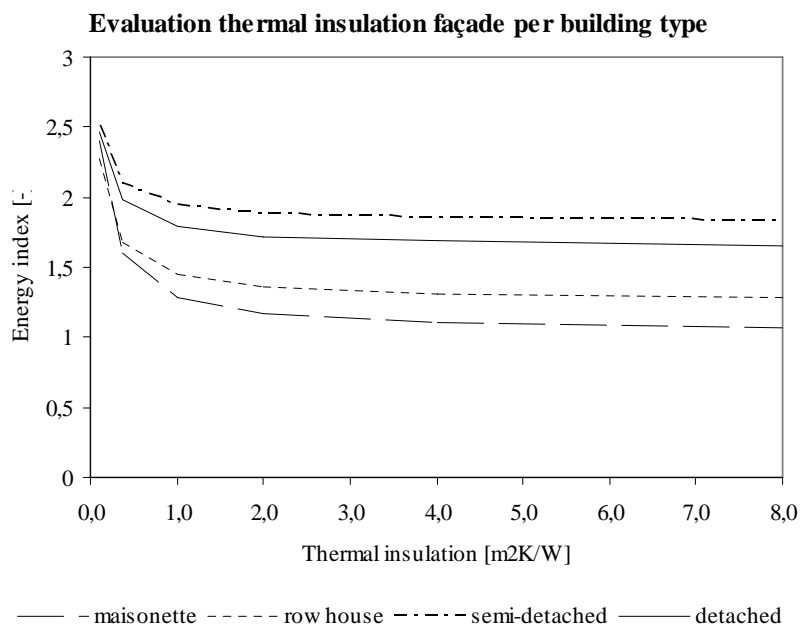


Figure 5. Comparison influence thermal insulation (façade) on EI per building type

3.3 Building period influence

The comparison of four different reference houses, consisting of a row house built before 1946, between 1946-1965, 1976-1979 and 1989-2000, shows the influence of the dependent input values like usable floor area, building envelope area and percentage of glass in the façades. The main differences between the building periods are mainly the thermal insulation of roof, floor and façade and the presence of a bath. The usable floor area, amount of residents, building envelope area and percentage of glass in the façades differs only little. To exclude the differences caused by the size of the houses, the building type is kept the same. The results for the energy index, total energy use and CO₂-emissions shown in table 4 differ between the four different building periods. This shows the input values thermal insulation of roof, floor and façade and the presence of a bath have an influence on the output. The last section of paragraph 3.1 already mentioned the large influence of the thermal insulation of the roof, façade and glass on the output.

Table 4. Results EPA calculation for a row house and four different building periods

Building period	Energy index [-]	Total energy use [MJ]	CO₂-emissions [kg]
< 1946	1,72	69199	3582
1946 - 1965	1,68	65266	3382
1976 - 1979	1,42	59779	3112
1989 - 2000	1,20	49261	2610

Besides differences between the building periods caused by the thermal insulation of the roof, floor and façade and the presence of a bath, the independent input values appear to have different influence on the output. When we look at the input values with the largest influence on the output mentioned in the last section of paragraph 3.1, most of them have equal results for each building period. The average inside temperature, floor boundary conditions and heating system show an decreasing influence on the output when the building period is younger (better insulation). The graph in figure 6 shows the influence of the average inside temperature on the energy index for three different building periods. The building period 1946-1965 is left out of the graph because it had almost equal results as the building period < 1946. The minimum value for the inside temperature is 10 °C, the reference value is 16,5 °C and the maximum is 20 °C.

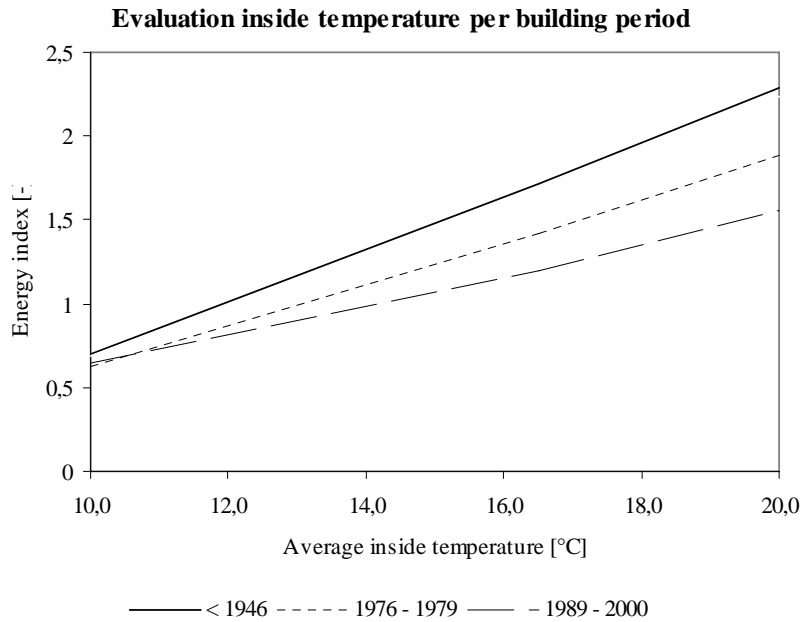


Figure 6. Comparison influence inside temperature on EI per building period

4. CONCLUSION

4.1 Independent input

Nine different reference houses, consisting of five building types and four building periods for a row house, are used in the screening analysis. Table 5 shows the most important independent variables in the EPA calculation.

For each independent variable, the minimum and maximum value for the energy index, total energy use and CO₂-emissions is determined to find the most important independent variables. The difference is divided by the reference value to compare the results among the independent variables. For instance the variable 'thermal insulation of the roof':

- minimum input value gives an energy index of 3,21;
- maximum input value gives an energy index of 1,58;
- reference value in case of a row house built before 1946 is 1,72.

- this gives a score of 0,95 as shown in the equation beneath.

$$\frac{|EI_{\min} - EI_{\max}|}{EI_{ref}} = \frac{|3,21 - 1,58|}{1,72} = 0,95$$

Because the influence of the independent variables differs per building type and building period, the average score for the nine reference houses is shown in table 5. The higher the score, the larger the influence of the variable on the output.

Table 5. Most important (independent) input values EPA calculation

	Input	Energy index	Total energy use	CO₂-emissions
1	Roof, opaque thermal insulation	0,981	0,980	0,953
2	Average inside temperature	0,885	0,885	0,862
3	Façade, opaque thermal insulation	0,578	0,578	0,560
4	Internal heat production	0,445	0,473	0,459
5	Ind. heating system, type	0,448	0,448	0,547
6	Ventilation correction factor	0,314	0,315	0,306
7	Floor, boundary condition	0,269	0,405	0,303
8	Amount of residents	0,227	0,239	0,233
9	Façade, transparent thermal insulation	0,167	0,167	0,162
10	Façade, transparent area	0,145	0,146	0,141
11	Ventilation system	0,131	0,131	0,136
12	Hot water system, type	0,128	0,130	0,138
13	Solar panel, area	0,126	0,126	0,148

4.2 Dependent input

Data of reference houses are used to vary the dependent variables useable floor area, building envelope area and house type. The screening results discussed in paragraph 3.2 and 3.3 show the dependent variables influence the output. These results only show the size of influence on the output of a group of dependent variables. At this stage it is not possible to determine the single influence of each dependent variable. Therefore, future work will consist of a sensitivity analysis which considers multiple variables. For this analysis, important variables retrieved from the screening analysis, will be varied at the same time. A regression analysis will then be applied, to determine the influence on the output per single dependent variable.

5. REFERENCES

- DGMR, 2006, *Formulestructuur EI en maatwerkadvies woningbouw*, SenterNovem, Sittard.
- Ekeris van J., 2006, "Energiebesparing en kwaliteit gaan hand in hand", *VV+*, October 2006, 660 – 663.
- Hoes, P., 2007, *Gebruikersgedrag in gebouwsimulaties, van eenvoudig tot geavanceerd gebruikersgedragmodel*, Technische Universiteit Eindhoven.
- Lazarus, N., 2004, *Beddington Zero (Fossil) Energy Development, Toolkit for Carbon Neutral Developments – Part III*, BioRegional, Wallington.
- Lomas, K.J., H. Eppel, 1992, "Sensitivity analysis techniques for building thermal simulation programs", *Energy and Buildings*, 19(1992), p. 21-44.
- Ministerie van Economische Zaken, 1995, *Derde Energienota*, SDU Uitgevers, Den Haag.
- Rooijers, F., S. Moorman, F. den Dulk and H. Buitenhuis, 2001, *EPL bestaande woningbouw; systematiek*, CE, Delft.
- SenterNovem, 2007a, *Voorbeeldwoningen bestaande bouw 2007*, SenterNovem, Sittard.
- SenterNovem, 2007b, *Cijfers en tabellen 2007*, SenterNovem, Sittard.
- Soethout, L.L., H.C. Peitsman, J. Shemeikka, et al, 1999, "Improving municipal energy management by motivational measures and knowledge transfer", *TNO report*.
- Sunikka, M.M., 2006, *Policies for improving energy efficiency in the European housing stock*, IOS Press BV, Amsterdam.
- VROM, 2007, *Cijfers over Wonen 2006*, Ministerie van VROM, Den Haag.
- World Energy Council, 2004, *Survey of energy resources*, Elsevier, Oxford.