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AN ENERGY-SAVING OFFICE FAÇADE ADAPTABLE TO OUTSIDE WEATHER CONDITIONS IN THE NETHERLANDS

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ABSTRACT

In order to reduce the environmental load (energy and materials) of buildings, a study was undertaken to develop and assess solutions for a dynamic, weather and daytime adaptable office façade. The following steps have been taken:

- The total environmental load (energy and materials) of a 1990 reference façade and some variants were determined.
- After analyzing the thermal behavior of the façades, theoretically possible solutions to save energy were developed and calculated. These are the possibilities to change the admittance of solar radiation, to change heat insulation value, and to enable thermal heat storage (both night cooling in summer and storage of solar radiation in winter). The energy consumption by application of these theoretical solutions was calculated.
- Based on the most promising energy-saving principles, several design concepts with more common and available materials were developed and their total environmental costs were determined. The technical feasibility of the concept was also taken into account.
- The most favorable option was worked out in detailed drawings and the final improvement in environmental impact The final façade design realizes a heating energy reduction of 66%, which comes down to a reduction in environmental costs of the energy consumption of 51%, also taking cooling energy into account. Including the use of materials, the final design has an environmental index of 183, indicating an improvement in total environmental impact by a factor 1.83 compared to the 1990 reference façade.

INTRODUCTION

Since the 1970's and the report “The limits to growth” by Meadows et al. [1972], it is generally known that the health of the environment is threatened by human activities. Natural resources are depleted and the environment is (irreparably) damaged. In the report known as “Our Common Future” [Brundtland et al., 1987] the concept of Sustainable Development is introduced, meaning a “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.

In 1990, it was argued that, to achieve this, the impact of human activity on the environment should be decreased by a factor 20 by the year 2040. This decrease can be expressed by an environmental index as used by the Dutch Government Buildings Agency[1], which relates the environmental impact to a 1990 reference.

The building industry is one of the main polluters, both due to the energy required to realize (thermal) comfort in buildings and due to the materials used in the building process. As long as energy is not produced in a sustainable manner, there is a need for buildings that consume less energy without of course reducing thermal comfort for its inhabitants or increasing the environmental load of its building components. Much research has already been done and is still being done in this field. This research investigates the energy-saving possibilities of adaptable office façades.

The building skin, which forms the separation between the outdoor and the indoor climate, plays an important part in the energy transport between the inner office and the outside. By making the façade adaptable to changing weather conditions, less energy is needed for room heating and cooling compared with a façade that is unable to adapt. This effect can already be seen when shading devices or

[1] This index represents the environmental performance of a certain situation or design, compared to a 1990 reference situation or design with an index of 100. The environmental index is calculated by dividing the environmental load of the 1990 reference by that of the situation or design of which the index is wanted. A solution reducing costs by 50% has an environmental index of 200. An index of 2000 means an improvement by a factor 20.

openable windows are used. There are, however, more façade properties which influence the energy transport and which might thus have a - positive - effect on energy consumption.

METHODOLOGY

In order to determine the energy demand, the façades were placed before a standard two-person office room. The computer software “Capsol” [Standaert, P., 1999] was used to simulate the dynamic heat-transfer in the office room and the computer software “GreenCalc” [Linden, K. van der, Spiekman, M., Haas, M. & Koster, P., 1999] was used for the calculation of the environmental load (energy and building materials). GreenCalc translates environmental data from life cycle assessments (LCAs) into environmental costs. Environmental costs are costs that are necessary for the prevention and treatment of environmental damage.

SIMULATIONS

Reference façades

The reference façade, see Figure 1, is a façade that was generally used in 1990, see Dobbelsteen et al. [2002]. The façade consists of heavy parapet (60%) with an insulation value of 1.8 m^2K/W and double-glazing with a heat transmission coefficient (U-value) of 2.8 W/m^2K. The reference office has an energy demand of 1310 kWh for heating and 86 kWh for cooling. Furthermore, a generally applied office façade from the SSO/SBR-publication 300 [Blankestijn, E.A. et al., 1994] with HR^+-glass and an improved window frame was used as an additional reference.

Energy-saving façade concepts

Assessment of the theoretical optimal façades (not described here) showed that adaptable insulation and storage of solar radiation decrease the energy demand. Several design concepts were developed based on these principles, however, using more common and readily available materials than in the above mentioned theoretical study. To also comply with other requirements, the façade is divided into different parts: two transparent ones for daylight access and view, and two for storage of solar radiation (see Figure 1b).

In the cooler season there is a time-period in which heating is required but no solar gain is available, this is mainly in the morning and in the evening. Additional insulation in the daylight and view parts is applied to decrease the loss of heat from the office room and thus decrease the time-period in which solar gain is necessary.

Three possibilities with which this additional insulation can be realized are: nighttime insulation by means of a roller blind, an additional sliding window or an additional cantilever panel made of transparent material (e.g. "Okalux"), see Table 1.

Figure 1: a. 1990 Reference façade and b. New energy saving façade

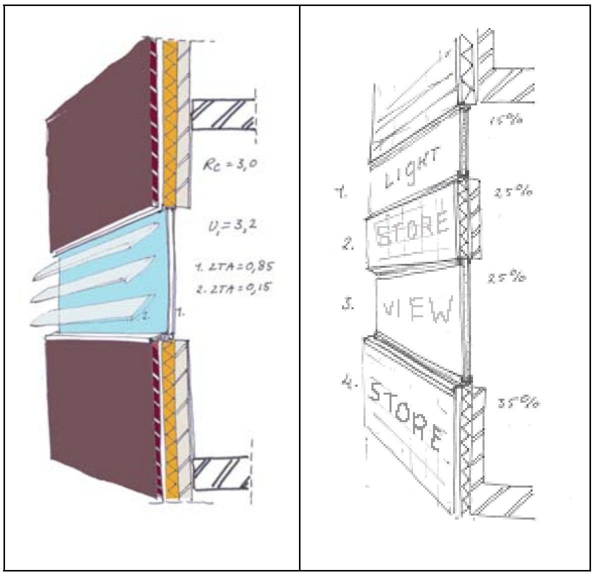
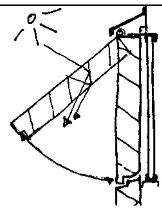


Table 1: Different variants for the insulation of the daylight and view opening

	SLIDING WINDOW
	CANTILEVER PANEL
	ROLLER BLIND

The thermal storage of solar radiation is realized through either a sand-lime brick parapet or through an aluminum water-filled parapet behind a transparent insulation material (e.g. “Okalux”). Sand-lime brick is chosen for its relatively large heat capacity combined with a relatively small environmental load. As a storage medium, water has a relatively low environmental load and a large heat capacity.

The semi-transparent insulation material "Okalux" was chosen because it is often used with Trombe-walls. It combines a relatively large solar gain with a high insulation value. Most transparent materials with a high insulation value usually have a lower solar gain. On the inside of the parapet, another removable insulating layer is applied. In this way the heat-flow from the parapet to the room can be controlled, see Figure 2. The removable insulation can be removed by means of a roller blind or by means of a cantilever panel. Thus, for storage of solar radiation, three variants are investigated, see Table 2.

Figure 2: Heat-storage in the winter (a. storage, b. release)

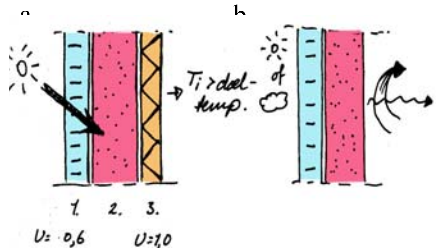
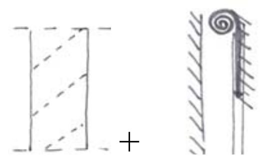
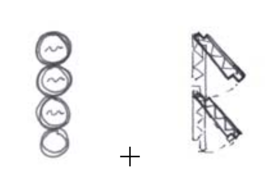
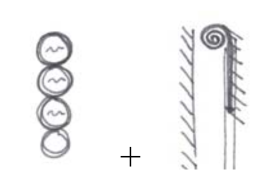


Table 2: Different variants for the parapet

	Lime-brick heat-storage wall with roller blind insulation on the inside
	Water-filled heat-storage wall with insulation through cantilever panels on the inside
	Water-filled heat-storage wall with roller blind insulation on the inside

Water with a phase-change material was not further investigated because Capsol is not equipped to calculate the energy demand for this material. Its performance as an energy storage material is not expected to be better than water; it will however require less space.

Aerogel, a very good insulating material, was not taken into account. Its possible energy-saving potential is as great as the energy-saving potential of the variant with optimal transmission, its environmental impact, however, is relatively great. The net environmental gain is therefore negative.

A façade in which the stored heat is transferred to the office space by controlled ventilation in order to decrease the energy demand is not investigated as the controlled ventilation demands additional energy.

As both the adaptable window insulation and the storage of solar radiation decrease the energy demand, a combination of both the adaptable window insulation (roller blind) and the storage of solar radiation (waterfilled & roller blind) is also investigated.

METHOD

Description of the office room

The office room used for energy demand calculations is the same office as described in the ISSO/SBR publication 300. It has a floor area of 21.30 square meters (see Table 4), an average thermal mass of 59 kg/m2 and is used by two employees with normal office equipment, resulting in an internal heat load of 35 W/m2. There is a minimum ventilation fold of two per hour and a maximum of 10 per hour. The minimum solar factor g (transmittance of solar radiation) of the window is 0.15, simulating good outside shading devices. The indoor thermal comfort requirements are determined with the help of Fanger's theory [Fanger, P.O., 1970] and are shown in Table 5.

Table 4: Dimensions of the reference office:

Width	4.10 [m]
Depth	5.20 [m]
Height	3.00 [m]
Façade area	13.50 [m^2]
Floor area	21.30 [m^2]
Volume	64.00 [m^3]
Total wall area	92.90 [m^2]

Table 5: Target temperatures for the office space during office hours. Outside the office hours a minimum temperature of 15 °C is required.

	minimum	maximum
December, January, February	18 °C	23 °C
March, April, October, November	19 °C	24 °C
May, September	19 °C	25 °C
June, July, August	20 °C	25 °C

Modeling of the various façade concepts in CAPSOL

Capsol is a computer program to calculate multizonal steady-state and dynamic heat transfer, including one dimensional heat conduction, convection, view factor based infrared radiation, multizonal ventilation and solar radiation. During the dynamic calculation, a system of energy balance equations is built and solved each calculation time step, using a finite difference method.

Capsol is based on a network of thermal resistances and thermal capacitors. Each wall is represented by a series of resistances and capacitors. The walls are separating the zones. Different zone types are possible. Zones can be external or internal. Internal zones have a volume and therefore a zone capacitor, external zones have not. One external zone can be the solar zone.

Capsol can simulate temperatures and energy demand through the use of controls. A control is a manipulation of the thermal behavior of the system considered in order to obtain a certain control-temperature. A control is activated or deactivated depending on the temperature in a sensor point, on the control-temperature in that point and on the control purpose (heating or cooling). Three types of controls are available: a power release in a certain point, a mechanical ventilation, and a sunshade action on a certain wall. In Tables 6, 7 and 8 a short overview is given of the modeling of the various façade concepts.

Table 7a: Standard comfort controls Winter

Control	What	Method	Value
$T_c = T_{targ}$	Heating	capacity	+ 3000 Watt
T_c = 21 °C	Cooling	sunshade	solar trans-mission = 0.15
T_c = 22 °C	Cooling	ventilation	540 m^3/h

Table 7b: Standard comfort controls Summer

Control	What	Method	Value
T_c = 21°C	Cooling	capacity	+ 3000 Watt
T_c = 22 °C	Cooling	sunshade	solar trans-mission = 0.15
T_c = 24.5 °C	Cooling	ventilation	540 m^3/h

Adaptability of the façade

The Netherlands has a mild sea-climate, which results in mild winters and cool summers. Nevertheless, the differences in temperature and solar radiation between summer and winter are large enough to make an adaptable façade useful.

A question in this research is for which time step the façade should be adaptable. Is it enough for the energy-demand to change the façade every three months, or are the differences within a month so large that the façade must be adapted more often?

The differences in temperature and solar gain over a month are generally large (April, for example, has days with temperatures below 10 ^oC and days with temperatures above 20 ^oC). This would require a façade that is at least daily adaptable. On the other hand, from the occupants' point of view, it is not desirable to perform large, time-consuming, adaptations every day.

For the Capsol simulations, two different adaptation time steps have been chosen. The first is a seasonal time step, i.e. cooling adaptations in the summer and heating adaptations in the winter. The second adaptation time step is the calculation time step, in this case two minutes, in which either the cooling (summer) or heating (winter) adaptations can be changed.

The energy demand for heating and cooling is calculated per month, based on temperatures and solar radiation data of the reference year (1964) from the Dutch climate. As it is difficult to calculate simultaneous cooling and heating, which, with Capsol, is necessary in May and September, these two months are not included in the calculations. As the demand for cooling and heating is not very large in these months, this exclusion does not lead to large errors in the annual energy demand calculation.

Control Temperatures

Before the calculations were performed, the so-called control-temperatures were determined, i.e. the temperatures at which a certain control is activated or deactivated (see Figure 7 for the values that are used for this paper). These temperatures, however, have a large influence on the energy-demand and on the indoor temperatures. The following effects have been found:

Turning the heating on when T_i is below 21.0 °C, instead of 20.0 °C, leads to an increase of approximately 15% in energy demand in January. Turning the cooling on when T_i is above 24.0 °C, instead of 24.5 °C, leads to a more than 20 % increase in energy demand. However, a higher control temperature will result in larger periods of time in which the temperatures are too high to achieve thermal comfort.

As a result of former investigations (see for details [Jansen, S.C., 2002]), the control temperatures were determined. The control temperatures for the standard comfort controls (see Figure 7) are identical for all façade concepts.

Table 6. Starting conditions of the input parameters of façade concepts.

Façade concept	Parapet (8.10 m^2)	Daylight (2.03 m^2) and View Opening (3.38 m^2)
1990-Reference	(R_c = 1.8 m^2K/W) brick 100 mm; mineral wool 50 mm; sand-lime brick 102 mm; plaster 6 mm	Double glazing (U = 2.8 W/m^2K, solar transmission = 0.7)
HR+-glazing	(R_c = 3.0 m^2K/W) brick 100 mm; mineral wool 90 mm; sand-lime brick 102 mm; plaster 6 mm	Double glazing, HR+-glass (U =1.7 W/m^2K, solar transmission = 0.7)
Roller Blind	see 1990-Reference	see 1990-Reference
Roller blind & HR+-glazing	see 1990-Reference	see HR+-glazing
Sliding window	see 1990-Reference	see 1990-Reference
Folding Panel	see 1990-Reference	Daylight: see HR+-glazing View: Single glazing (U = 5.64 W/m^2K, solar transmission = 0.7)
Lime-brick Removable	(U =0.44 W/m^2K) Transparent layer; Sand-lime brick (ρ = 2000 kg/m^3, c = 840 J/m^3); Removable insulation	see 1990-Reference
Waterfilled Removable;	(U =0.44 W/m^2K) Transparent layer; Water (ρ = 1000 kg/m^3, c = 2400 J/m^3); Removable insulation	see 1990-Reference

Q_{intern} = 750 Watt, from 8:00 h to 18:00 h
Ventilation = 65 m^3/h at night, 130 m^3/h in daytime

Table 8: Additional comfort controls for the various façade concepts

Façade concept	When	Where	Method	Value
1990-Reference; HR+-glazing	---	---	---	---
Roller Blind	October-April: 18.00-8.00 hours	Daylight + view	Screen-Insulation	U-value = 1.6 W/m^2K
Roller Blind & HR+-glazing	October-April: 18.00-8.00 hours	Daylight + view	Screen-Insulation	U-value = 1.1 W/m^2K
Sliding window	November-March: $T_c < 21°C$	Daylight + view	Glass plane- Insulation	U-value = 1.4 W/m^2K
	October + April: 18.00-8.00 hours	Daylight + view	Glass plane- Insulation	U-value = 1.4 W/m^2K
Cantilever Panel	November-March: $T_c < 21$ °C	Daylight	Okalux- Insulation	U-value = 2.3 W/m^2K
	October + April: 1800-8.00 hours	Daylight	Okalux- Insulation	U-value = 2.3 W/m^2K
Lime-brick & cantilever panel, Lime-brick & roller blind, Waterfilled & roller blind	November-February: $T_{storage} > 22$ °C	Parapet	No Insulation	U-value = 0.78 W/m^2K
	October, March, April: $T_C < T_{target} - 1$ °C	Parapet	No Insulation	U-value = 0.78 W/m^2K
	$T_C > 22$ °C	Parapet	Sunscreen	solar transmission = 0
Roller Blind & HR+-glazing & Waterfilled removable	see Roller Blind and Waterfilled removable			

Modeling of the various façade concepts in GreenCalc

GreenCalc can quantify the total environmental impact of a building. The program consists of four modules: materials, energy, water and travel. For the façade, only the materials module is necessary as use of water and travel is the same for all façades and energy is already investigated by means of the Capsol computerprogram.

The materials module of GreenCalc is based on the TWIN-model[2]. Environmental effects for which no quantitative data is available are also included in the final evaluation. These effects are converted into treatment and prevention costs (in €) In GreenCalc two steps are taken: the inventory and the aggregation. In the inventory all relevant environmental data of a product is collected. In the aggregation stage, all data is sorted by environmental impact and its contribution is determined.

GreenCalc's database contains the environmental costs for a large number of building materials, based on Dutch production processes. It is possible to make an educated guess for products that are not (yet) entered in the database.

RESULTS

Environmental Impact

Table 9 presents the results of the calculations for the various façade concepts. As the total environmental impact consists of both the materials cost and the energy demand for cooling and heating, it is important to consider the way in which both aspects are taken into account. For the materials a reference life span of 75 years is assumed, for the energy demand only 35 years is assumed due to the expected predominant contribution of sustainable energy sources by that time. Thus the total environmental cost for a life span of 75 years consists of the total materials cost added to 35 times the yearly energy demand.

Table 9 leads to the conclusion that the contribution of building materials to the environmental load is relatively small. This is partly due to the fact that only the materials of the façade were taken into account and partly due to the long reference life span.

All calculated variants have a better performance than the 1990 reference façade. Compared with the current standard façade with HR+-glazing the differences are small and not always positive. Choosing the best combination of a daylight-view part and parapet is difficult because the differences are so small. The Roller Blind with HR+-glazing is the best variant of the daylight-view variants. For the parapet the differences are very small.

Technical Aspects

In Table 10 a quantitative judgment of the technical feasibility of the different design concepts is presented. As the environmental impact of the various design concepts is comparable, the technical feasibility will have a large impact on the final design.

FINAL DESIGN

In the final design, the additional insulation for the daylight-view opening is realized through an inside roller blind which insulates through the air-cavity created between the double glazing and the roller blind. Thermal storage of solar radiation is realized by means of a water-filled parapet behind a transparent insulating material, which transports the solar energy to the water-filled parapet. In order to comply with other requirements, e.g. view, the façade is divided into different parts: two transparent parts for both daylight access and view, and two non-transparent ones for storage of solar radiation. The façade area in front of the floor construction is used for photovoltaic cells, since it cannot be used for daylight access, view or storage of solar radiation.

The roller blind on the inside, which provides a higher insulation value, is semi-transparent, and can therefore also be used against discomfort glare which is required by the Dutch Agency for Safety and Health at Work. For its insulation function it is not necessary that the roller blind is transparent as calculations showed that the use of additional insulation outside office hours saves almost as much energy as additional insulation during the whole twenty-four hour period. The proposed roller blind in combination with high efficiency glazing saves 40% of the heating energy demand.

Thermal storage of solar radiation is realized by applying an aluminum element filled with water behind a transparent insulation material (in this case "Okalux"). On the inside, another insulating layercan be added through a roller blind. This is necessary in order to control the heat flow from the parapet to the room. This free heat-gain saves an additional 26% when there is no solar radiation present, resulting in a total saving of 66% on heating energy.

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[2] TWIN-model; Milieu Classificatie-model Bouw NIBE 1997

Table 9: Environmental impact in € and indices for the façade concepts; calculated with Capsol and GreenCalc.

Façade concept	Energy cost *35 years (in €)	Energy index	Materials cost (in €)	Materials index	Total cost (in €)	Total Environmental Index
1990-reference	9170	100	1952	100	11122	100
HR+-glazing	7175	128	1405	139	8580	130
Roller blind	7175	128	1504	130	8679	128
Sliding window	6545	140	1599	122	8144	137
Cantilever panel	6790	135	1581	123	8371	133
Roller Blind & HR+-glazing	6405	143	1504	130	7909	141
Lime-brick & cantilever panel	7105	129	1701	115	8806	126
Lime-brick & roller blind	7105	129	1314	149	8419	132
Waterfilled & roller blind	7070	130	1632	120	8702	128
roller blind & HR+-glazing & Waterfilled & roller blind	4725	194	1744	112	6469	172

Table 10: Quantitative judgment of the technical feasibility

<table>
<tr><th>Façade concept</th><th>Practical feasibility</th><th>Control system complexity</th><th>Life span and maintenance</th><th>Viability present technology</th><th>Comparison with reference</th></tr>
<tr><td rowspan="2">Roller blind, Roller blind & HR+-glazing</td><td>Good, but extra operation</td><td>Simple</td><td>Short, but easy to replace</td><td>Good</td><td>0/-</td></tr>
<tr><td colspan="5">If the screen is transparent and serves as glare stop, no additional operations are necessary</td></tr>
<tr><td>Slinding window</td><td>Good, but extra operation</td><td>Simple</td><td>Short, but easy to replace</td><td>Good</td><td>-</td></tr>
<tr><td>Cantilever pane</td><td>Rather difficult, outside mounting</td><td>Simple</td><td>Difficult to replace</td><td>Good</td><td>-</td></tr>
<tr><td>Lime-brick & roller blind</td><td>Good from the inside</td><td>Somewhat complicated</td><td>Easy to replace</td><td>Good</td><td>-</td></tr>
<tr><td rowspan="2">Waterfilled & roller blind</td><td></td><td></td><td>Easy to replace</td><td>Reasonable</td><td>-/--</td></tr>
<tr><td colspan="5">If the water filled wall is also a heating and cooling element, the control system will get more complex. On the other hand, no other heating or cooling appliance will be necessary.</td></tr>
</table>

The environmental impact of the energy demand is caused by both heating and cooling. Since there is no decrease in cooling energy compared with the reference façade, the environmental impact reduction of the total energy consumption is not 66%, but 51%, compared with the 1990 reference façade.

Assessment of the final design

The environmental costs of the materials used in the final design are almost 20% lower than those of the 1990 reference façade. The material costs have a lower influence on the total environmental costs due to their relatively small contribution. The total environmental costs are shown in Figure 3; the environmental indices of the energy demand, the materials used and the total are shown in Figure 4.

Remarks

If the parapet is not used for thermal heat storage but as a power generator through photovoltaic cells, about the same amount of energy can be gained as is saved by using thermal heat storage. However, since both options are only valuable for south, southeast, or southwest façades, and because the heat surplus of the waterfilled thermal heat storage element can be transferred to e.g. the northern façade, and because the environmental impact of the materials of the PV-cells is relatively high, the total environmental impact of the heat storage wall is larger for the photovoltaic cells. If the efficiency of photovoltaic cells improves, however, things might be different. In some circumstances, e.g. in other climates or when the cooling energy demand is higher due to a higher internal heat load, it might be better to use the parapet as a power generator instead of a thermal heat generator.

Figure 3: Environmental costs final design.

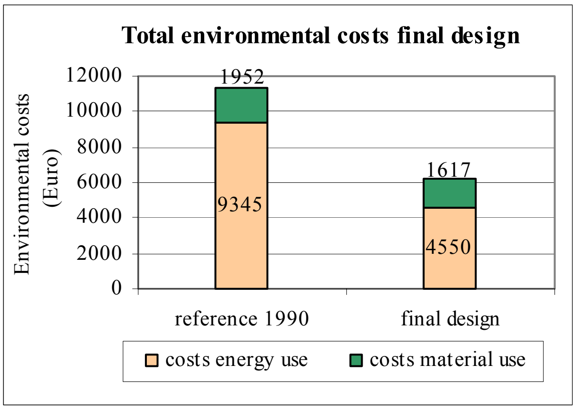
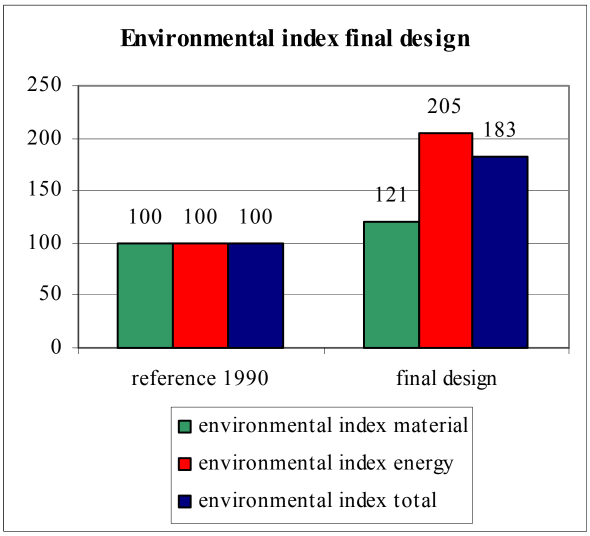


Figure 4: Environmental index of the final design.



CONCLUSIONS

Adaptation of solar radiation admittance, ventilation-fold and insulation value can realize large energy savings compared with the chosen 1990 reference façade as well as with other currently used façades. The final façade design realizes a heating energy reduction of 66%, a reduction in total energy demand of 51% (cooling included). Including the use of materials, the final design has an environmental index of 183, indicating an improvement in total environmental impact by a factor 1.83 compared with the 1990 reference façade. This improvement is similar to that of the pilot projects of the Dutch Ministry of Housing. Further possibilities for improvements, in order to reach the required factor 20 in 2040, should be sought in other types of technical and non-technical measures such as flexible workspaces, sustainable energy, and heat recovery from ventilation air.

Recommendations

The actual energy performance of the façade design should be investigated using a prototype.

The effect of the control mechanism (and its time step) on the office inhabitants should also be studied.

The materials database of GreenCalc should be expanded to avoid too much speculation on environmental costs.

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