THE RELATION BETWEEN THE ADOPTION OF SUSTAINABLE MEASURES AND THE COMPOSITION OF AN ENVIRONMENTAL ASSESSMENT TOOL FOR BUILDINGS.

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Abstract

Owing to a general perception of resource efficiency and due to the fact that the construction industry is traditionally a large user of natural resources, the necessity to design buildings with a low environmental impact is increasing. In the last decade many tools were developed to calculate the environmental impact of buildings and many measures came available to make buildings more sustainable. However, not many papers address the influence of the composition of the assessment tool on the adoption decision of its user.

In this research an assessment tool named GreenCalc was used to value and to improve the sustainability of an office building. To this end, more than one hundred and forty civil engineering students were involved as users of this tool. One group of students was asked to lower the environmental impact of the building with help of GreenCalc and another group was asked to do the same thing using a newer version named GreenCalc^{+}. By using two different versions of the tool it is possible to reflect on the impact of the structure of the tool and the preferences of the students for particular techniques or measures. The most and least favourable aspects, and the way the assessment tool can stimulate the use of certain techniques, are addressed.

1. Introduction

Assessment tools have an important role in coming to more sustainable buildings. In the design process they enable stakeholders to communicate about the possibilities to cope with environmental performance objectives of the future building. In the construction phase and during exploitation the output of the assessment tool can be used to express the environmental attractiveness of the object by using for example certificates or labels. Besides these intended functions of the assessment tools, it could be that certain measures addressed by the assessment tools are unintentionally more applied by the users than others, because of there location or visual appearance within the tool.

In the Netherlands the assessment tool GreenCalc is commonly known. The national Government Buildings Agency has initiated its development and is stimulating the use of this particular tool (Haas et al, 2006). Multiple environmental friendly buildings are for example brought together on a poster with their GreenCalc assessment results to set an example for other project developers and redevelopers. The fact that this assessment tool has been adopted by the Dutch Government Buildings Agency is an important reason for the University of Twente to adopt this particular tool in their educational program for civil engineers.

In this research the assessment tools GreenCalc and GreenCalc^{+} will be compared with each other to find out what the influence is of their user interface. In 2007 sixty-four students were using GreenCalc and in 2008 eighty-two students were using the new edition GreenCalc^{+} to improve the environmental index of a Dutch office building called “ThermoStaete”. The measures to be adopted by the students were related to the material use, energy consumption, water use, and transport need. The suggested improvements were reported per couple and graded regarding quantity and quality.

Firstly, the outline of the assessment tools GreenCalc and GreenCalc^{+} will be described in section 2. Secondly, the regarded case object will be presented and a more detailed description of the assignment will be given in section 3. Thirdly, the results of the students will be shown and analysed in section 4. Fourthly, the analysis on the derived data takes place in section 5, before finishing the paper with the conclusions and recommendations in section 6 and 7.

2. GreenCalc

In 1997 GreenCalc was introduced being an instrument to assess and compare the sustainability of office buildings based on their environmental impact during the whole lifecycle. Van Hal (2007) adds to this function that GreenCalc is also a communication instrument for sustainable building. It was developed by

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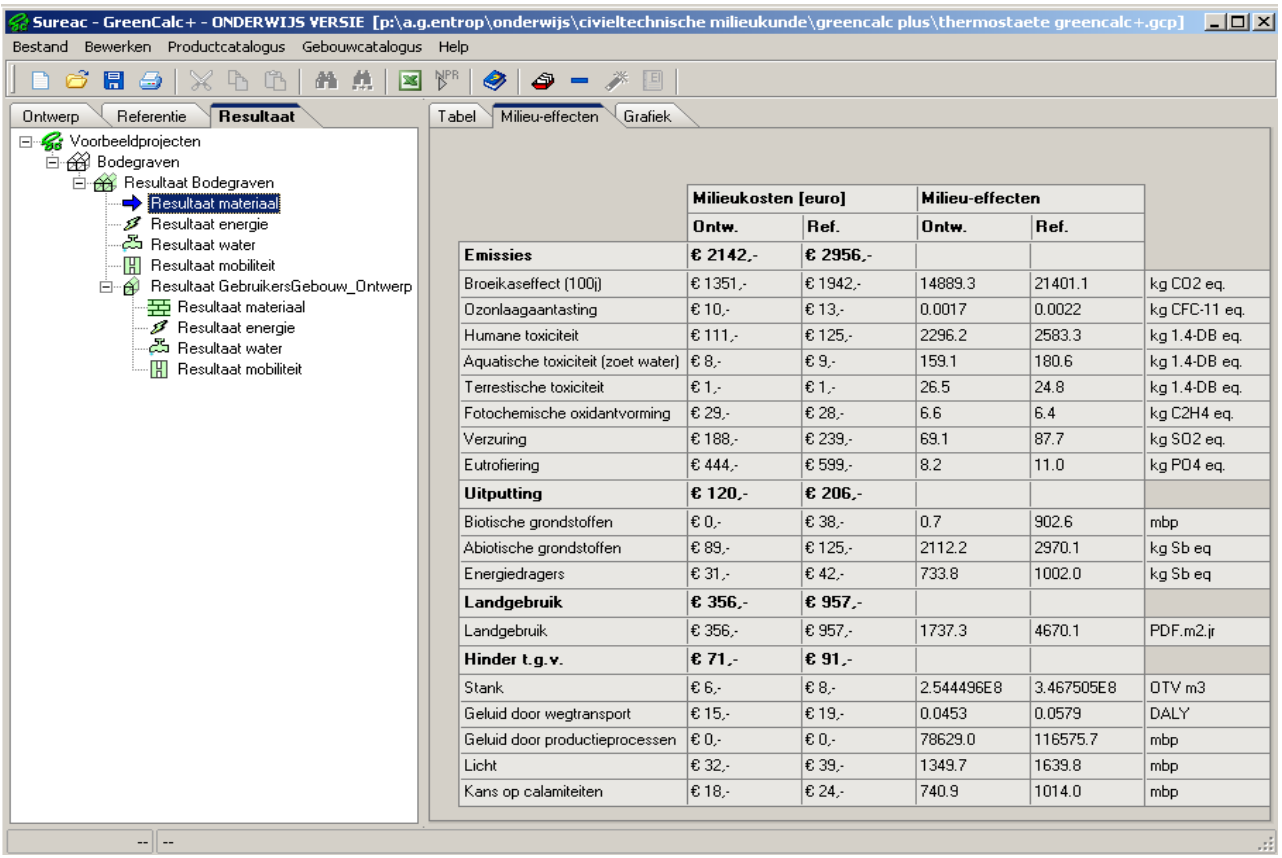
NIBE (Dutch Institute for Building Biology and Ecology) in order of the Dutch Government Buildings Agency (Seo, 2002).

Four aspects are in the first GreenCalc version addressed, namely the material use, energy use, water consumption and transport needs. Detailed information of the office design on these four aspects needs to be imported in the computer program. The program is able to calculate the amount of emissions, rate of exhaustion, land use, and the degree of nuisance involving these aspects. These values are then expressed in environmental hidden costs using Euros per year and per square meter (Straatman et al, 2001; Loomans et al, 2002). Furthermore an environmental index is given, that expresses the relation between the newly imported (environmental friendly) design and an automatically derived reference design. The score is given within a scale from 1 to 2,000. The reference design shows how the building traditionally was designed in 1990 having an index of 100. In 2050 the goal is to design buildings with a score of 2,000 (Seo, 2002).

With the introduction of GreenCalc$^+$ in 2005 it was also possible to calculate the environmental impact of other buildings on two different levels. The first level reflects on the object itself and the second level involves the entire neighbourhood. Also the handling has been further improved, resulting in a time reduction of importing the construction into the computer program. The methodology stayed the same, but in this version the environmental impact of the design can also be shown in other units (e.g. kg CO_2 and environmental impact points) than Euros (see Figure 1). Now, the four aspects materials, energy, water and transport will be explained in more detail.



	Milieukosten [euro]		Milieu-effecten		
	Ontw.	Ref.	Ontw.	Ref.	
Emissies	**€ 2142,-**	**€ 2956,-**			
Broeikaseffect (100j)	€ 1351,-	€ 1942,-	14889.3	21401.1	kg CO2 eq.
Ozonlaagaantasting	€ 10,-	€ 13,-	0.0017	0.0022	kg CFC-11 eq.
Humane toxiciteit	€ 111,-	€ 125,-	2296.2	2583.3	kg 1.4-DB eq.
Aquatische toxiciteit (zoet water)	€ 8,-	€ 9,-	159.1	180.6	kg 1.4-DB eq.
Terrestische toxiciteit	€ 1,-	€ 1,-	26.5	24.8	kg 1.4-DB eq.
Fotochemische oxidantvorming	€ 29,-	€ 28,-	6.6	6.4	kg C2H4 eq.
Verzuring	€ 188,-	€ 239,-	69.1	87.7	kg SO2 eq.
Eutrofiering	€ 444,-	€ 599,-	8.2	11.0	kg PO4 eq.
Uitputting	**€ 120,-**	**€ 206,-**			
Biotische grondstoffen	€ 0,-	€ 38,-	0.7	902.6	mbp
Abiotische grondstoffen	€ 89,-	€ 125,-	2112.2	2970.1	kg Sb eq
Energiedragers	€ 31,-	€ 42,-	733.8	1002.0	kg Sb eq
Landgebruik	**€ 356,-**	**€ 957,-**			
Landgebruik	€ 356,-	€ 957,-	1737.3	4670.1	PDF.m2.jr
Hinder t.g.v.	**€ 71,-**	**€ 91,-**			
Stank	€ 6,-	€ 8,-	2.544496E8	3.467505E8	OTV m3
Geluid door wegtransport	€ 15,-	€ 19,-	0.0453	0.0579	DALY
Geluid door productieprocessen	€ 0,-	€ 0,-	78629.0	116575.7	mbp
Licht	€ 32,-	€ 39,-	1349.7	1639.8	mbp
Kans op calamiteiten	€ 18,-	€ 24,-	740.9	1014.0	mbp

Figure 1 Lay-out of GreenCalc$^+$ v2.1.0 showing the environmental impacts and costs of the materials.

2.1 Materials

By importing detailed information on the used amount and types of materials it is possible to calculate the environmental impact of the construction. The methodology is based on the TWIN-model (Haas, 1997). The software contains a large database of construction materials with their environmental impact. The students learn during a practicum how to use this database and how to compose construction elements using materials from this database, like walls, roofs and floors.

In GreenCalc$^+$ seven parts of the construction are being distinguished, namely foundation, facades, inner walls, floors, roof, installations, and finishing. Regarding the installations in the building, it is not necessary to incorporate every single meter of plumbing and wiring; instead general values are used based on the gross floor area of the construction. The average annual environmental impact of materials is strongly related to the expected life time of the designed object. GreenCalc uses default life times of 35 years for offices and shops and 75 years for dwellings, schools and basic health care facilities.

2.2 Energy

During the use of a building the energy consumption accounts for the main part of the environmental impact. In the section energy the applied installations can be chosen conform the national standard on the energy performance of commercial and residential buildings (NEN 2916 and NEN 5128). This means that besides the environmental impact also the Energy Performance Coefficient is computed, that is enforced by the national Building Code. The following elements make part of the aspect energy: the use of the building, constructional specifications (shading and perimeter), climate systems, warm tap water, photovoltaic panels and/or windmills, lighting, and office equipment. Additionally some extra adjustments by means of natural gas consumption, electricity use, and heat use can be included, which can not be incorporated directly in the computer program.

2.2 Water

The third aspect to be addressed is the water consumption. The elements of this aspect are the facilities (to eat, for sports and green areas), sanitary facilities, and the use of rain water. Again it is possible to make adjustments in the water use by addressing additional savings, expressed by m^3/year. New techniques can therefore always be imported in the computer program.

2.2 Transport & mobility

The fourth and last aspect in GreenCalc is transport and mobility. The accompanying transport needs of buildings have a major impact on the air quality and depletion of fossil fuels. In GreenCalc the environmental impact was part of the object's index, but in the new GreenCalc$^+$ it is part of the environmental index of the neighbourhood. The location, availability of public transport, and the mode of personal transport are the three elements to complete this aspect.

3. Assignment and case object

With the assignment to improve the environmental index of ThermoStaete (see Figure 2) within a defined financial budget, the students received the specifications of the case object in form of a description, drawings and a file, that can be directly used in GreenCalc and GreenCalc$^+$. The available budget for adopting sustainable measures was in 2007 two million Euros. This budget was reduced in 2008 to one million Euros.

Information on the relevance of assessing the environmental impact of buildings and the background of the assignment were provided in a 1.5 hours lecture and two practica of 4 hours each. Besides these contact hours, readers were provided containing a manual for GreenCalc, the assignment, and the grading scheme for the reports (Brouwers, 2007; Brouwers et al., 2008). During the practica the students were able to use GreenCalc to come to their improved object and were allowed to ask questions about its use. After the practica the students had more than one month to hand over their reports, during which it was still possible to use the software.

Figure 2 The case-object offered to the students was ThermoStaete, home office of DWA

The studied office building ThermoStaete has, according to Haas et al. (2006), an Environmental Index of 251 and offers a gross floor area of 2,324 m^2. The office building is located at Bodegraven in The Netherlands, but the students were allowed to design the improved building for a new location. Although it was already built in 1999, it still ranks a position among the ten most environmental friendly buildings in The Netherlands. In the files supplied to the students the building accounted for an Environmental Index of 285 in GreenCalc and in 252 in GreenCalc$^+$. Some examples of environmental friendly measures are:

1. Materials: the construction has self supporting facades made out of lime-sandstone;
2. Energy: photovoltaic panels cover a surface of 85 m^2;
3. Water: storm water is being used to flush the toilets;
4. Mobility: the office is located relatively close to a railway station.

4. Results

In this section the outcomes of the assignment will be discussed regarding the adopted sustainable techniques by students using GreenCalc. Firstly, the results will be shown of the students using GreenCalc V2.01 in 2007. Secondly, the results will be presented of the students using GreenCalc$^+$ V2.1.0 in 2008.

4.1 GreenCalc

The first group of students used GreenCalc V2.01. In their thirty-two reports suggestions were made how to lower the environmental impact of the construction. In Table 1 an overview is given of the most popular measures among the students for each aspect. This means that all measures mentioned by ten or more couples are included. Twenty-one groups suggested replacing the PVC-roofing by EPDM-roofing. Within the aspect energy it is possible to choose for green electric energy supplied by the energy company. This was the most favourite measure among the students of 2007. However, one can debate about how close the relation is with the design and composition of the office. For the aspect water two measures were equally favoured from an environmental point of view, but removing the pantry from the building could be considered as socially not desirable, like many student reports addressed. Regarding transport 23% of the groups tried to alter the transport modalities themselves for multiple reasons, e.g. carpooling.

Table 1: Most often adopted techniques in GreenCalc

Materials		**#**	**%**
Foundation	A. Concrete foundation pile was replaced by wooden pile	16	50.0
Foundation	E. Compact concrete was replaced by a lime-sandstone foundation on sand	13	40.6
Superstructure	A. Floor of concrete hollow-core slabs was replaced by a pinewood floor	15	46.9
Superstructure	C. Steel columns were replaced by pinewood columns	12	37.5
Finishing	B. False ceiling with gypsum tiles was replaced by fibre glass tiles	11	34.4
Finishing	D. Ceramic tiles were replaced by natural stone	10	31.2
Finishing	G. Ballast provided by concrete tiles was replaced by slate	10	31.2
Completion	A. PVC roofing was replaced by EPDM roofing	21	65.6
Energy		**#**	**%**
Climate systems	C. Surface increase solar thermal collectors	10	31.2
Lighting	A. Dim connection on lighting	14	43.8
Green energy	A. Using 100% green energy	29	90.6
Water		**#**	**%**
Facilities	A. Reducing surface with controlled humidification rate	10	31.2
Facilities	B. Remove pantry from building	10	31.2
Transport & mobility		**#**	**%**
Location	A. Place building not on the edge, but in the center of the city	14	43.8
Public transport	A. Reduce distance to train station	10	31.2
Public transport	B. Reduce distance to bus stop	11	34.4
Private transport	A. Reducing capacity of parking lot	16	50.0
Private transport	D. Different (unique) occupation rates for each modality	23	71.9

The mostly adopted measures involve the aspect materials. On average 7.3 measures focusing on materials were mentioned per group. The grading scheme of this assignment supported the students to mention two times more measures for this aspect than for the other individual aspects. In total fifty-five different measures were mentioned for this aspect of the building. The most favourite material to come to a lower environmental impact is timber. Most groups adapted the volume of the material to roughly compensate for the lower strength of the replacement, when this was necessary. For the aspects energy, water and transport the students were expected to mention at least five measures each. On average the groups came to 3.3 (energy), 0.8 (water) and 3.3 (transport) measures.

The requirements regarding budget and effectiveness were not influencing many groups. Although most groups tried to calculate the costs, the budget was in their opinion more than sufficient to cope with these costs. Only a small number of groups weighed the investment and its effectiveness. Eight groups did not mention the Energy Performance Coefficient and at least nine groups did not reflect on all aspects regarding the hidden environmental costs. Therefore, these groups were as a matter of fact not able to derive a conclusion regarding the effectiveness of their complete package of measurements.

4.2 GreenCalc+

The second group of students used GreenCalc+ V2.1.0, developed in 2007. Their forty-one reports showed that different measures were adopted compared to the group of students using GreenCalc. Their favourite measures, adopted by ten or more groups, are presented in Table 2.

Table 2: Most often adopted techniques in GreenCalc+

Materials		**#**	**%**
Foundation	A. Concrete foundation pile was replaced by wooden pile, with FSC trademark and a head of concrete	26	63.4
Foundation	C. Sand is replaced by foil	12	29.3
Building shell – façade	A. Ceramic tiles, polystyrene plates, and lime-sandstone was replaced by timber frame/glass wool/gypsum	11	26.8
Building shell – façade	B. Doors and doorframes of hardwood are replaced by doors and doorframes of European plywood	10	24.4
Building shell – inner walls	A. Metal stud with gypsum plates, glass wool and gypsum plates was replaced by timber frame with pinewood and rock wool	31	73.8
Building shell – inner walls	B. Gypsum stucco is replaced by loam stucco	11	26.8
Building shell – floors	A. Concrete, polystyrene plates, and RO-anhydrite was replaced by wood, polystyrene plates, and PE	16	39.0
Building shell – floors	B. Concrete hollow-core slabs with 0% granulate were replaced by plywood and beams of pinewood with FSC trademark	14	34.1
Building shell – roof	A. Concrete hollow-core slabs with mineral wool, PVC and PE are replaced by plywood, concrete, hardboard, foil and mineral wool	10	24.4
Building shell – roof	B. Concrete hollow-core slabs with PE, mineral wool and PVC tracks were replaced by pinewood beams and polystyrene plates	11	26.8
Building shell – roof	N. HR++ Aluminium is replaced by HR+ glass with European hardwood	10	24.4
Installations	A. Mechanical ventilation with air treatment and heat recovery is replaced by natural air supply with mechanical carry off	20	48.8
Installations	B. Mechanical ventilation with air treatment and heat recovery is replaced by self-regulating grids	12	29.3
Finishing	A. By the false ceiling, L shaped profiles of steel are replaced by L shaped profiles of pinewood	17	41.5
Energy			
Structure	C. Automatic awning	14	34.1
Climate systems	A. No mechanical ventilation	16	39.0
Climate systems	B. Natural air supply with mechanical carry off	14	34.1
Climate systems	G. Electrical heatpump with as source used air	19	46.3
PV / windmills	A. Use of a windmill	23	56.1
PV / windmills	C. Surface increase PV Cells	12	29.3
Water			
Facilities	B. Use of a pantry	10	24.4
Sanitary	A. Increased number of urinals	11	26.8
Sanitary	B. Decreased volume reservoirs of toilets	20	48.8
Transport & mobility			
Public transport	A. Reduce distance to train station	17	41.5
Public transport	B. Reduce distance to bus stop	32	78.0
Private transport	F. Promotion of carpooling	11	26.8

Timber was again a common used material to come to a lower environmental impact. One similar measure compared to 2007 is the replacement of the concrete piles in the foundation by timber ones. Furthermore, the tables reveal that the students tried to replace the ceramic tiles. The students of 2008 unfortunately made the mistake that their replacement cannot withstand the outdoor environment by itself. For reducing the environmental impact of the aspect energy 56.1% suggested to use a windmill. The volume of reservoirs should be reduced regarding the water consumption and the aspect transport is being improved by relocating a bus stop. Reducing the distances to the train station and bus stop were also important measures among the students of 2007 and 2008.

In case of measure N in the category Building Shell of the aspect Materials concerning a roof window (see Table 2), many students did not notice that the environmental impact regarding energy use increased when

HR+ glazing was selected. Furthermore, the same kind of links were absent for measure A and B in the category Installations of the aspect Materials on the one hand and measure A and B in the category climate systems of the aspect Energy on the other hand.

The budget for implementing sustainable techniques was one million Euros. Although placing a windmill or photovoltaic panels were regarded as long term investments, not many groups saw the budget as a constraint not to adopt these techniques. Eleven groups did not mention the total costs of the adopted measures. Furthermore, many groups did not use all the output of the assessment tool. At least eighteen groups did not reflect on the Energy Performance Coefficient. Sixteen groups did not mention the improvements quantitatively regarding the total environmental performance of their new alternative.

5. Comparative analysis

In this section the results of the GreenCalc assignments in 2007 and 2008 will be compared, regarding:

1. The total number of measures per aspect;
2. The number of unique measures per aspect;
3. The number of measures per group per aspect.

Many measures were of course mentioned by more than one group. In 2007 471 measures were suggested in the student reports; 233 materialistic measures, 107 energetic measures regarding energy, 27 water related measures regarding water, and 104 measures regarding mobility were mentioned. Using GreenCalc$^+$ the total number of measures was 727. There were 416 measures focusing on materials, 149 involving energy, 69 on water, and 93 on mobility (see Figure 3).

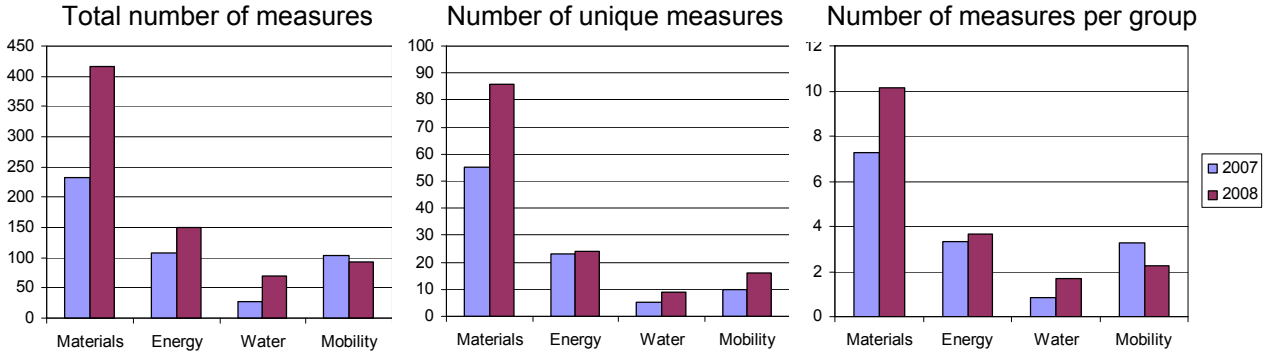


Figure 3 Histograms showing the total number of measures, the number of unique measures and the number of measures per group for each aspect of GreenCalc and for each group of students

The group of students using GreenCalc mentioned in 2007 fifty-five unique measures regarding materials, twenty-three on energy, five on water, and ten regarding mobility and transport (see Figure 3). All reports combined, 93 unique measures were suggested with the intention to lower the environmental impact of the construction. 135 unique measures were proposed using GreenCalc$^+$, which is significantly higher than the year before. This increase was not really due to additional energetic measures, but due to increases within the other three aspects, which can be seen in Figure 4. This is quite surprising, because especially by the end of 2007 and in the beginning of 2008 energy saving was (and still) is an important topic in the (Dutch) news.

On average 14.7 measures were suggested per group in 2007, although the grading scheme of assignment showed that 25 measures per group were requested. Using GreenCalc$^+$ on average 17.7 measures per group were mentioned, which is already 3.0 higher compared to GreenCalc. Only the number of measures regarding mobility strongly decreased, but the other three aspects were better represented. Figure 5 shows that the presence of the aspect energy was relatively reduced. The grading scheme aims on a distribution of 40%, 20%, 20% and 20%, that was according to Figure 5 best met by the students of 2007. Nevertheless, the expected amount of 25 measures was best met the students of 2008. The target of ten materialistic measures was on average met by them by 10.1 measures. The average number of measures per group for energy was 3.6, water 1.7, and transport 2.3.

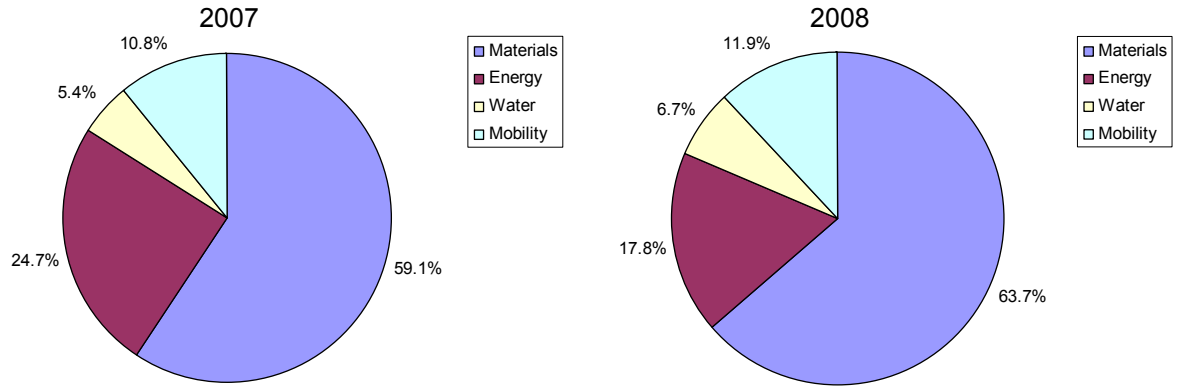


Figure 4 Pie charts showing the percentage of unique measures for each aspect of GreenCalc(+)

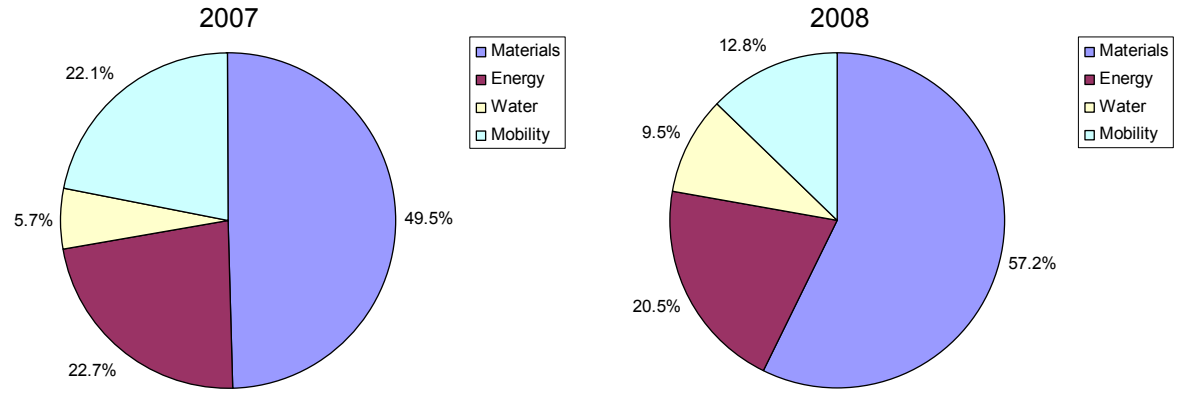


Figure 5 Pie charts showing the relative distribution of measures per aspect of GreenCalc(+)

6. Conclusions

The interface of the new GreenCalc+ seems to stimulate the students to come up with more environmental friendly measures than GreenCalc. More unique measures, an increase of 0.4 unique measures per group, and on average three more measures per group were given. There are however two small exceptions regarding this main conclusion.

The aspect mobility has in GreenCalc+ less influence on the performance of the individual object. This aspect has been upgraded to the level of the neighbourhood. Using GreenCalc, 10 unique measures and in total 104 transport measures were given. In GreenCalc+, 16 unique measures and in total 93 measures were given. In GreenCalc+ only one single field was provided to assess the environmental impact of this aspect within the direct context of the building. This field contains ten variables and the possibility to correct the eight generated modality factors. In GreenCalc three sub-topics were included, namely: location, public transport, and personal transport. In total thirteen variables were mentioned and all could be altered. It seems that the different outline and the smaller number of variables had their influence. Furthermore, it can be mentioned that the students of 2008 mentioned more social measures for this aspect than the students 2007. Some examples are “green” car insurance, promoting carpooling, and promoting public transport. By altering the position of this aspect within the tool, the attention of the students was turned to the other aspects.

A second exception is the aspect energy. More measures were indeed mentioned, but the diversity in these energetic measures was relatively smaller. GreenCalc+ misses the possibility to buy green electric energy from an external supplier, which was a favourite among the students of 2007. However, GreenCalc+ does offer options, additional to GreenCalc, to assess awning, photovoltaic installations, and windmills directly. These three extra options were often used, because with 34.1%, 29.3% and 56.1% (see Table 2) they belong to the most favourite energetic measures. The number of varieties within the aspect energy is much smaller than for materials, because the aspect energy is not based on a huge database offering environmental friendly options. As a matter of fact the building has already a very good energy performance and the number of possibilities to choose an improved item per variable is quite limited. In this regards the 24 unique measures could be close to the maximum value.

The use of GreenCalc+ brought also some qualitative advantages, besides the mentioned quantitative advantages. More students succeeded in lowering the Energy Performance Coefficient. It seems they were better aware of the relation between the heat resistance of materials as part of the aspect materials, and the

energy consumption assessed within the aspect energy. Both versions of GreenCalc calculate the heat resistance of walls, floors, and roofs automatically. GreenCalc$^+$ incorporates also the environmental impact of installation materials being one of the sub-aspects of the aspect materials, which vice versa could have triggered the students of 2008 more to have a closer look at the relations between the aspects materials and energy, compared to the students of 2007 did using GreenCalc.

7. Recommendations and future research

In the future it is expected that GreenCalc$^+$ will be used and not GreenCalc. GreenCalc$^+$ can be preferred because of its clear composition and user friendliness. Nevertheless, some changes to improve the assignment in meeting the objectives of the course are suggested.

The case ThermoStaete offers a limited number of possibilities for improvement. Although a large number of unique measures can be proposed, it seems that this case limits the students to come up with additional measures regarding water consumption. The standard design of ThermoStaete already incorporates the most interesting and effective measures. Furthermore, the aspect energy use receives less attention from the students than was expected, probably because they are not familiar enough with the Energy Performance Coefficient and technical alternatives for the already adopted heat pump. An assignment involving the design of a new object or a case object with a higher environmental impact to start with will offer the students more freedom. When designing a (small) new object the total investment costs could be calculated by the students, this will give them more insights in the relation between traditional and sustainable measures regarding their (financial) costs and potential (financial) benefits.

Furthermore, the meaning and use of the environmental indices and Energy Performance Coefficient should be more profoundly explained to the students in the reader, and courses, although the Energy Performance Coefficient was already addressed in the reader, assignment, and course. The interface of the GreenCalc$^+$ could be adapted in such a way, that the main screen shows the total hidden environmental costs and Energy Performance Coefficient all the time. The influence of every alteration in adopted measures is in that case directly computed and visible.

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