The Contribution of the Albedo in the Life Cycle Assessment (LCA) of Three Roofs

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Life Cycle Assessment

An Evaluation from ‘Cradle to Grave’
Life Cycle Assessment

Goal; Functional Unit; System Boundaries

Inventory

Emissions

Evaluation of the Environmental Impact

Classification  Characterization  Normalization  Evaluation

Materials  Processes

Energy

The procedures of the LCA are part of the ISO 14000 environmental management standards.
Life Cycle Assessment in Four Steps

**Classification:** All the substances are sorted into classes according to the effect they have on the environment.

**Characterization:** The substances are aggregated within each class (impact categories) to produce an *effect score*. It is not sufficient just to add up the quantities of substances involved without applying weightings. Some substances may have a more intense effect than others.

**Normalization:** Each effect calculated for the life cycle of a product is benchmarked against the known total effect for this class (damage category).

**Evaluation:** In the evaluation phase the normalized effect scores are multiplied by a weighting factor representing the relative importance of the effect.
The method: Impacts 2002+

The damage categories:

- Ecosystem Quality [PDF*m/yr = Potentially Disappeared Fraction of plant species];
- Human Health [DALY = Disability Adjusted Life Years];
- Climate Change [CO\textsubscript{2}];
- Resources [MJ = Additional energy requirement to compensate lower future ore grade].
LCA’s Strengths and Weaknesses

**Strength:** Life Cycle Assessment is considered an objective tool capable to express the final environmental burdens of a product, a good or a service in eco-score.

**Weakness:** This tool has been created for industrial products. When it is applied to buildings or components of buildings it does not take into account some characteristics and the relationship with the urban environment.
Problem: In a ‘traditional’ LCA the surface albedo is not considered.

Solution: Here, a broadening of the LCA method has been proposed considering the surface albedo of three roofs (black, white and green);
Roof Replacement Phase:

- the effects of the surface albedo through the CO$_2$ equivalency have been modeled in the software SimaPro 7.1 (climate-change damage category);

Not considered: the transportation, the end life of the building materials and the additional benefits of the water retention and pollutants uptake (green roof) are not included.

Service Life Phase:

- field data have been used in order to evaluate the heat fluxes through the roofs and the environmental impacts relative to the use of energy.
Surface Albedo

Albedo ($\alpha$) = Reflected short waves/Incident short waves

Low albedo surface

High albedo surface

Incoming Short Wave radiations

Outgoing Short Wave radiations

Surface Temperature

Surface Temperature
Radiative Forcing (RF)

RF = received energy – re-radiated energy [Wm\(^{-2}\)]

**The Climatologic Model**

\[ +0.01\alpha \text{ m}^{-2} = -1.27 \text{ Wm}^{-2} \]

- The Akbari model* has been used for the evaluation of the effects of the surface albedo on the climate change damage category;

- The increase of the surface albedo produces an increase of the reflected solar radiation (Radiative Forcings).

The Climatologic Model

\[ +0.01 \alpha \ m^{-2} = -2.55 \text{ Kg CO}_2\text{ eq m}^{-2}(\text{\textasteriskcentered}) \]

- The values about the radiative forcings can be translated into kg of equivalent CO\(_2\) emitted or avoided;

- This value has been used in the software SimaPro 7.1 as avoided emission in the atmosphere;

- The black roof has been considered as reference.

\((\text{\textasteriskcentered})\) Akbari H, Menon S, and Rosenfeld A, 2009 Global cooling: increasing world-wide urban albedos to offset CO\(_2\). *Climatic Change* 94 275-286
Black vs. White vs. Green roof

The three roofs are installed in Con Edison ‘Learning Center’ office building in Long Island City, Queens, New York.
Black vs. White vs. Green roof

Full weather stations have been installed on the roofs
Black and White Roofs

Same Thermal Resistance: \( R=3.810 \, \text{m}^2\text{K/W} \)

Different albedo (\( \alpha \)).

White/black roof: cross section
Green Roof

Thermal Resistance: \( R = 4.458 \text{ m}^2\text{K/W} \)

![Green roof: cross section](image)
Green Roof Albedo (Reflected SW/Incident SW)

Reference: Stuart R. Gaffin ¹,* , Reza Khanbilvardi ² and Cynthia Rosenzweig Sensors 2009, 9,
Surface Albedo

Black roof: $\alpha = 0.05$

White roof: $\alpha = 0.6$

Green roof: $\alpha = 0.2$
Roof Replacement Phase

50 years evaluation

<table>
<thead>
<tr>
<th>Material</th>
<th>Life expectancy (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense deck</td>
<td>20</td>
</tr>
<tr>
<td>Rubber membrane</td>
<td>20</td>
</tr>
<tr>
<td>Polystyrene board</td>
<td>40</td>
</tr>
</tbody>
</table>

For the green roof, the protection action of the growing media permits the building materials underneath the soil to have a longer life expectancy. No maintenance operations are requested in the 50 years evaluation.
Model Results for the Environmental Impacts of the Three Roofing Systems

50 years evaluation: roof replacement phase

<table>
<thead>
<tr>
<th>Roofing System</th>
<th>Human Health</th>
<th>Ecosystem Quality</th>
<th>Climate Change</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Roof</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Roof</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green Roof</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Software: SimaPro 7.1
Method: Impact 2002+
Daily Averaged Temperatures:
October 2008 - May 2009

T [°C]

Local Time

Air Temp
Black roof Surface
Daily Averaged Temperatures:
October 2008 - May 2009

Local Time

Air Temp
Black roof Surface
White Roof Surface

Local Time

Air Temp
Black roof Surface
White Roof Surface
Green Plant Surface

- Air Temp
- Black roof Surface
- White Roof Surface
- Green Plant Surface
- Soil Bottom (10 cm)
Surface Temperature

T [°C]

Date

01/06/2009
08/06/2009
15/06/2009
22/06/2009
29/06/2009
06/07/2009
13/07/2009
20/07/2009
27/07/2009
03/08/2009
10/08/2009
17/08/2009
24/08/2009
31/08/2009

Black Roof
White Roof
Air
Green Plant
North Soil Bottom
The heat fluxes have been calculated in a steady state using a one-dimensional equation:

\[ Q = \frac{\Delta T}{R} \text{ (Wm}^{-2}\text{)} \]

Where \( \Delta T \) is the difference between the surface temperature and the temperature at the ceiling, expressed as °K and \( R \) is the thermal resistance of the roofs (m\(^2\)K/W).

The indoor temperatures have been fixed considering the adaptive behavior of the employees in the offices according to the mean monthly outdoor temperature.
Hypothesis 1: Use of electric power

- Heat Flux [W/m² per day]

- Month

- Black Roof
- White Roof
- Green Roof Surface
- Poli. (Black Roof)
- Poli. (White Roof)
- Poli. (Green Roof Surface)
Hypothesis 2: Use of Electric Power for Cooling and Natural Gas for Heating
LCA: Roof Service Life Phase

50 years evaluation

Electric Power for Cooling and Heating

- Black Roof
- White Roof
- Green Roof

Electric Power for Cooling and Natural Gas for Heating

- Black Roof
- White Roof
- Green Roof

Software: SimaPro 7.1
Method: Impact 2002+

Human Health
Ecosystem Quality
Climate Change
Resources
LCA: Roof Replacement + Service Life Phase

50 years evaluation

Electric Power for Cooling and Heating

<table>
<thead>
<tr>
<th>Roof Type</th>
<th>Black Roof</th>
<th>White Roof</th>
<th>Green Roof</th>
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Electric Power for Cooling and Natural Gas for Heating

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Software: SimaPro 7.1
Method: Impact 2002+

Human Health | Ecosystem Quality | Climate Change | Resources
RESULTS:

- the growing media on the green roof preserves the underneath layers increasing the life span of the building materials;

In the building materials replacement phase using as reference the traditional flat black roof:

- the high albedo of the white roof contributes to a decrease in the climate-change damage category of 220,13%;

- the albedo of the green roof contributes to a decrease in the climate-change damage category of 160,93%.

In both cases not only the impact in the climate change damage category has been nullified but the higher albedo has a positive feedback on climate.
RESULTS:

In the roof service life phase the albedo contributes to the decrease energy use of:

- 9 - 18% for the white roof;
- 30 - 37% for the green roof.

-During the warmest months: the average heat fluxes through the white roof are 62% less and through the green roof are about 75% less than those through the black roof in the period May – August 2009;

This means that there is a significant reduction of the probability of blackouts that typically occur in summer.

-The final impact of the white roof is 10% less than that of the black roof, while the final impact of the green roof is about 31% less than a traditional flat black roof.
CONCLUSIONS:

- The use of the surface albedo is an important broadening for the use of the LCA evaluation;

- Albedo in LCA is an additional parameter to consider in order to determine the more environmentally preferable choice;

- Now, mitigation and adaptation strategies can be successfully assessed through the use of LCA;

- Mitigation and adaptation strategies can be assessed in a space dependent evaluation;

- The introduction of the surface albedo in the LCA is an important step for assessing the relationship between urban surfaces and local warming phenomena (i.e., the urban heat island).
THANK YOU FOR THE ATTENTION!
ANY QUESTIONS?