Italian National Agency for New Technologies, Energy and Sustainable Economic Development

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Black, Green and White Roofs Evaluated Through the Use of an Implemented Life Cycle Assessment (LCA) Methodology

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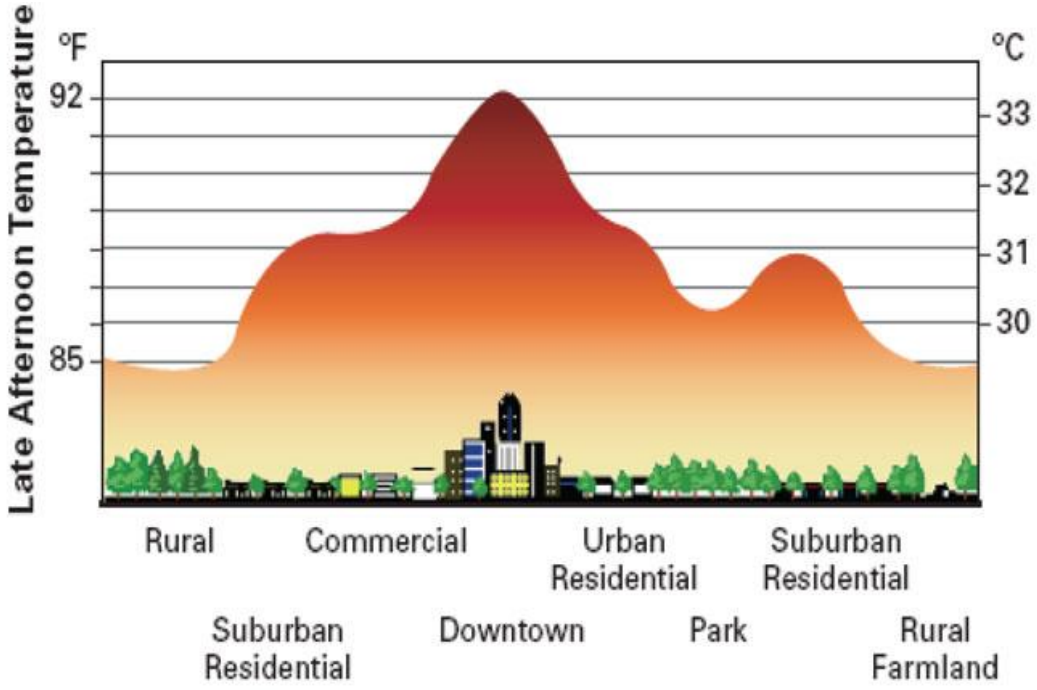
Background

Green and White Roofs

- Energy use for heating and cooling;
- urban heat island (UHI);

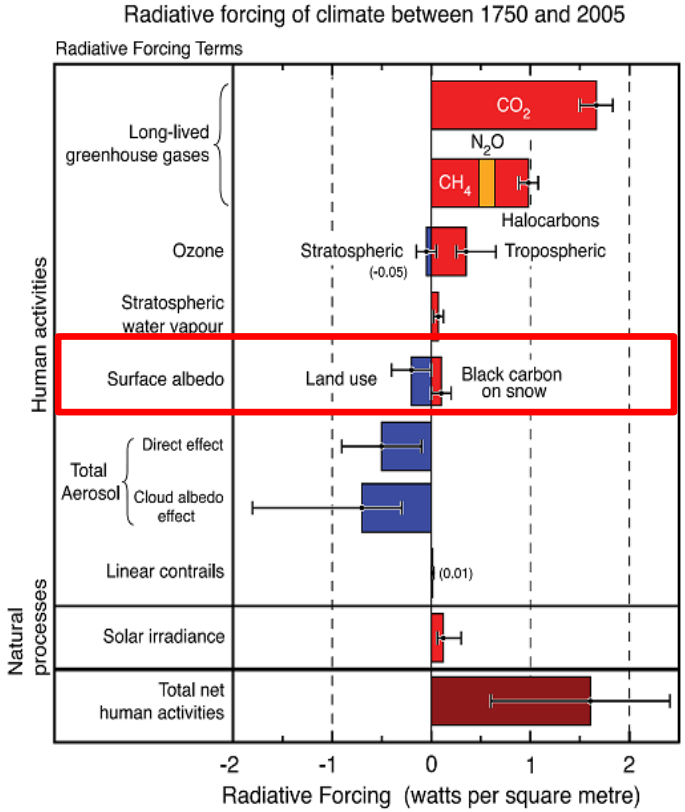


Source: Lawrence Berkeley National Laboratory

Background

Green and White Roofs

- effects on radiative forcing.



Source: IPCC (2007)

Objectives

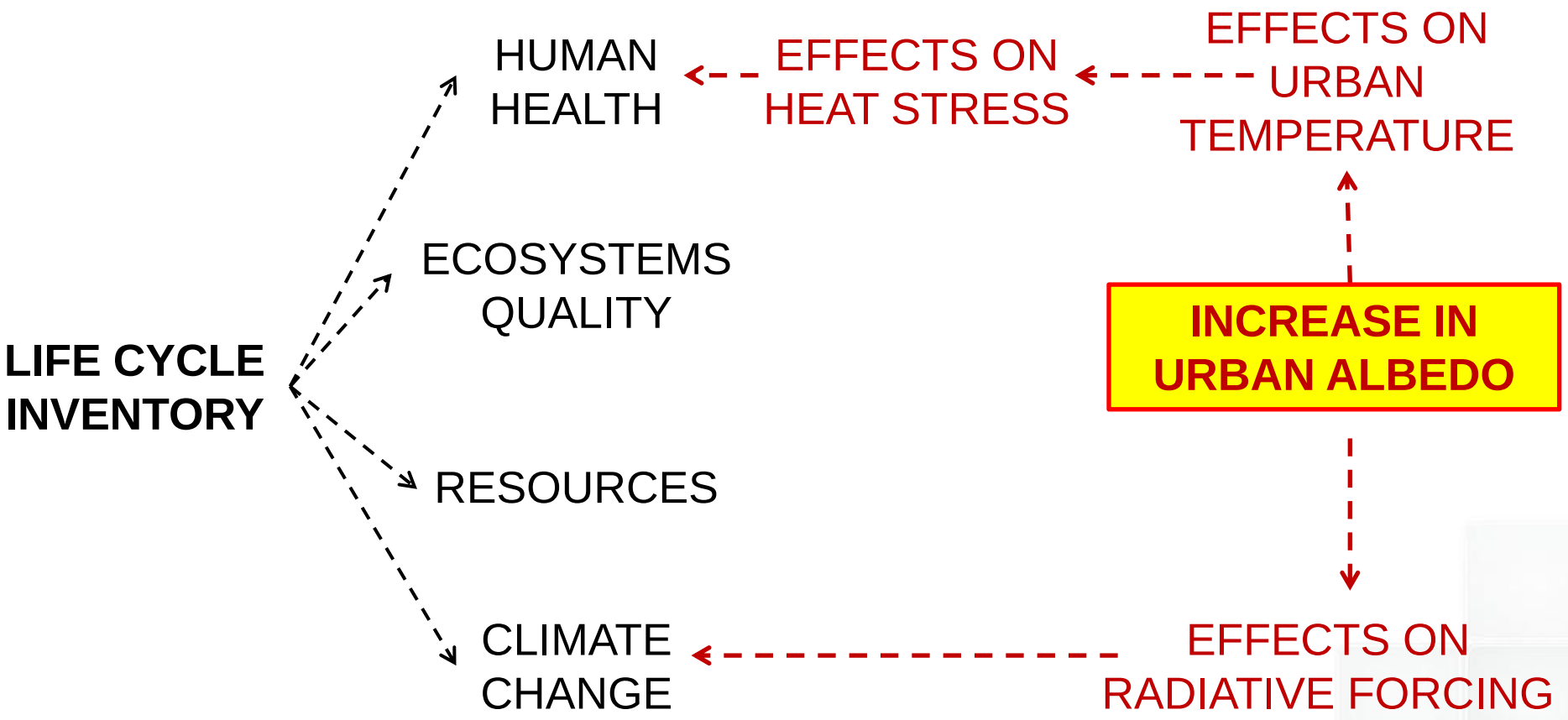
To Compare 3 Roofing Systems:

- a black roof;
- a white roof;
- a green roof.

To Use a Multiscale Approach that Considers the Effect on:

- Energy use (microscale);
- Global climate (macroscale);
- Urban climate and human health (mesoscale).

Framework


HUMAN HEALTH
EFFECTS ON HEAT STRESS
EFFECTS ON URBAN TEMPERATURE
ECOSYSTEMS QUALITY
INCREASE IN URBAN ALBEDO
LIFE CYCLE INVENTORY
RESOURCES
CLIMATE CHANGE
EFFECTS ON RADIATIVE FORCING

Framework

Energy Use

Difference in energy fluxes: $\Delta Q = \frac{\Delta T}{R}$

Life Cycle Impact Assessment

Evaluation of Surface Albedo per m^2

Akbari et al. (2009)*

Short-term (20-50 yrs): +0.01α is equivalent to a decrease of $2.55\ kg\ CO_2$

* Akbari et al. (2009). Global cooling: increasing world-wide urban albedos to offset CO_2. *Climatic Change*, 94, 275-286.

Framework

Life Cycle Impact Assessment

Surface albedo:Time-dependent evaluation*

- Based on existing relations;
- Mean values.

$$+0.01\,\alpha = \frac{-1.38 \cdot t}{\int_0^t \text{Decay } CO_2(t)\,dt}$$

$$0.01\alpha = \frac{-1.38 \cdot t}{\int_0^t \left(0.217 + 0.259\, e^{-t/172.9} + 0.038\, e^{-t/18.51} + 0.186\, e^{-t/1.186}\right) dt}$$

* Susca, T., (2012). Enhancement of life cycle assessment (LCA) methodology to include the effect of surface albedo on climate change: Comparing black and white roofs. *Environmental Pollution,* 163, 48–54

Framework

Life Cycle Impact Assessment

Human Health

- Climatological model developed by Oleson et al. (2010)*;

- decrease in summer UHI;

- no modification in winter UHI.

* Oleson, K. W., Bonan, G. B., & Feddema, J. (2010). Effects of white roofs on urban temperature in a global climate model. Geophysical Research Letters, 37

Life Cycle Impact Assessment

Human Health

Risk Ratio = “the measure of the risk of a certain event happening in a group compared to the risk of the same event happening in another group” (Dictionary of Cancer Terms)

Life Cycle Impact Assessment

Human Health

Daily mortality before and after the increase in urban-wide rooftop albedo

$$N_{deaths} = RR_{NYC} \cdot N$$

$$N_{deaths\ mit} = RR_{\ NYC\ mit} \cdot N$$

$$\Delta N = N_{deaths} - N_{deaths\ mit}$$

$$\Delta N_{summer} = \Delta N \cdot 92$$

Framework

Life Cycle Impact Assessment

Human Health

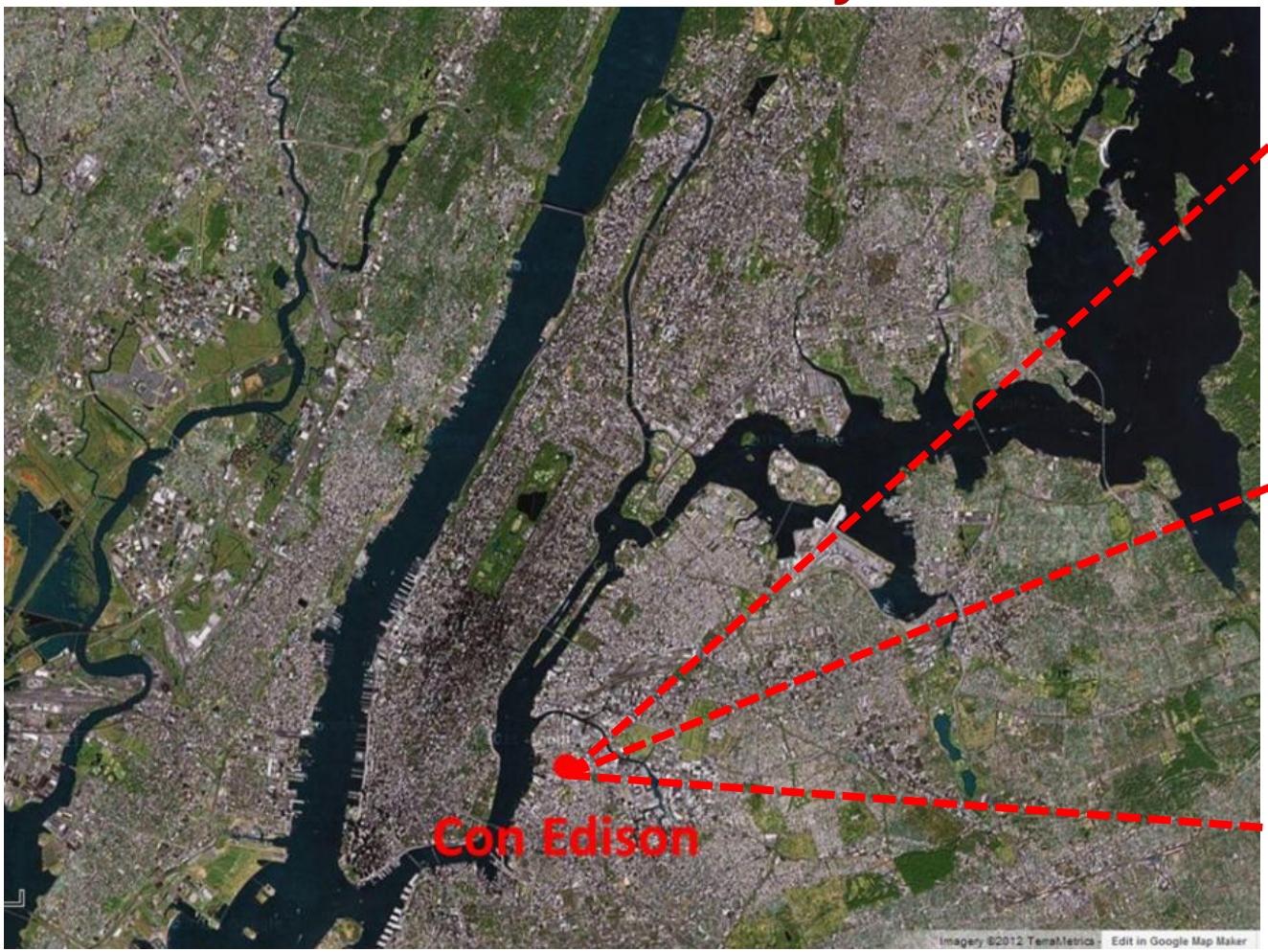
Evaluation of the avoided Disability Adjusted Life Years (DALY) per year = Years of Life Lost (YLL)

$$\text{Avoided } DALY = \Delta N_{summer} \cdot \Sigma\, Perc_{\,i} \cdot Exp_i$$

The avoided impact has been extended to the time horizon.

Case Study

New York City



Source: © 2012 Google Imagery Terra Metric

Goal and Scope

Comparative LCA of the roofs:

- Functional Units: 1 m^2;
- Time-horizons: 50 years;
- System boundaries: surface albedo, energy use construction and replacement;
- Life cycle impact assessment: climate change.

Case Study

Surface Albedo: 50 years

The black roof was considered as reference

Roofing System	Surface Albedo	Albedo Evaluation [kg CO_2 eq]*
Black	0.05	
White	0.6	-140.25
Green	0.2	-38.25
* Model developed by Akbari et al. (2009)		

Case Study

Annual Difference in Energy Use

Roofing System	Thermal Resistance [m²K/W]	Difference in heat fluxes (winter) [W/m²]	Difference in heat fluxes (summer) [W/m²]
Black	3.810		
White	3.810	-341	-2876
Green	4.458	-1543	-2921

* Minus means less heat fluxes of the white and the green roof compared to the black roof

- The black roof was considered as reference;
- Two scenarios: electric power for heating and cooling and electric power for cooling and natural gas for heating.

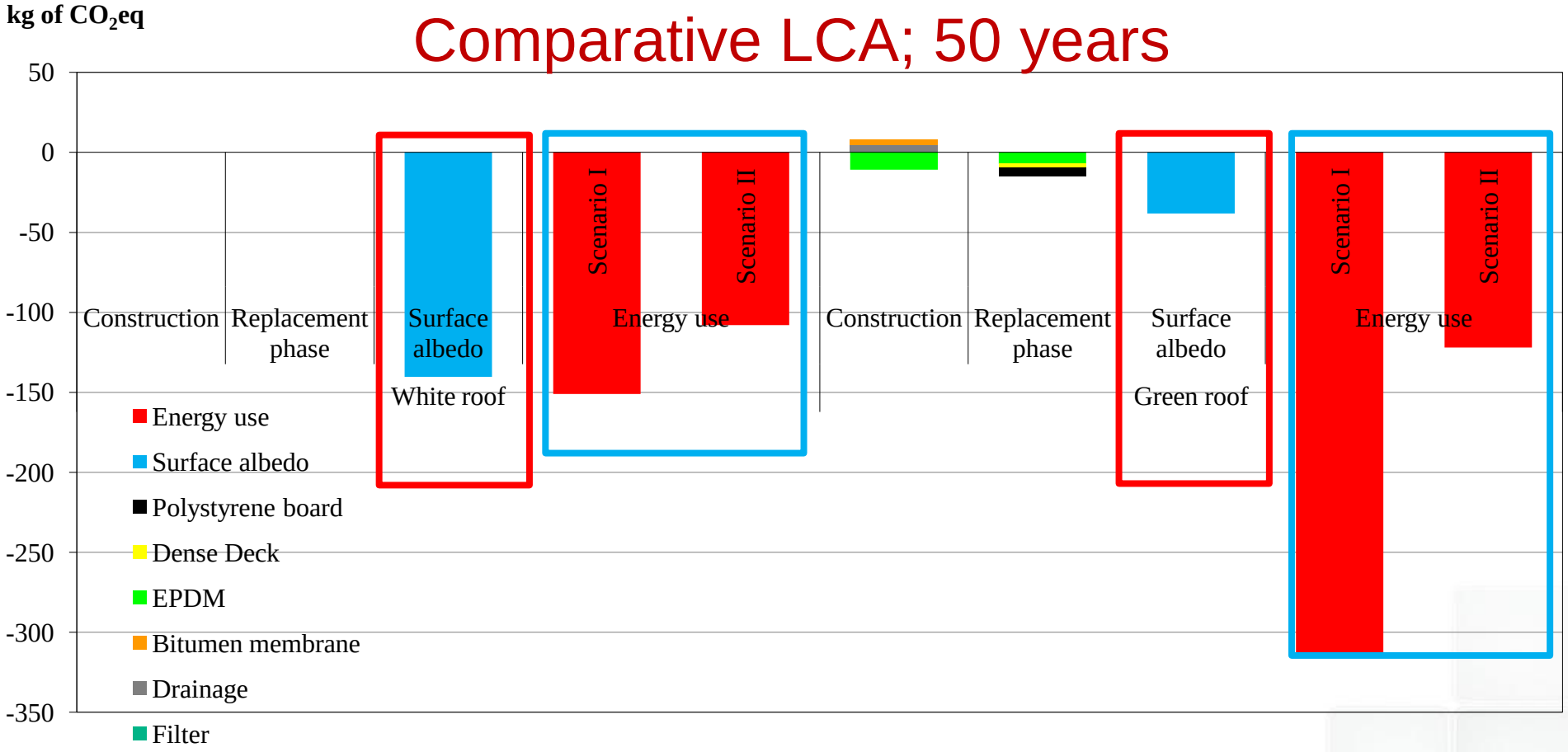
Case Study

Construction and Replacement

Green Roof		White and Black Roof	
Building Layer	**Life Span**	**Building Layer**	**Life Span**
Soil	50	EPDM	20
Filter	50	Dense Deck	20
Bitumen Membrane	50	Polystyrene Board	40
Dense Deck	50	Gypsum Board	50
Polystyrene Board	50	Dense Deck	50
Gypsum Board	50	Steel	>100
Dense Deck	50		
Steel	> 100		

Case Study

Results*
Comparative LCA; 50 years



* Susca et al., 2011. Positive effects of vegetation: urban heat island and green roofs. *Environmental Pollution*, 159 (8-9), 2119-2126

Case Study

White and Black Roof

Comparative LCIA (black roof as baseline) focused on climate change [CO_2 eq] evaluation:

- Functional unit: 1 m^2;
- Primary energy use (2 scenarios);
- Time-dependent albedo evaluation;
- Initial and aged albedos;
- Time-horizons: 50 and 100 years.

Case Study

Albedo	Black Roof	White Roof	Albedo Evaluation [kg CO_2 eq]**	
			50 years*	100 years*
Initial	0.05	0.8	-184	-217
Aged	0.15	0.6	-110	-131
* Minus means less impact of the white roof compared to the black roof				

** Susca, T., (2012). Enhancement of life cycle assessment (LCA) methodology to include the effect of surface albedo on climate change: Comparing black and white roofs. *Environmental Pollution,* 163, 48–54

Case Study

Energy Saving for the White Roof [kg CO_2 eq]			
50 years*		**100 years***	
I Scenario**	II Scenario***	I Scenario**	II Scenario***
-143	-106	-286	-211

* Minus means less energy use of the white roof compared to the black roof

** Electric power for heating and cooling

*** Electric power for cooling and natural gas for heating

Case Study: Mesoscale

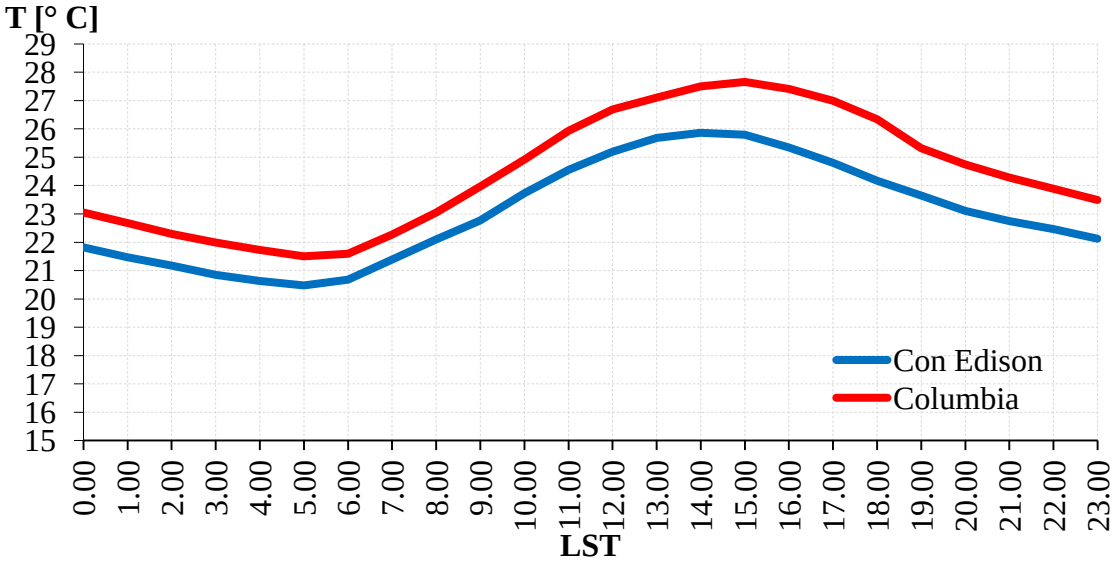
Evaluation of the Effect of the Urban-wide Increase in Rooftop Albedo*

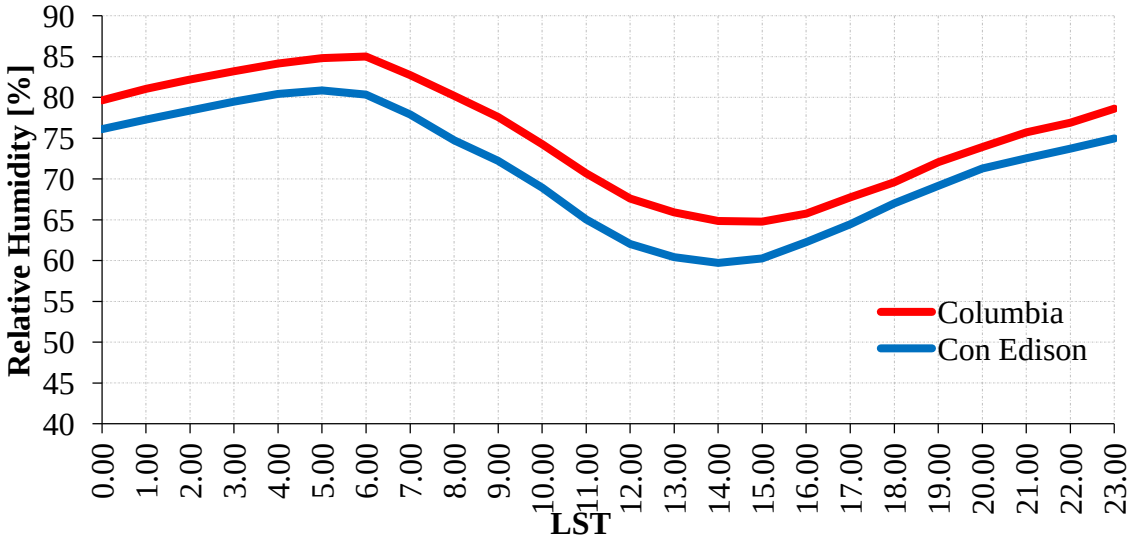
- Functional unit: New York City;
- Evaluation of the effect on human health;
- Incidence of surface albedo on construction and replacement phase;
- Time-horizons: 50 and 100 years.

* Susca T., (in press). Multi-scale approach to the life cycle assessment: Evaluation of the effect of the New York City increase in rooftop albedo on human health. *Journal of Industrial Ecology*

Case Study

Data: June 1st – August 31st 2009.
Source: Columbia University, New York City, New York





Case Study

- Climatological model developed by Oleson et al. (2010)* for New York City' cell;

- decrease in summer UHI;

- no modification in winter UHI due to the low incoming solar radiation;

- time-regression model by Metzger et al. (2010) for the evaluation of variation in risk ratio** human mortality for natural causes.

* Oleson, K.W., G.B. Bonan, and J. Feddema. 2010.Effects of white roofs on urban temperature in a global climate model. *Geophysical Research Letters 37.*

** Metzger, K.B., K. Ito, and T.D. Matte. 2010. Summer heat and mortality in New York City: How hot is too hot? Environmental Health Perspectives 118 (1): 80-86.

Case Study

Evaluation of the Avoided Impact

Age	Number of Deaths	Life Expectancy [Exp]	Percentage [Perc]	Avoided deaths per year [ΔN]
0	545	80.6	1.1	0.5
7	167	74.1	0.3	0.1
20	245	61.3	0.5	0.2
30	461	51.6	0.9	0.4
40	1242	42	2.5	1.1
50	3830	33	7.6	3.4
60	7124	24.6	14.2	6.4
70	8737	16.9	17.4	7.8
80	12106	10.2	24.1	10.8
85	15823	7.5	31.5	14.2

Source: NYC Vital Signs (2011)

Case Study

Evaluation of the Avoided Impact

- Annual avoided DALY = 751
- 50 year time-horizon: 37550 avoided DALY;
- 100 year time-horizon: 75100 avoided DALY.

Case Study

Evaluation of the Avoided Impact

Impact category	Unit	Time horizons	White roof Impact assessment	Effect of albedo on human health	Total	Avoided impact [%]
Human health	DALY	50 yrs	$116.48 \cdot 10^4$	$-3.7 \cdot 10^4$	$112.78 \cdot 10^4$	3.2
		100 yrs	$116.48 \cdot 10^4$	$-7.5 \cdot 10^4$	$109 \cdot 10^4$	6.4
Ecosystem quality	PDF·m^2·yr	50 yrs	$255 \cdot 10^8$	—	$255 \cdot 10^8$	—
		100 yrs	$276.64 \cdot 10^8$	—	$276.64 \cdot 10^8$	—
Climate change	kg CO_2	50 yrs	$175 \cdot 10^8$	—	$175 \cdot 10^8$	—
		100 yrs	$247.52 \cdot 10^8$	—	$247.52 \cdot 10^8$	—
Resources	MJ primary	50 yrs	$289 \cdot 10^9$	—	$289 \cdot 10^9$	—
		100 yrs	$497.12 \cdot 10^9$	—	$497.12 \cdot 10^9$	—

Method: Impact 2002+

Case Study

Results

- Green and white roofs are environmentally preferable choices to black roofs;
- Surface albedo plays an important role in decreasing the impact of white roofs;
- The additional thermal insulation provided by the soil and biomass decreases the energy use for cooling and heating the spaces below the green roof.

Case Study

Results

- Albedo is an important optical parameter to consider in LCA evaluation;
- The evaluation of the urban wide increase in albedo is able to enhance the evaluation of rooftops.

Thank you for the attention!

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