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AGRICOLTURA,
ALIMENTAZIONE
E AMBIENTE



Interreg
Italia-Malta



GREEN LAB

Progettazione di soluzioni basate sulla natura per la mitigazione del rischio idraulico in ambito urbano e sub-urbano



Green Infrastructures to mitigate flood risks in Urban and sub-urban areas and to improve the quality of rainwater discharges

Soluzioni tecnologiche e prestazioni energetiche dei tetti verdi

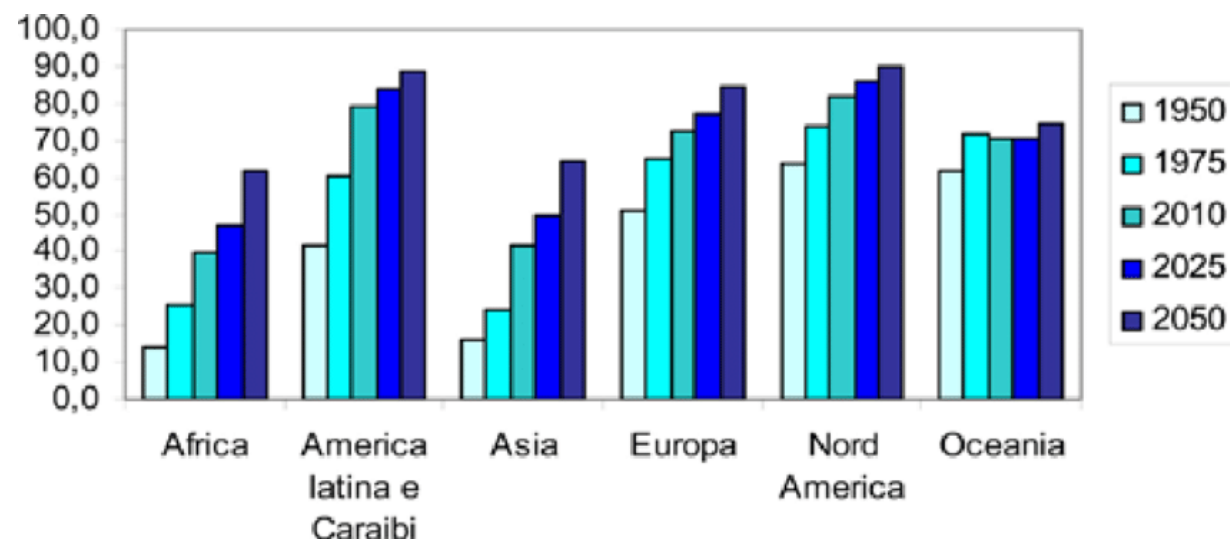
Ing. Stefano Cascone

Università Mediterranea di Reggio Calabria



Di3A – Aula G

31 luglio – 1 agosto 2023

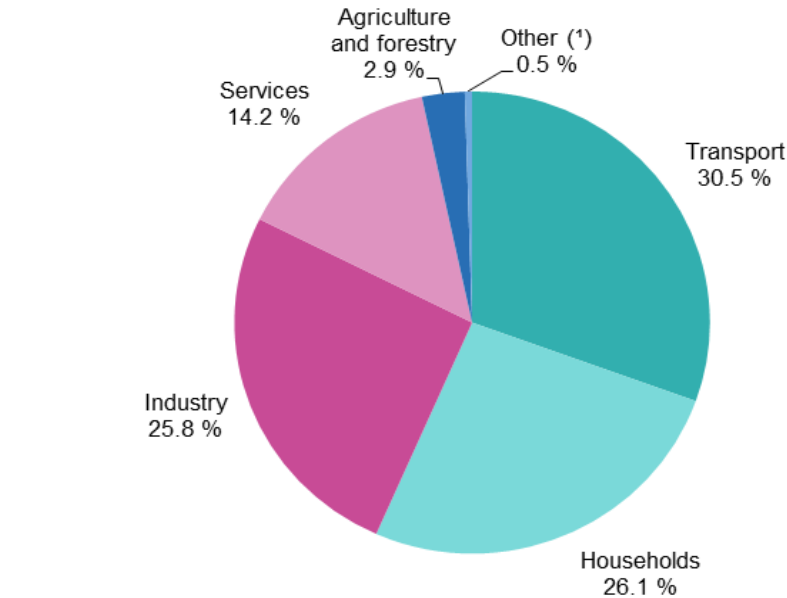


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Final energy consumption by sector, EU-27, 2018
(% of total, based on tonnes of oil equivalent)

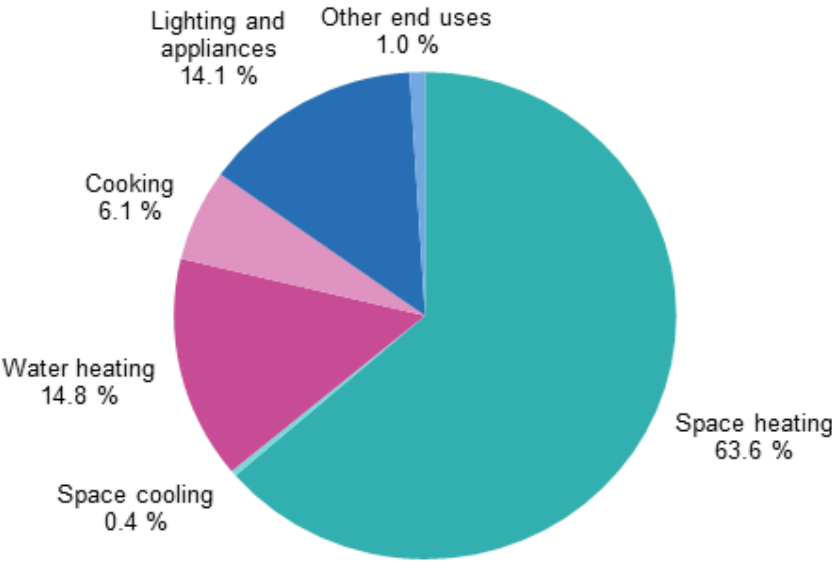


(*) Data on "international aviation" are not included in category Transport and hence are included in the category "Other".

Source: Eurostat (online data code: nrg_bal_s)

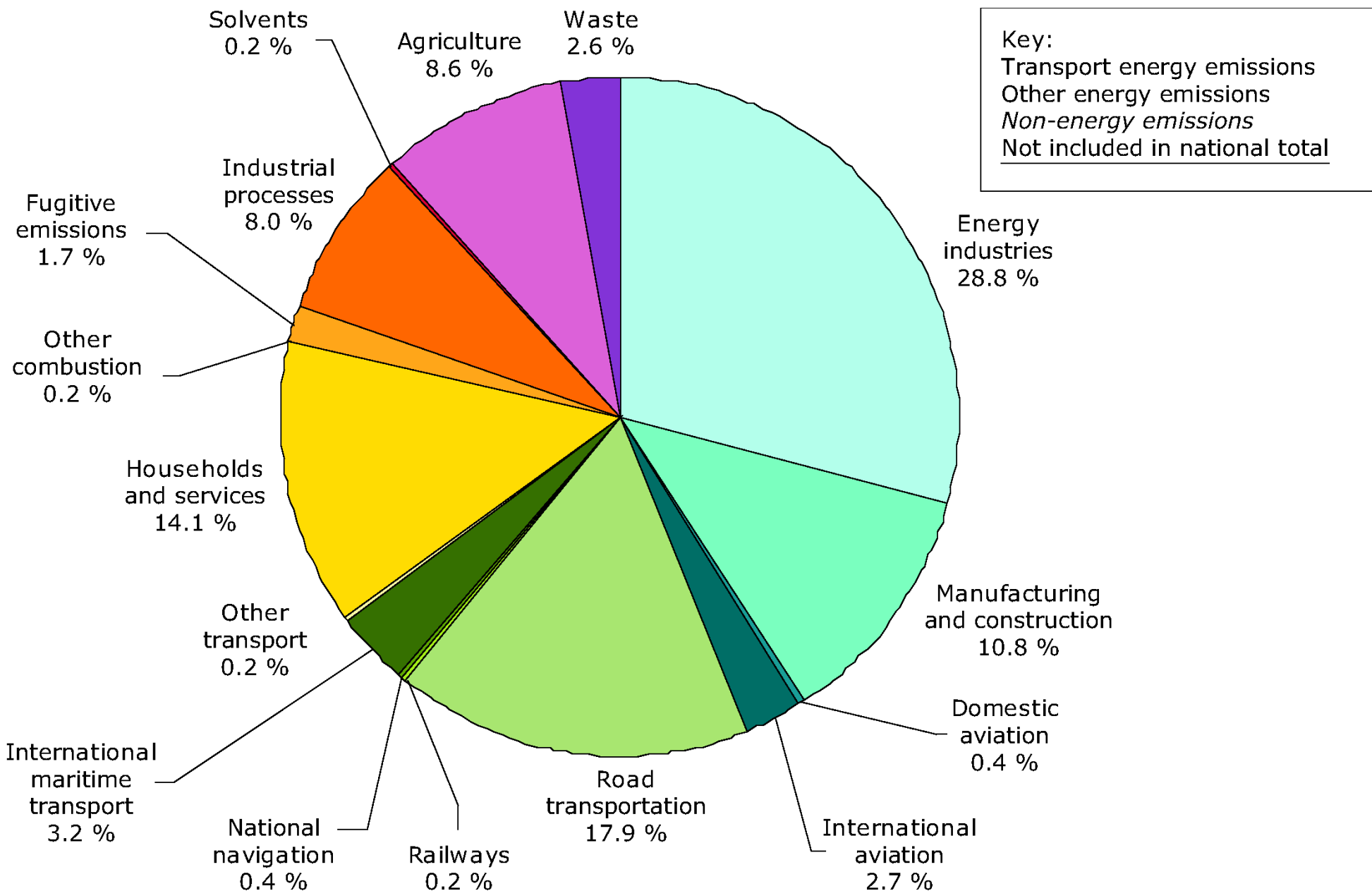
eurostat 

Final energy consumption in the residential sector by use, EU-27, 2018



Source: Eurostat (online data code: nrg_bal_c)

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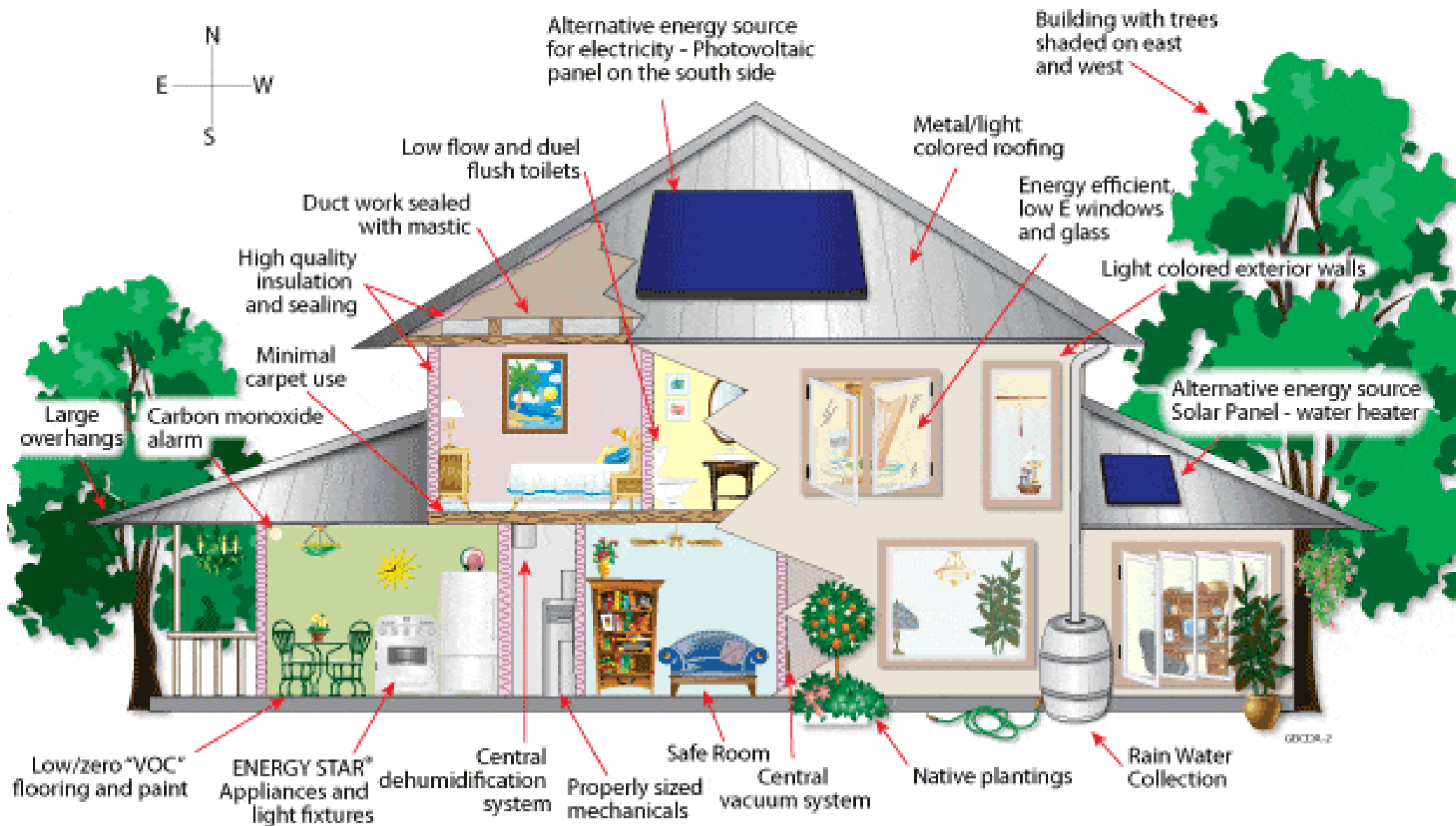
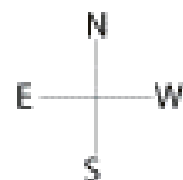




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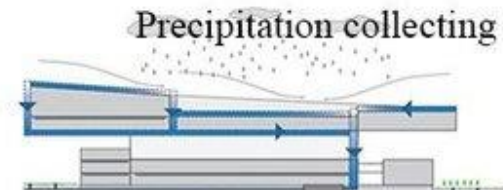
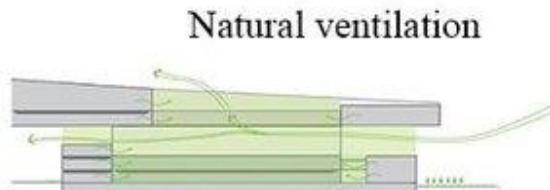
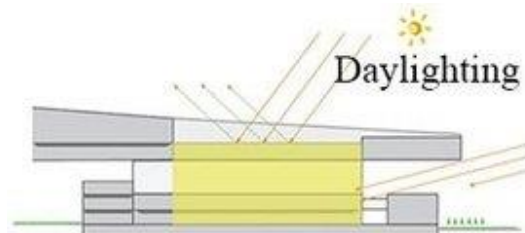


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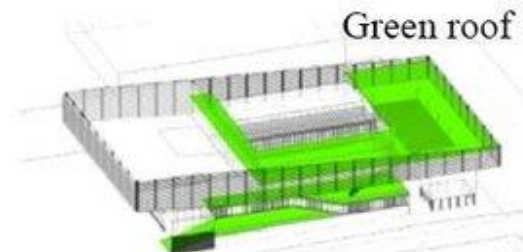
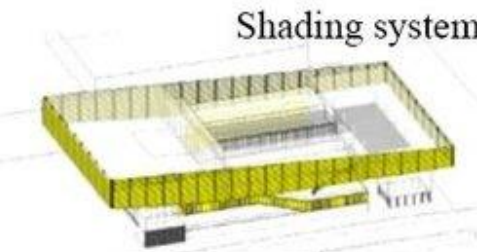
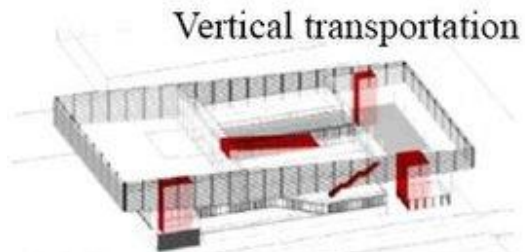


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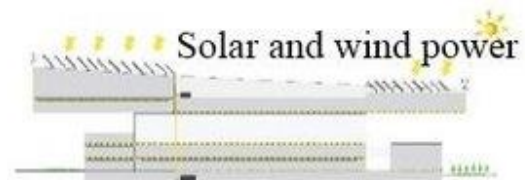
Regenerative design



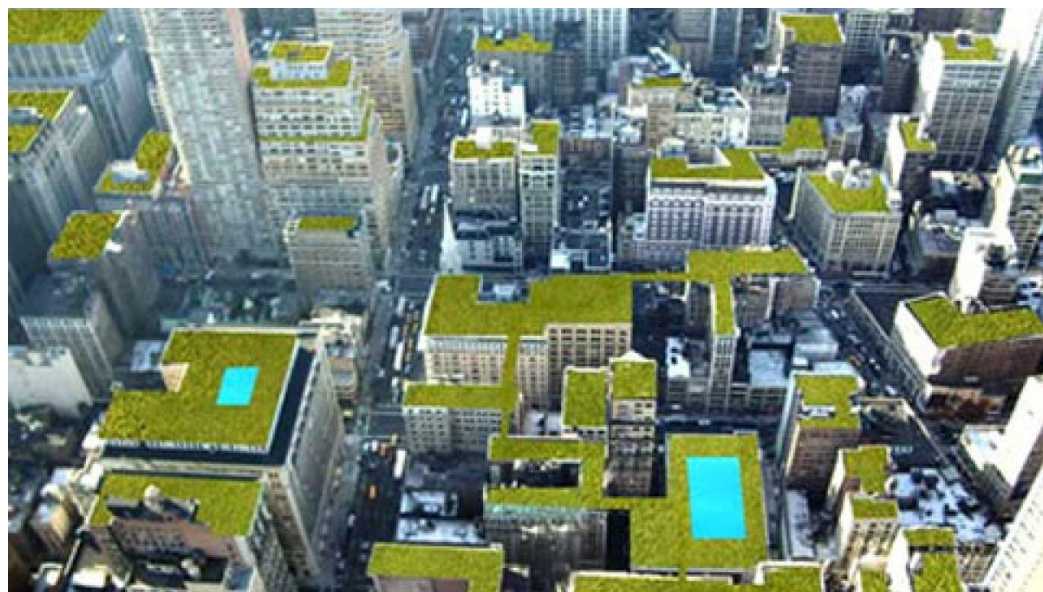
a) Passive design and construction techniques



b) New technologies and systems



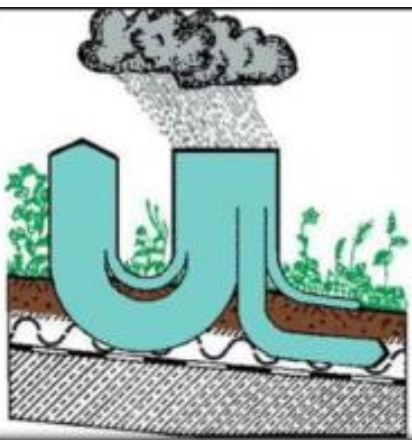
c) Use of renewable energy sources



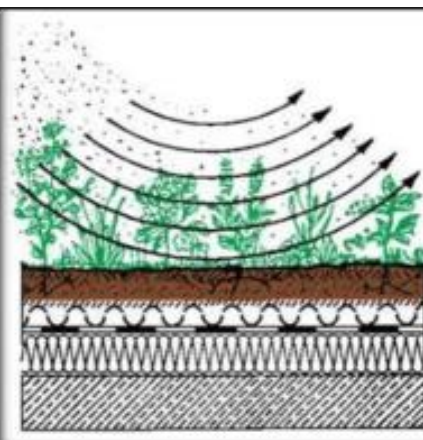
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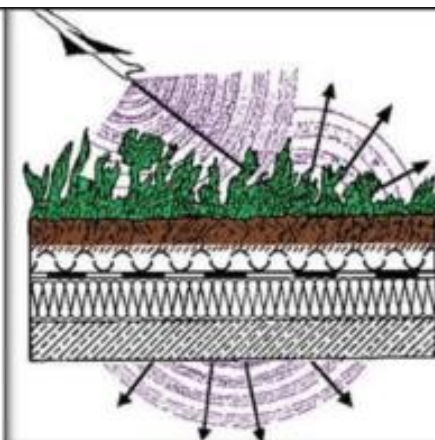




Amount of waste water reduces



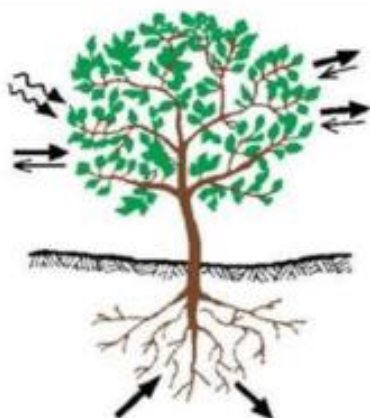
Less dusty environments are created



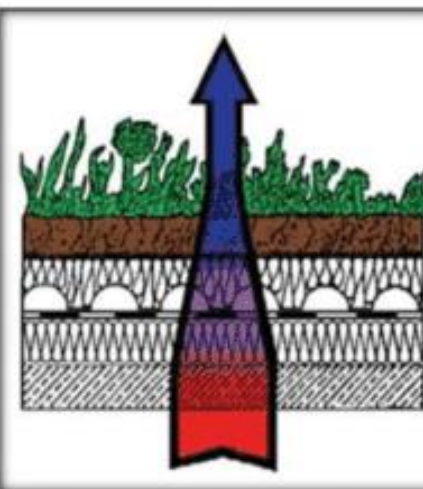
Ambient noise reduces



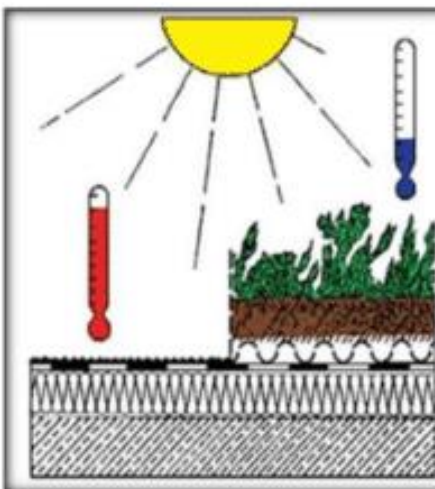
New utilization areas are obtained



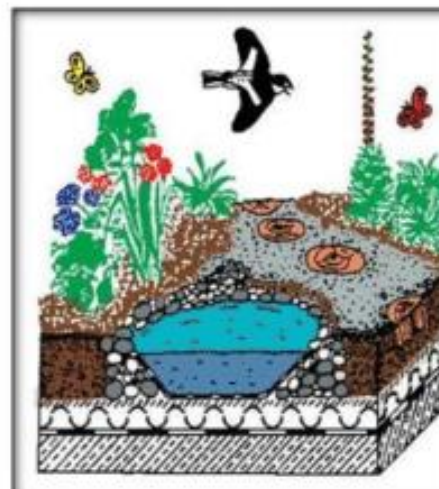
The climatic characteristics of environment change



Thermal insulation of the roof increases



Becoming longer service life of water insulation is provided

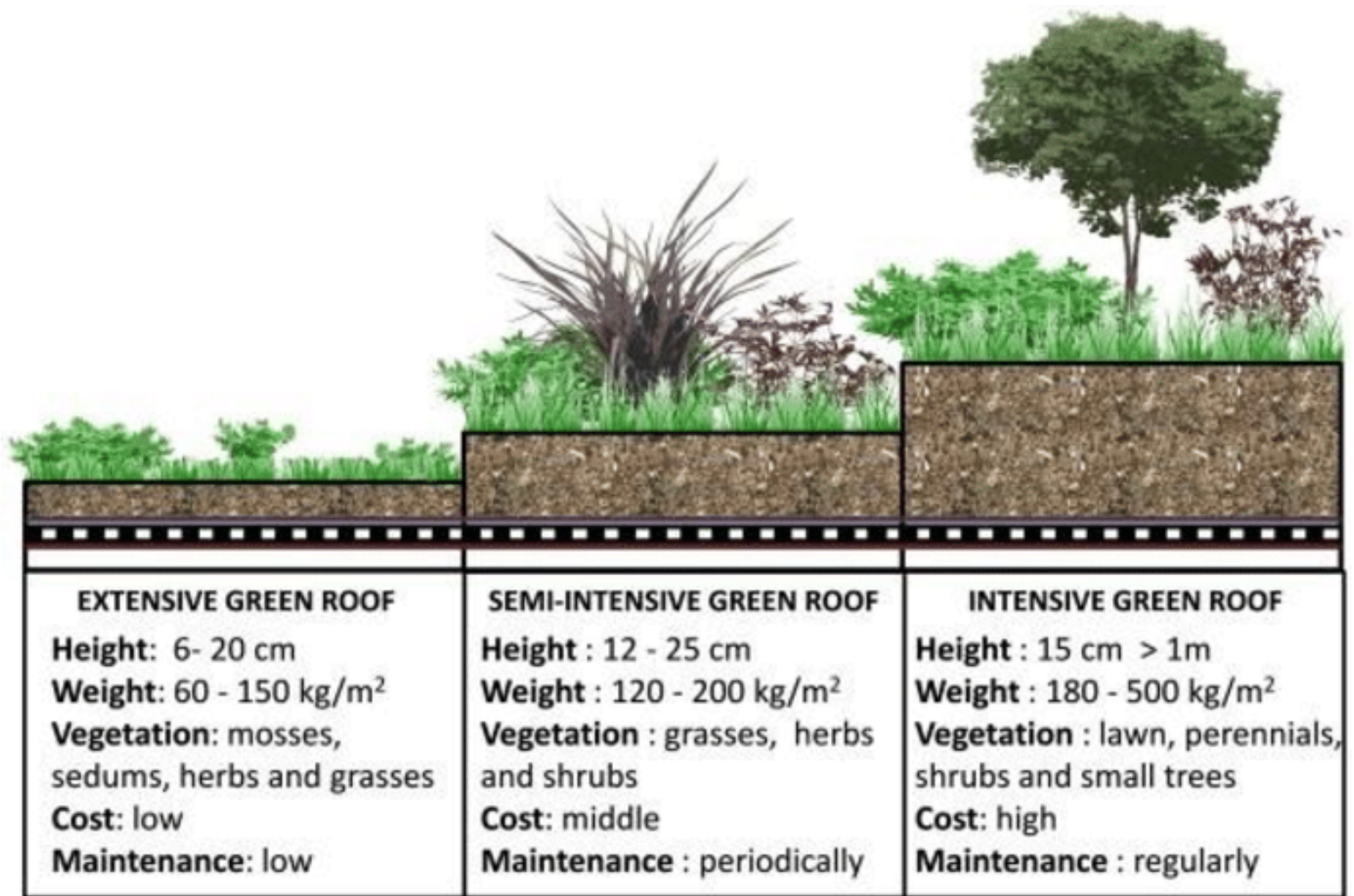


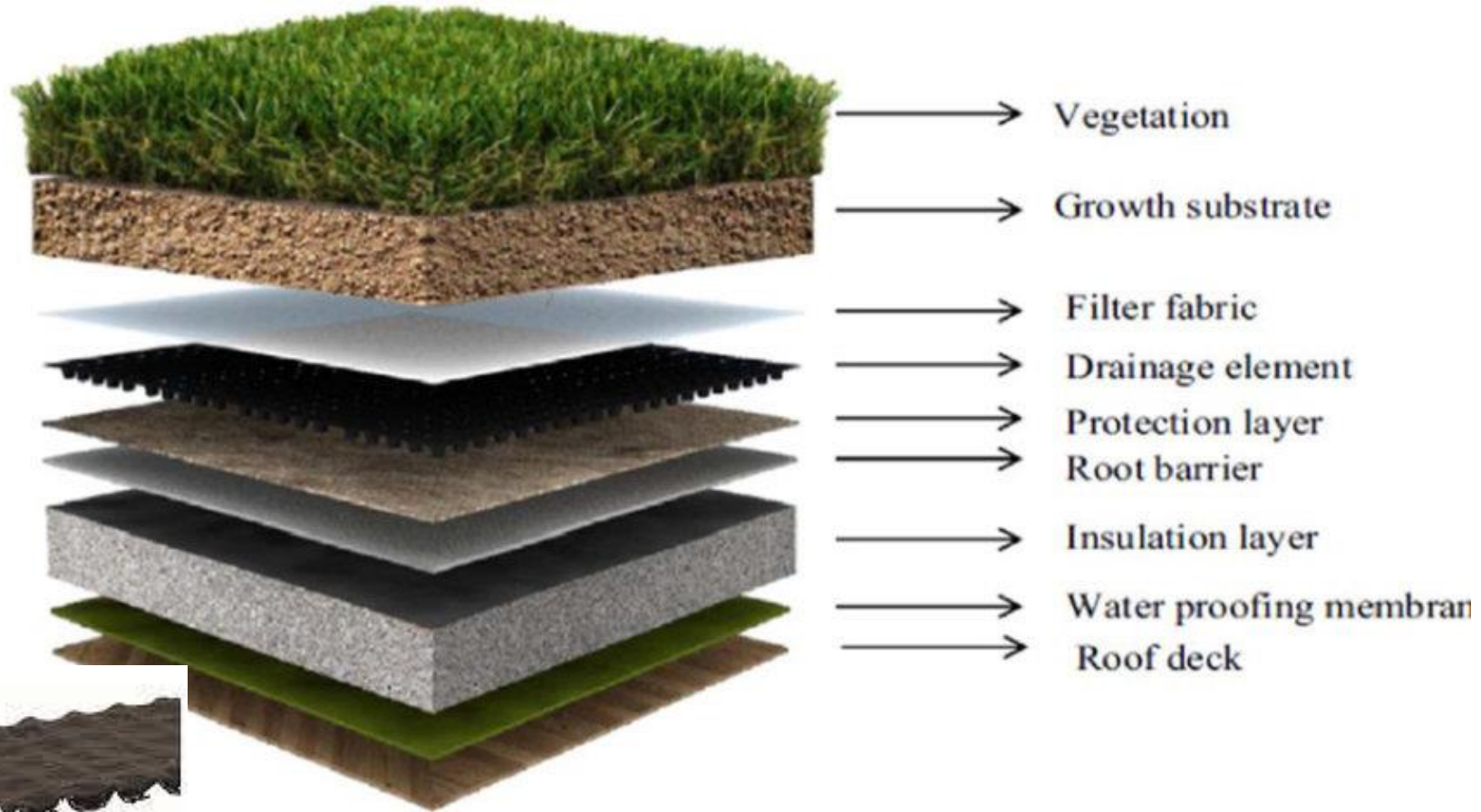
Natural environment means beauty

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• Cusped



• Entanglement



• Granular



• Structural

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LABORATORY TEST FOR THE DETERMINATION OF PHYSICAL AND THERMAL CHARACTERISTICS

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Fondo Europeo di Sviluppo Regionale
European Regional Development Fund



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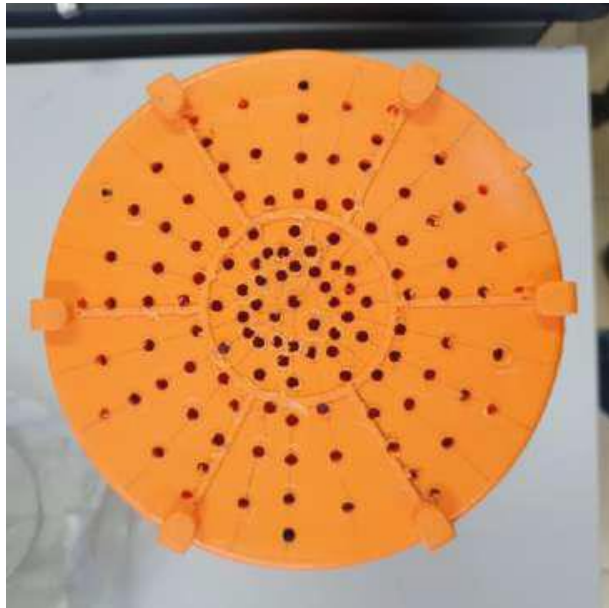
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Ash volcanic sample preparation (on the right), sample into the oven (in the middle), container filled with volcanic ash to achieve the moist state.



Tube base with 125 holes (on the left), geotextile mesh, mesh and lead disc on the top of the material to avoid floating (in the middle), capillary saturation of the sample from the bottom to the top (on the right).



TLS 100 measurements on dry and moist sample (on the left) and on saturated sample (on the right).

Moisture condition	Thermal conductivity [W/mK]
Dry	0.125
Moist	0.243
Saturated	0.278

Note: The values presented in the table represent the average thermal conductivity measured at three different points for each moisture condition.

Thermal conductivity of volcanic ash in different moisture conditions using TLS 100.





Square container 30 x 30 x 2.5 cm (on the left) and thermal conductivity measurement with the HFM 436/3/1 Lambda (on the right).

Moisture condition	Mean temperature [°C]	Thermal conductivity [W/mK]
Dry	10	0.101
Dry	20	0.102
Dry	30	0.097
Moist	10	0.181
Moist	20	0.179
Moist	30	0.187
Saturated	10	0.201
Saturated	20	0.199
Saturated	30	0.200

Note: The values presented in the table represent the average thermal conductivity measured at various mean temperatures for each moisture condition

Thermal conductivity of volcanic ash in different moisture conditions and mean temperatures using the HFM 346/3/1 Lambda.

Moisture condition	TLS 100 [W/mK]	HFM 436/3/1 Lambda [W/mK]
Dry	0.125	0.100
Moist	0.243	0.182
Saturated	0.278	0.200

Note: The values presented in the table represent the average thermal conductivities of volcanic ash in dry, moist, and saturated conditions obtained using TLS 100 and HFM 436/3/1 Lambda.

Comparison of average thermal conductivities of volcanic ash in dry, moist, and saturated conditions obtained using TLS 100 and HFM 436/3/1 Lambda.

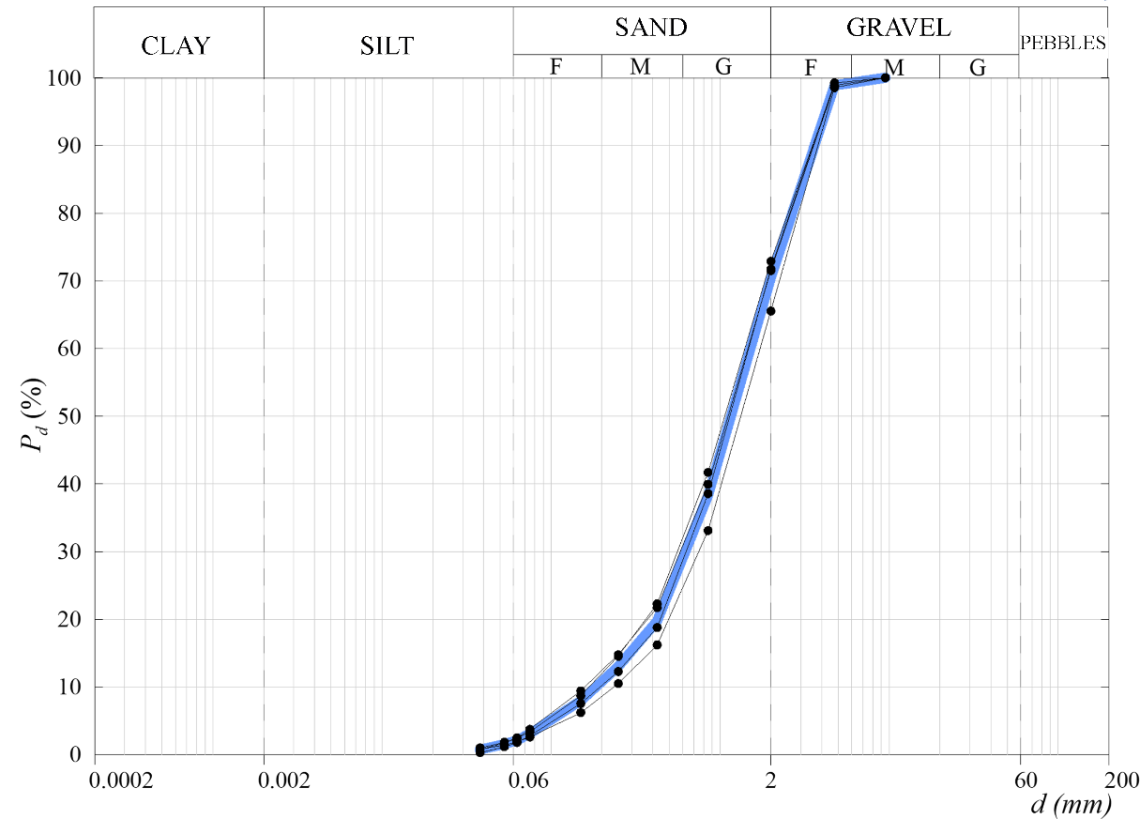


Moisture condition	Density [kg/m ³]
Dry	1,043
Moist	1,326
Saturared	1,334

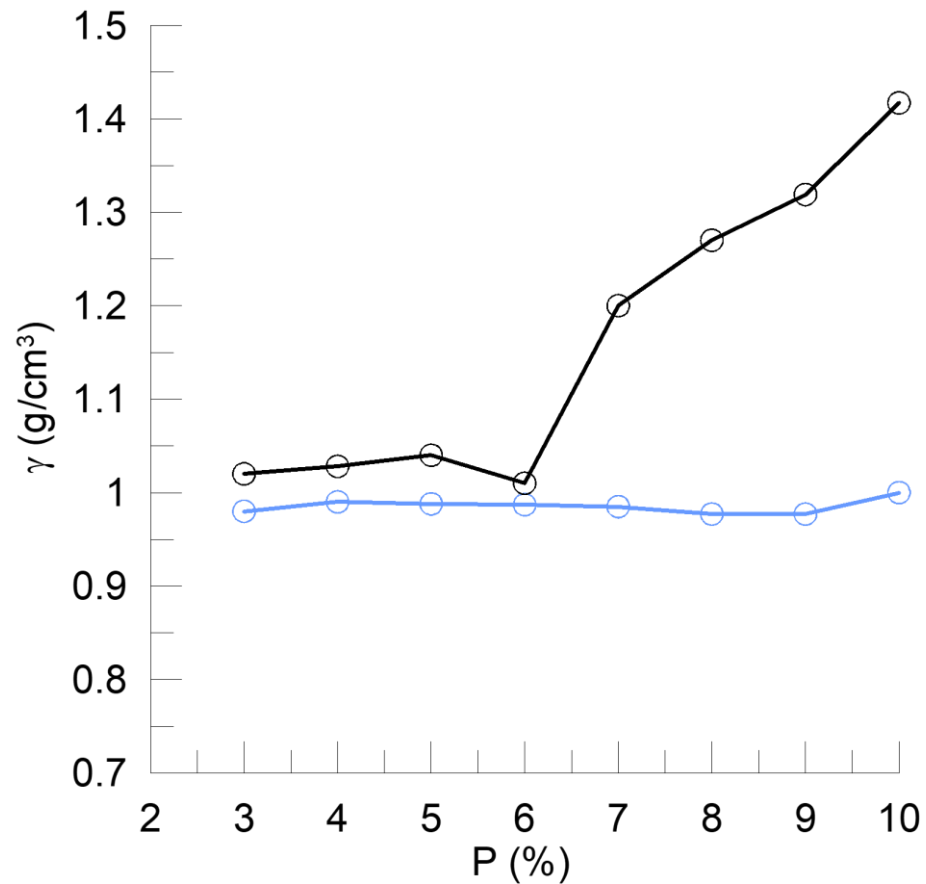
Density of volcanic ash in different moisture conditions.



Sieves for particle size analysis (on the left), maximum density equipment (in the middle), permeability test
(on the right).



Particle size distribution of volcanic ash.



Maximum and minimum index density of volcanic ash.

Drainage material	Permeability
MAT. 1	2.482E-04
MAT. 2	2.298E-04
MAT. 3	2.296E-04
MAT. 4	2.370E-04
Perlite	7.476E-06
MAT. 6	2.292E-04
Volcanic ash	2.630E-03
Volcanic ash (20%)	3.300E-03

Comparison of permeability [m/s] of different materials for the drainage layer.

	Dry	Moist	Saturated
Expanded clay	410.4	442.4	579.3
Perlite	164.2	144.8	510.5
Polyethylene	329.4	329.4	411.7
Volcanic ash	1,043	1,326	1,334

Comparison of bulk density [kg/m^3] of different materials for the drainage layer.

	Dry	Moist	Saturated
Expanded clay	0.125	0.151	0.230
Perlite	0.076	0.087	0.297
Polyethylene	0.099	0.099	0.145
Volcanic ash	0.100	0.182	0.200

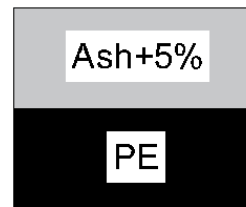
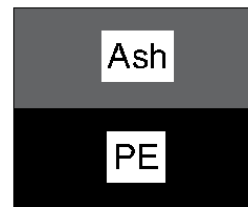
Comparison of thermal conductivity [W/mK] of different materials for the drainage layer.

	Dry	Moist	Saturated
Substrate S1	0.119	0.334	0.453
Substrate S2	0.137	0.271	0.449
Substrate S3	0.086	0.175	0.426
Volcanic ash	0.100	0.182	0.200

Comparison of thermal conductivity of different materials for the substrate.

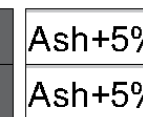
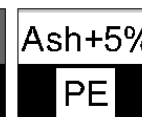
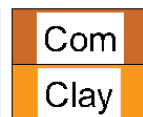
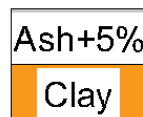


d = 28 cm



x n.4 vegetations

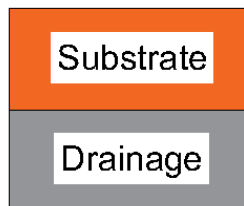
d = 18 cm



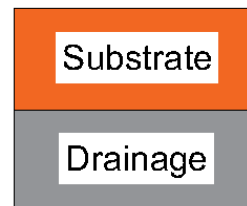
x n.4 vegetations

Vegetation

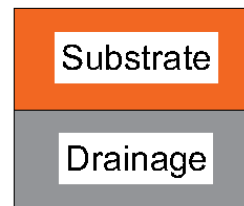
Essenza 1



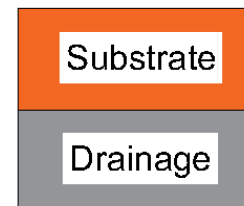
Essenza 2



Essenza 3



Essenza 4



x n.3 d = 28 cm

x n.8 d = 18 cm

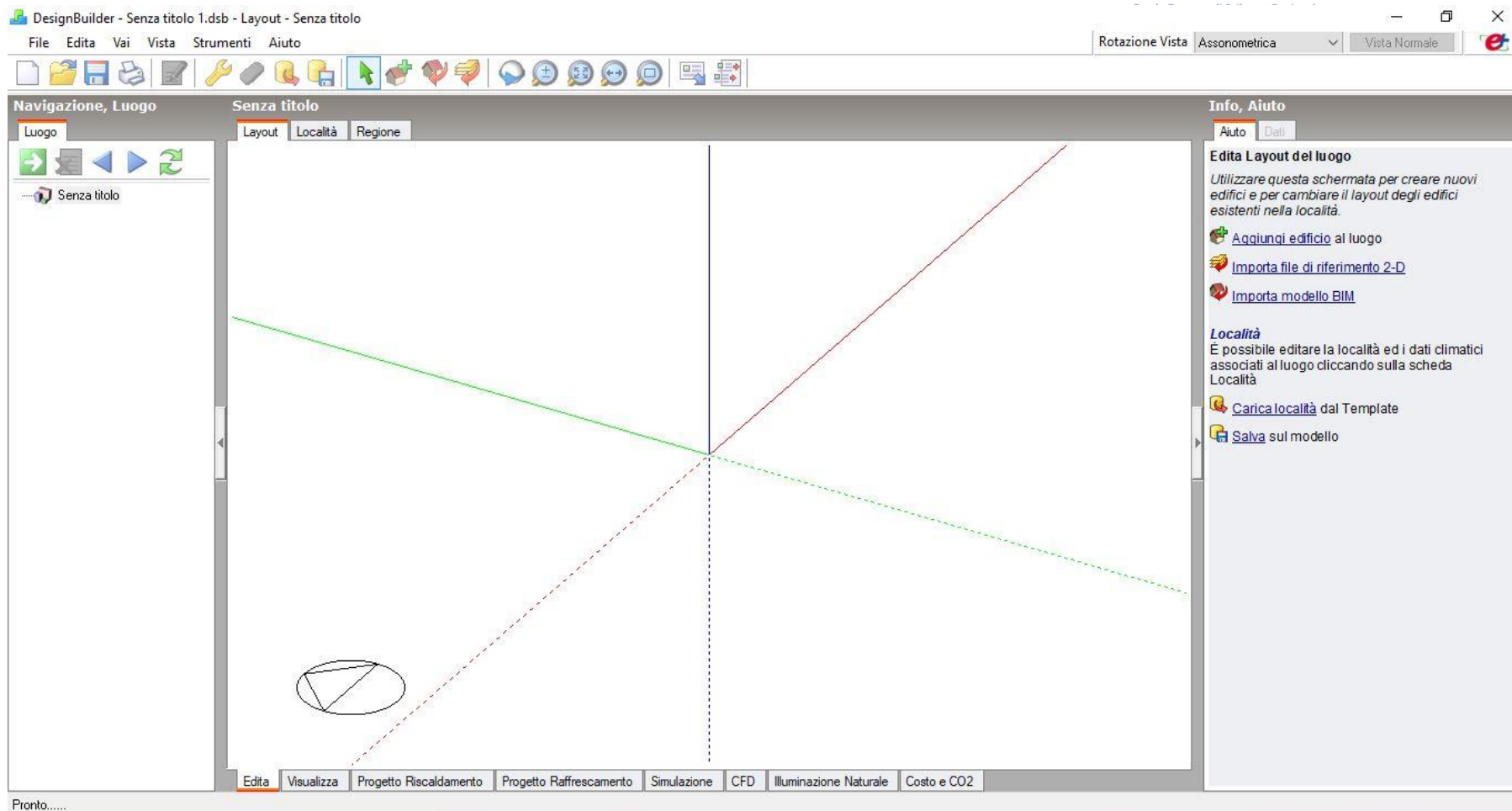
Schematic summary of the green roof installation.

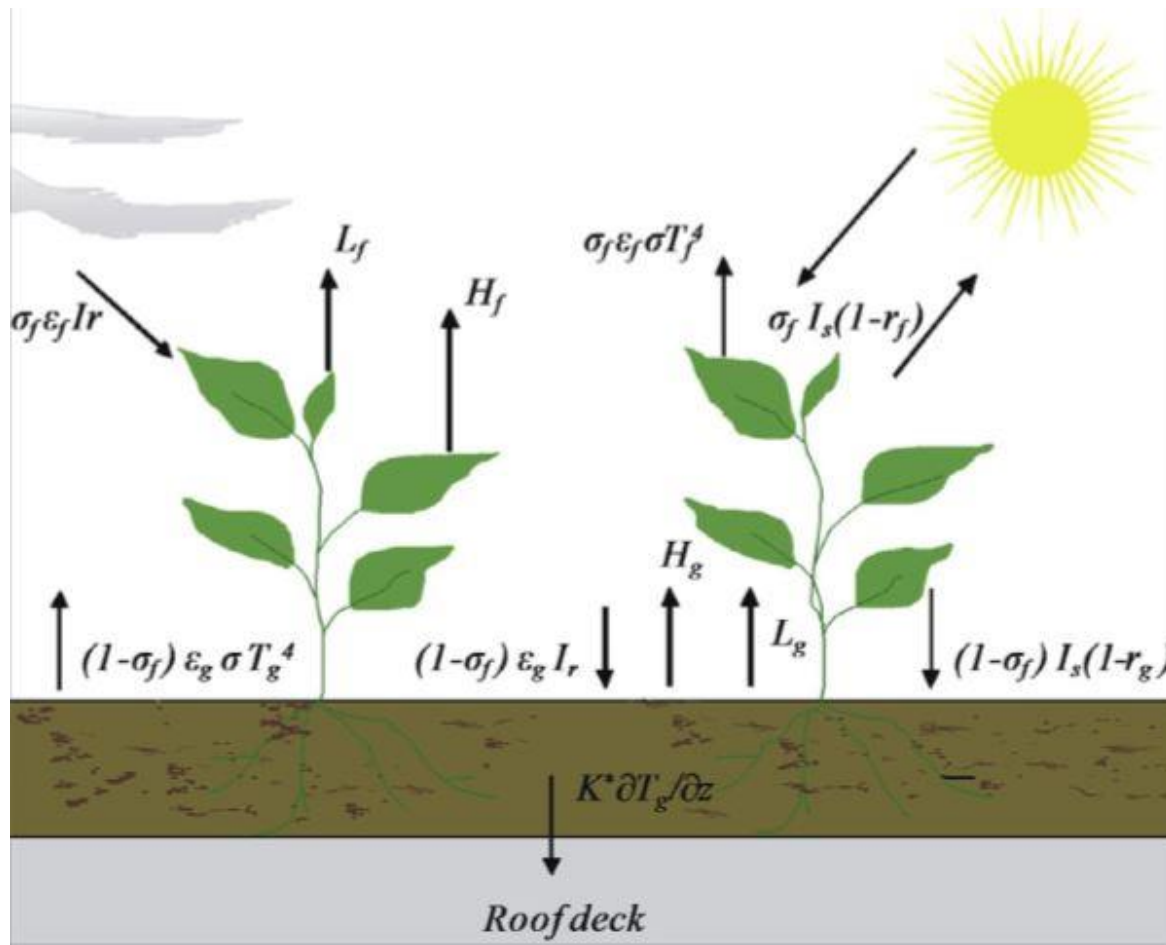


Green roof installation.

ENERGY PERFORMANCE

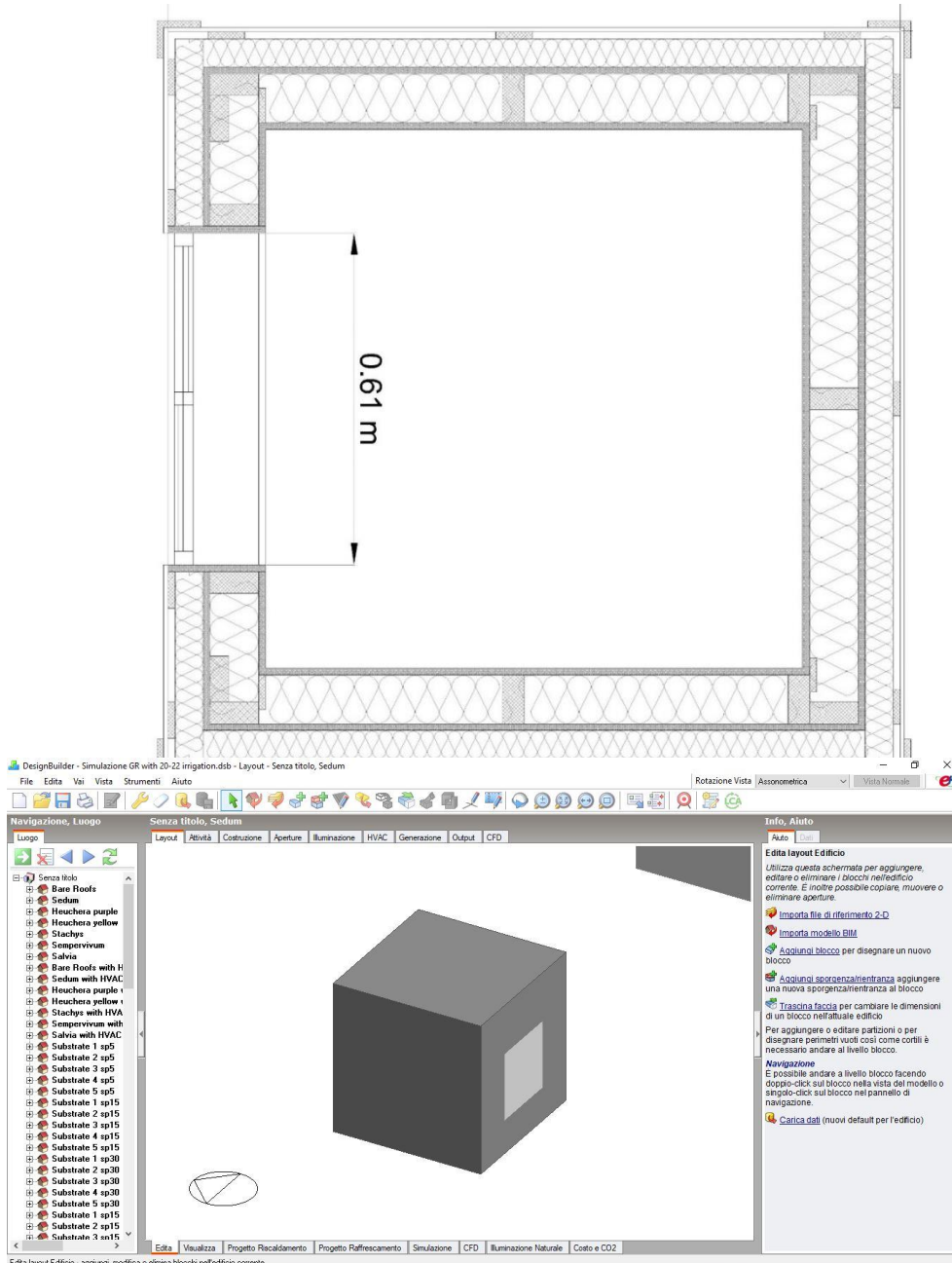






$$F_f = \sigma_f [I_s (1 - r_f) + \epsilon_f I_r - \epsilon_f \sigma T_f^4] + \frac{\sigma_f \epsilon_f \epsilon_g \sigma}{\epsilon_1} (T_g^4 - T_f^4) + H_f + L_f$$

$$F_g = (1 - \sigma_f) [I_s (1 - r_g) + \epsilon_g I_r - \epsilon_g \sigma T_g^4] - \frac{\sigma_f \epsilon_f \epsilon_g \sigma}{\epsilon_1} (T_g^4 - T_f^4) + H_g + L_g + K \frac{\delta T_g}{\delta z}$$



Wall							
	Drywall	Glass Wool	OSB	Vapor Barrier	XPS	Air Space	Plywood
S [mm]	10.0	89.0	11.0	0.50	51.0	13.0	5.0
λ [W/mK]	0.180	0.044	0.130	-	0.043	0.079	0.130
ρ [kg/m³]	950.0	12.0	650.0	-	35.0	1.23	560.0
Cp [J/kgK]	840.0	840.0	1700.0	-	1400.0	1000.0	2500.0

Bare Roof							
	Metal Sheet	Water Membrane	OSB	Air Space	XPS	Drywall	-
S [mm]	1.0	1.0	11.0	38.0	140.0	11.0	-
λ [W/mK]	44.000	0.210	0.130	0.233	0.0430	0.1800	-
ρ [kg/m³]	7824.0	1300.0	650.0	1.23	35.0	950.0	-
Cp [J/kgK]	500.0	1800.0	1700.0	1000.0	1400.0	840.0	-

	Wall	Window	Bare roof	Floor
U-value [W/m²K]	0.308	1.960	0.306	0.299

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Modifica materiale - Green Roofs Sedum

Materiali

Generale | Proprietà della superficie | **Tetto verde** | Carbonio incorporato | Cambiamento di fase | Costo

Tetto Verde

☒ Tetto verde

Metodo di calcolo della diffusione dell'umidità	1-Semplice
Altezza piante (m)	0,1250
Indice area fogliame	2,8000
Riflessione fogliame	0,180
Emissività fogliame	0,970
Resistenza minima degli stomi	105,000
Contenuto di umidità massima in saturazione	0,500
Contenuto di umidità minima residua	0,010
Contenuto di umidità iniziale	0,150

Aiuto

Info | Dati

Tetto Verde

I tetti verdi possono essere usati per ridurre i carichi di raffreddamento fornendo una capacità termica ed un raffreddamento evaporativo attraverso la traspirazione delle piante. Per utilizzare questo materiale come un tetto verde, nel pacchetto costruttivo di una copertura, selezionare l'opzione 'Tetto verde' ed inserire i dati.

Si noti che il valore di conducibilità definito nel primo tab del materiale del tetto verde è per la terra asciutta.

Si noti inoltre che lo spessore massimo del layer per il materiale utilizzato per il tetto verde è di 0.5m

Dati modello

Aiuto | Annulla | OK

Modifica materiale - Green Roofs Sedum

Materiali

Generale | Proprietà della superficie | Tetto verde | Carbonio incorporato | Cambiamento di fase | Costo

Generale

Nome Green Roofs Sedum

Descrizione

Fonte ASHRAE Handbook

Categoria Sabbie, pietre e terreni

Regione ITALY

Spessore Strato di Materiale

☐ Spessore forza

Proprietà Termiche

Proprietà dettagliate

Proprietà termofisiche del materiale

Conducibilità (W/m-K)	0,3000
Calore specifico (J/kg-K)	1000,00
Densità (kg/mc)	1900,00

Resistenza (valore-R)

Resistenza alla Diffusione del Vapore

Trasferimento dell'umidità

Aiuto

Info | Dati

Dati del materiale

I materiali sono usati per definire la stratigrafia dei pacchetti strutturali dell'edificio. È possibile definire le caratteristiche del materiale scegliendo tra due sistemi:

- Definizione proprietà dettagliate** - Comprende le proprietà termofisiche, le proprietà di superficie e l'aspetto visivo del materiale.
- Definizione resistenza** - Senza capacità termica. Questa opzione sarà utilizzata per modellare intercapedini d'aria.

Dati modello

Aiuto | Annulla | OK



Plant species	Height of plants [m]	LAI [m ² /m ²]	Leaf reflectivity -	Leaf emissivity -	Stomatal resistance [mmol/m ² s]
Sedum mix	0.125	2.80	0.180	0.97	105.0
Heuchera “Obsidian” Purple	0.250	5.00	0.200	0.97	170.0
Heuchera “Electra” Yellow	0.150	4.50	0.205	0.97	195.0
Stachys byzantina	0.375	4.25	0.195	0.97	255.0
Sempervivum “Reinhard”	0.050	3.25	0.155	0.97	105.0
Salvia officinalis “Berggarten”	0.475	5.00	0.220	0.97	300.0

* A mat of Sedum species used as an industry standard



Sample identifier	Coco peat %	Compost %	Crushed wastes %	Sand %	Pozzolana %	Conductivity [W/mK]	Density [Kg/m ³]	Specific heat [J/kgK]
Substrate 1	0	40	0	20	40	0.2	873.2	788
Substrate 2	25	25	40	10	0	0.21	759.6	923
Substrate 3	N/A	6	N/A	N/A	N/A	0.284	772.7	1360
Substrate 4	25	40	30	5	0	0.288	748.4	546
Substrate 5	60	15	20	5	0	0.229	724	375

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Substrate 1



Substrate 2



Substrate 3



Substrate 4

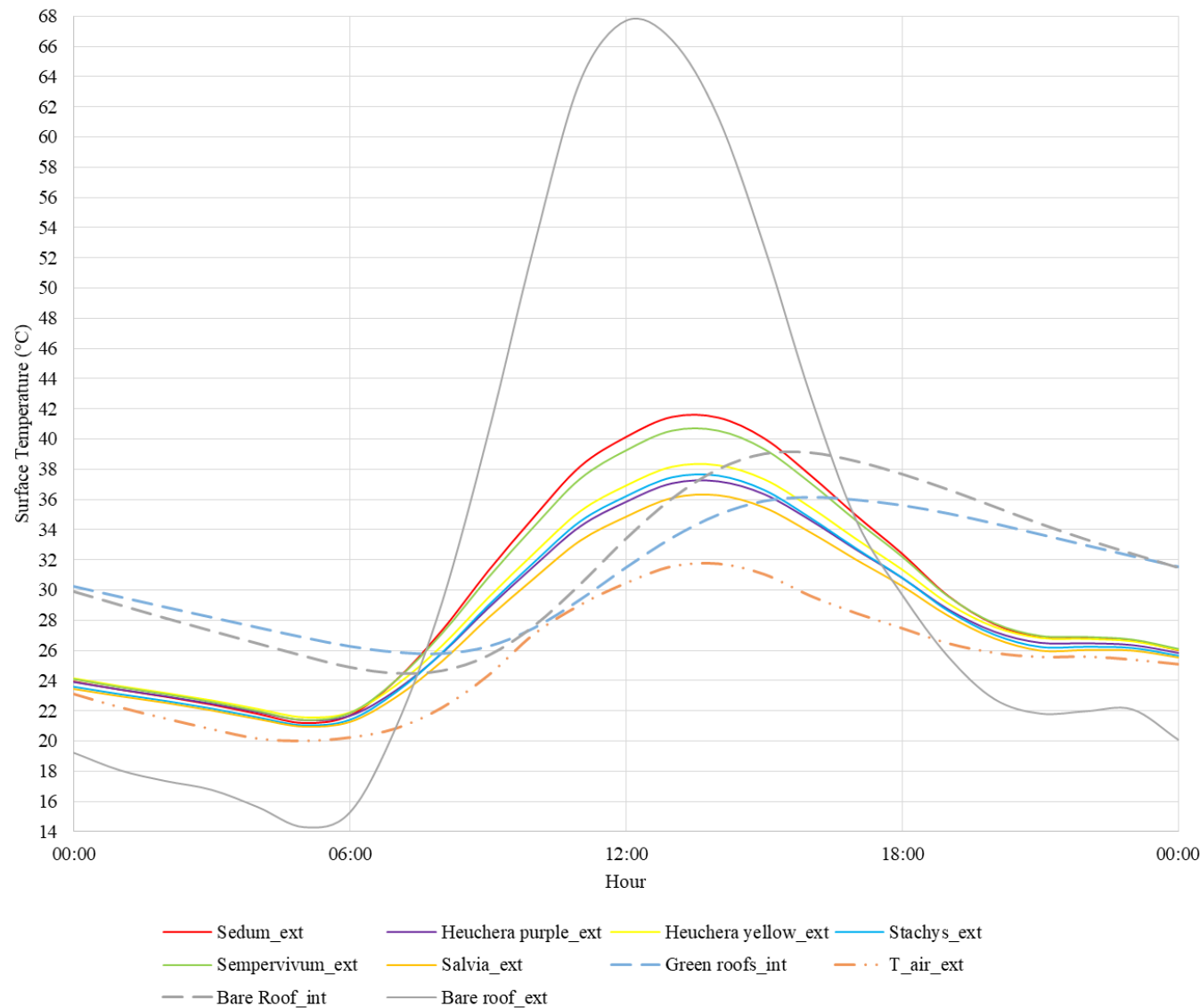


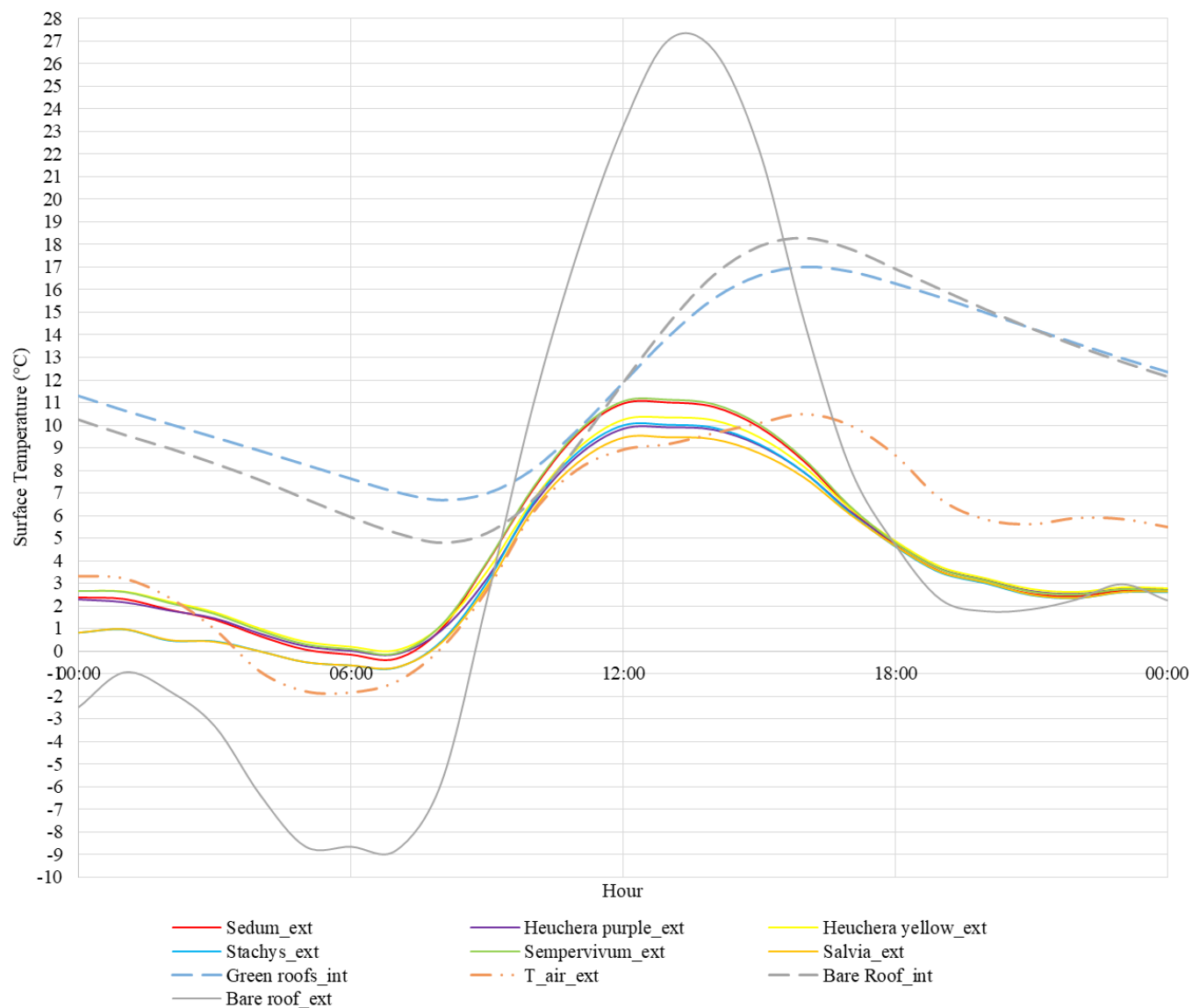
Substrate 5

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Roof type	$T_{\text{ext_max}} - T_{\text{ext_min}}$ [°C]	Δ [%]	$T_{\text{ext_max}} - T_{\text{ext_min}}$ [°C]	Δ [%]	Cooling energy consumption [Wh/m ²]	Cooling energy saving [%]	Heating energy consumption [Wh/m ²]	Heating energy saving [%]
Bare roof	53.42	-	35.87	-	43606	-	49860	-
Sedum	20.28	62.05	11.34	68.38	34603	20.65	45668	8.41
Purple Heuchera	15.81	70.4	10.04	72.02	33761	22.58	46214	7.31
Yellow Heuchera	16.69	68.75	10.3	71.27	34126	21.74	45991	7.76
Stachys	16.54	69.04	10.75	70.03	33621	22.9	46363	7.01
Sempervivum	19.16	64.14	11.23	68.7	34583	20.69	45674	8.4
Salvia	15.33	71.31	10.18	71.61	33345	23.53	46529	6.68

Plant species	Height of plants [m]	LAI [m ² /m ²]	Leaf reflectivity -	Leaf emissivity -	Stomatal resistance [mmol/m ² s]
Sedum mix	0.125	2.80	0.180	0.97	105.0
Heuchera “Obsidian” Purple	0.250	5.00	0.200	0.97	170.0
Heuchera “Electra” Yellow	0.150	4.50	0.205	0.97	195.0
Stachys byzantina	0.375	4.25	0.195	0.97	255.0
Sempervivum “Reinhard”	0.050	3.25	0.155	0.97	105.0
Salvia officinalis “Berggarten”	0.475	5.00	0.220	0.97	300.0



INDEX OF PERFORMANCE

$$STR_{av} = \frac{T_{av}}{T_{av,bare}}$$

Energy consumption

$$ETR_{max} = \frac{T_{max}}{T_{av,air}}$$

Urban heat island

$$TER = \frac{T_{max} - T_{min}}{T_{max,bare} - T_{min,bare}}$$

Temperature fluctuations on waterproofing membrane

Pacchetto Tetto verde	STRav Cooling	STRav Heating	ETRmax Cooling	ETRmax Heating	TER Cooling	TER Heating	Score	Ran k
Salvia + Substrato 1	28.23	1.19	25.91	0.70	4.97	0.41	61.41	13
Salvia + Substrato 2	28.40	1.27	26.32	0.64	5.07	0.38	62.08	12
Salvia + Substrato 3	30.00	2.67	30.00	0.00	6.00	0.00	68.67	2
Salvia + Substrato 4	27.65	0.61	25.11	0.72	4.72	0.57	59.37	15
Salvia + Substrato 5	26.29	0.00	22.31	1.15	4.08	0.77	54.60	20
Stachys + Substrato 1	21.40	3.12	20.46	2.85	4.00	0.85	52.68	23
Stachys + Substrato 2	21.55	3.22	20.91	2.78	4.10	0.82	53.38	22
Stachys + Substrato 3	23.12	4.78	25.23	2.06	5.19	0.40	60.78	14
Stachys + Substrato 4	20.68	2.52	19.82	2.88	3.76	1.02	50.67	25
Stachys + Substrato 5	19.34	1.85	16.45	3.39	3.00	1.24	45.26	30
Heuchera p. + Substrato 1	21.24	4.29	21.53	2.54	4.31	0.69	54.60	21
Heuchera p. + Substrato 2	21.35	4.42	21.99	2.45	4.42	0.65	55.29	19
Heuchera p. + Substrato 3	22.65	6.23	26.40	1.71	5.57	0.19	62.75	11
Heuchera p. + Substrato 4	20.34	3.51	20.72	2.59	4.02	0.89	52.07	24
Heuchera p. + Substrato 5	19.34	2.78	17.28	3.19	3.20	1.15	46.94	28
Heuchera y. + Substrato 1	14.76	6.98	16.95	4.30	3.54	0.98	47.51	27
Heuchera y. + Substrato 2	14.86	7.19	17.46	4.23	3.66	0.93	48.33	26
Heuchera y. + Substrato 3	16.10	10.06	22.44	3.39	4.95	0.38	57.32	18
Heuchera y. + Substrato 4	13.77	6.45	16.20	4.42	3.24	1.19	45.27	29
Heuchera y. + Substrato 5	12.92	17.96	12.27	17.54	2.29	3.68	66.66	3
Sempervivum + Substrato 1	4.85	24.93	8.15	21.94	1.88	4.13	65.89	6
Sempervivum + Substrato 2	4.96	24.35	8.67	21.19	2.01	3.98	65.16	7
Sempervivum + Substrato 3	6.31	21.20	14.20	11.55	3.40	1.88	58.53	17
Sempervivum + Substrato 4	3.84	26.83	7.38	22.41	1.57	4.46	66.49	4
Sempervivum + Substrato 5	2.83	29.53	3.21	27.85	0.61	5.59	69.62	1
Sedum + Substrato 1	2.15	26.25	4.92	24.47	1.23	4.66	63.69	8
Sedum + Substrato 2	2.28	25.70	5.44	23.75	1.35	4.51	63.04	10
Sedum + Substrato 3	3.76	22.61	10.99	16.43	2.73	2.82	59.34	16
Sedum + Substrato 4	1.18	27.12	4.10	24.90	0.92	4.96	63.19	9
Sedum + Substrato 5	0.00	30.00	0.00	30.00	0.00	6.00	66.00	5

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