

# Effectiveness of cool and green roofs inside and outside buildings in the Brazilian context

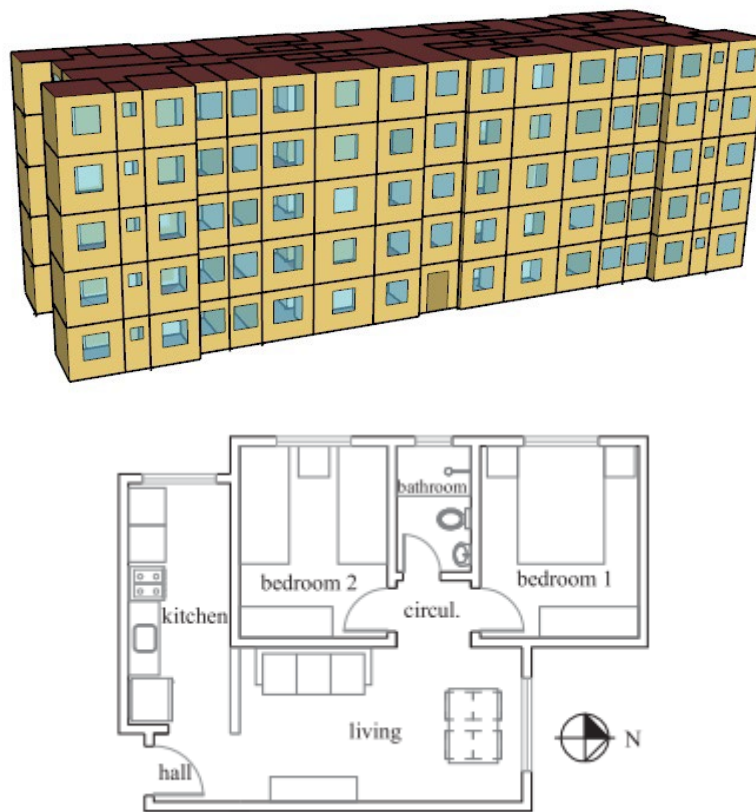
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## Supplementary material



**Figure S1.** Multifamily building model: (a) perspective of the building and (b) floor plan of the flat used in the simulation. Source: Based on [1].

**Table S1.** Envelope characteristics. Source: Based on [1].

<b>Ceiling</b>	Height of 2.60m.	
<b>Walls</b>	Concrete blocks with internal and external plaster, thermal transmittance of 2.78 W/m <sup>2</sup> .K and thermal capacity of 209 kJ/m <sup>2</sup> .K.	
<b>Doors</b>	Wooden doors with 3.5 cm thick and a surface area of 1.68 m <sup>2</sup> (hall), 1.47 m <sup>2</sup> (bedrooms) and 1.26 m <sup>2</sup> (bathroom).	
<b>Windows</b>	Living room	Two sashes slide horizontal, single glazing with 3 mm, ventilation factor of 0.45 and area of 1.80 m <sup>2</sup> .
	Kitchen and bedrooms	Two sashes slide horizontal, single glazing with 3 mm, ventilation factor of 0.45 and area of 1.44 m <sup>2</sup> .
	Bathroom	Hung tilting window, single glazing with 3 mm, ventilation factor of 0.80 and area of 0.36 m <sup>2</sup> .

**Table S2.** Internal loads for people considered in the building model. Source: NBR 15575-1 [2].

Room	Heat produced per area of body surface (W/m <sup>2</sup> )	Heat produced by a person with a body surface area of 1.80 m <sup>2</sup> (W)	Period of use
Living room	60	81	14:00 - 21:59*
Bedrooms	45	108	00:00 - 07:59 and 22:00 - 23:59

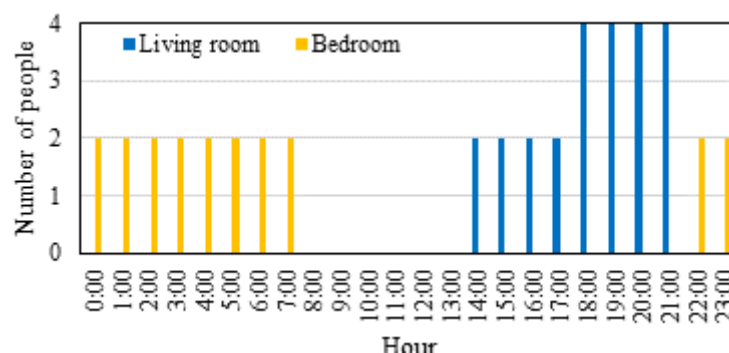
\* The room is occupied by two people between 14:00 and 17:59 and by four people during the remaining hours.

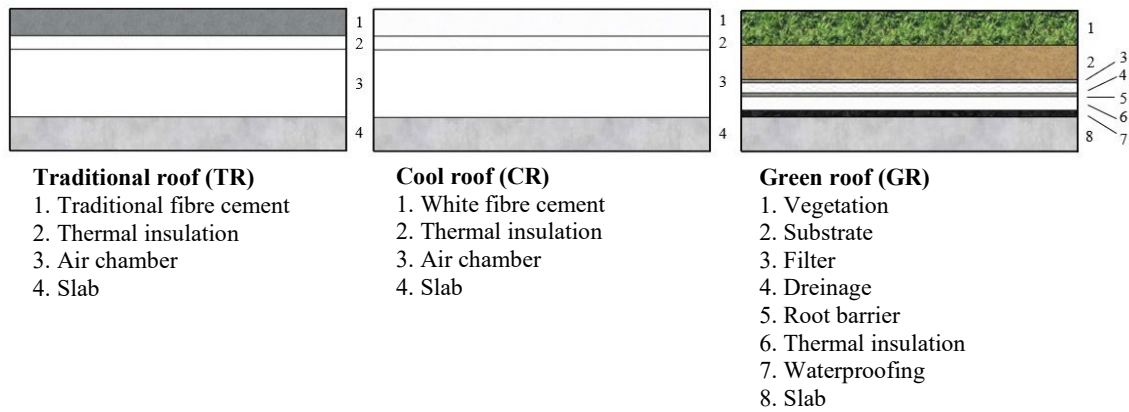
**Table S3.** Internal loads for lighting considered in the building model. Source: NBR 15575-1 [2].

Room	Power per floor-plan area (W/m <sup>2</sup> )	Period of use
Living room	5.00	16:00 - 21:59
Bedrooms	5.00	00:00 - 07:59 and 22:00 - 23:59

**Table S4.** - Internal loads for equipment considered in the building model. Source: NBR 15575-1 [2].

Room	Power (W)	Period of use
Living room	120	14:00 - 21:59

**Figure S2.** Occupancy schedule. Source: NBR 15575-1 [2].



**Figure S3.** Roof typologies considered in the study.

**Table S5.** Thermophysical properties of traditional and cool roofs. Source: NBR ISO 10456 [3] and NBR 15220-2 [4].

Layer	Thickness (mm)	Density (kg/m <sup>3</sup> )	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)	Thermal resistance (m <sup>2</sup> .K/W)
Fibre cement	6.0	1,800	0.65	840	-
Thermal	0 e 40	15	0.04	1,420	1.0
Air chamber	> 50	-	-	-	0.21

**Table S6.** Radiant properties of fibre cement and white fibre cement tiles.

Tile	Radiant properties
Fibre cement	The thermal emittance, solar absorptance and visible absorptance of the roof tiles were 0.88, 0.64 and 0.62, respectively, according to [5]. However, to consider the natural ageing process, the degradation of the solar absorptance of the roof tiles was taken into account following NBR 15571-1 [2]. Therefore, the solar absorptance after three years of degradation (0.68) was used in the simulation and was considered constant throughout the analysis horizon.
White fibre cement	The thermal emittance, solar absorptance and visible absorptance of the roof tiles were 0.90, 0.25 and 0.21, respectively, also obtained from [5]. However, the simulation was run considering the solar absorptance after three years of degradation (0.42), calculated according to NBR 15571-1 [2]. Around 70% of the degradation of the reflectance of coatings occurs in the first few months of application, and then this degradation tends to stabilise after the second year [6]. Although washing can restore the solar reflectance of cool roofs, dirt accumulates within a few months, and frequent washing is considered unlikely in the contexts analysed.

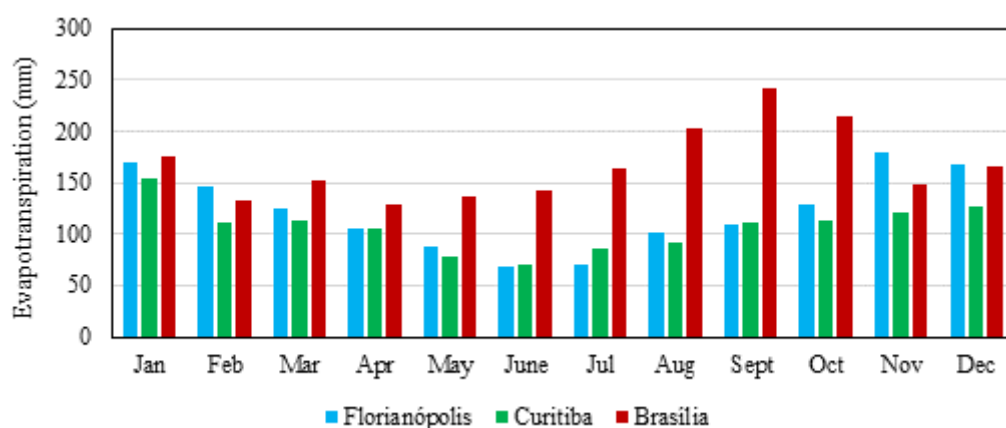
**Table S7.** Thermophysical properties of the vegetation and substrate of the green roof. Source: Cascone et al. [7], Shi et al. [8] and Ziogou et al. [9].

Layer	Parameter	Value
Vegetation	Vegetation height (m)	0.10
	Leaf area index (LAI)	3.00
	Leaf reflectivity	0.19
	Leaf emissivity	0.97
	Minimum stomatal resistance (s/m)	120
Substrate	Thickness (m)	0.10
	Dry soil conductivity (W/m.K)	0.20
	Dry soil density (kg/m <sup>3</sup> )	1,020.00
	Dry soil specific heat (J/kg.K)	1,093.00
	Saturated volumetric moisture content	0.26
	Residual volumetric moisture content	0.01
	Initial volumetric moisture content	0.15

**Table S8.** Thermophysical properties of the filter, drainage, thermal insulation, root barrier and waterproofing layers of the green roof. Source: NBR ISO 10456 [3] and Gagliano et al. [10].

Layer	Thickness (mm)	Density (kg/m <sup>3</sup> )	Thermal conductivity (W/m.K)	Specific heat (J/kg.K)
Filter	1.0	910	0.22	1,800
Drainage (water)*	10	1,000	0.60	4,190
Root barrier	0.4	920	0.33	2,200
Thermal	0 e 40	15	0.04	1,420
Waterproofing	5.0	1,100	0.23	1,000

\* According to Koroxenidis and Theodosiou [11], the draining layer shows seasonal variation in moisture content within its cavities; therefore, its height (25 mm in this case) can be divided into 60% air and 40% water. Despite the air layer, it cannot be considered an insulator, as it is not constant and the cavities interrupt it, potentially acting as thermal bridges when filled with water. Thus, only the water layer can be modelled to represent the drainage layer.



**Figure S4.** Annual evapotranspiration from green roofs in Florianópolis, Curitiba and Brasília.

**Table S9.** Hours of discomfort and thermal comfort in long-term rooms with traditional, cool and green roofs in Florianópolis.

Roof typology	Room	Hours	Summer	Autumn	Winter	Spring
TR00	Living room	Cold discomfort	0	16	68	0
		Heat discomfort	555	234	27	267
		Comfort	109	486	641	461
	Bedroom 2	Cold discomfort	0	176	310	14
		Heat discomfort	382	23	0	50
		Comfort	448	721	610	846
	Bedroom 1	Cold discomfort	0	176	354	41
		Heat discomfort	260	19	0	18
		Comfort	570	725	566	851
TR04	Living room	Cold discomfort	0	0	23	0
		Heat discomfort	578	267	22	225
		Comfort	86	469	691	503
	Bedroom 2	Cold discomfort	0	141	247	5
		Heat discomfort	381	27	0	37
		Comfort	449	752	673	868
	Bedroom 1	Cold discomfort	0	157	298	23
		Heat discomfort	253	18	0	10
		Comfort	577	745	622	877
CR00	Living room	Cold discomfort	0	32	102	0
		Heat discomfort	482	129	10	164
		Comfort	182	575	624	564
	Bedroom 2	Cold discomfort	0	194	351	30
		Heat discomfort	263	14	0	16
		Comfort	567	712	569	864
	Bedroom 1	Cold discomfort	0	190	376	58
		Heat discomfort	186	12	0	5
		Comfort	644	718	544	847
CR04	Living room	Cold discomfort	0	0	31	0
		Heat discomfort	541	221	17	172
		Comfort	123	515	688	556
	Bedroom 2	Cold discomfort	0	151	265	7
		Heat discomfort	344	18	0	23
		Comfort	486	751	655	880
	Bedroom 1	Cold discomfort	0	163	313	28
		Heat discomfort	216	17	0	5
		Comfort	614	740	607	877
GR00	Living room	Cold discomfort	0	4	53	0
		Heat discomfort	480	158	9	121
		Comfort	184	574	674	607
	Bedroom 2	Cold discomfort	0	167	294	12
		Heat discomfort	283	14	0	16
		Comfort	547	739	626	882
	Bedroom 1	Cold discomfort	0	172	337	43
		Heat discomfort	190	13	0	4
		Comfort	640	735	583	863
GR04	Living room	Cold discomfort	0	0	22	0
		Heat discomfort	542	241	19	159
		Comfort	122	495	695	569
	Bedroom 2	Cold discomfort	0	137	240	6
		Heat discomfort	344	19	0	23
		Comfort	486	764	680	881
	Bedroom 1	Cold discomfort	0	156	300	25
		Heat discomfort	216	17	0	4
		Comfort	614	747	620	881

Note: The living room is occupied for 2,864 hours of the year, and the bedrooms for 3,580 hours. Abbreviations: traditional roof without insulation (TR00), traditional roof with insulation (TR04), cool roof without insulation (CR00), cool roof with insulation (CR04), green roof without insulation (GR00) and green roof with insulation (GR04).

**Table S10.** Hours of discomfort and thermal comfort in long-term rooms with traditional, cool and green roofs in Curitiba.

Roof typology	Room	Hours	Summer	Autumn	Winter	Spring
TR00	Living room	Cold discomfort	0	41	146	0
		Heat discomfort	252	220	69	188
		Comfort	412	475	521	540
	Bedroom 2	Cold discomfort	29	253	481	131
		Heat discomfort	56	2	7	15
		Comfort	745	665	432	764
	Bedroom 1	Cold discomfort	71	302	509	218
		Heat discomfort	36	4	7	10
		Comfort	723	614	404	682
TR04	Living room	Cold discomfort	0	26	124	0
		Heat discomfort	195	206	51	87
		Comfort	469	504	561	641
	Bedroom 2	Cold discomfort	0	197	419	98
		Heat discomfort	31	0	4	4
		Comfort	799	723	497	808
	Bedroom 1	Cold discomfort	50	249	460	175
		Heat discomfort	21	2	6	2
		Comfort	759	669	454	733
CR00	Living room	Cold discomfort	0	72	177	10
		Heat discomfort	158	134	32	73
		Comfort	506	530	527	645
	Bedroom 2	Cold discomfort	44	297	558	167
		Heat discomfort	22	0	2	2
		Comfort	764	623	360	741
	Bedroom 1	Cold discomfort	81	349	558	270
		Heat discomfort	20	0	5	1
		Comfort	729	571	357	639
CR04	Living room	Cold discomfort	0	31	141	0
		Heat discomfort	159	170	36	62
		Comfort	505	535	559	666
	Bedroom 2	Cold discomfort	3	218	451	115
		Heat discomfort	16	0	1	1
		Comfort	811	702	468	794
	Bedroom 1	Cold discomfort	53	271	479	194
		Heat discomfort	13	2	4	1
		Comfort	764	647	437	715
GR00	Living room	Cold discomfort	0	38	151	0
		Heat discomfort	130	124	23	43
		Comfort	534	574	562	685
	Bedroom 2	Cold discomfort	7	242	488	123
		Heat discomfort	14	0	0	0
		Comfort	809	678	432	787
	Bedroom 1	Cold discomfort	59	290	510	205
		Heat discomfort	12	0	4	0
		Comfort	759	630	406	705
GR04	Living room	Cold discomfort	0	26	122	0
		Heat discomfort	149	167	36	52
		Comfort	515	543	578	676
	Bedroom 2	Cold discomfort	0	205	430	102
		Heat discomfort	15	0	0	0
		Comfort	815	715	490	808
	Bedroom 1	Cold discomfort	49	253	465	181
		Heat discomfort	12	2	4	1
		Comfort	769	665	451	728

Note: The living room is occupied for 2,864 hours of the year, and the bedrooms for 3,580 hours. Abbreviations: traditional roof without insulation (TR00), traditional roof with insulation (TR04), cool roof without insulation (CR00), cool roof with insulation (CR04), green roof without insulation (GR00) and green roof with insulation (GR04).

**Table S11.** Hours of discomfort and thermal comfort in long-term rooms with traditional, cool and green roofs in Brasília.

Roof typology	Room	Hours	Summer	Autumn	Winter	Spring
TR00	Living room	Cold discomfort	0	0	0	0
		Heat discomfort	407	579	517	406
		Comfort	257	157	219	322
	Bedroom 2	Cold discomfort	3	0	5	0
		Heat discomfort	92	32	85	163
		Comfort	735	888	830	747
	Bedroom 1	Cold discomfort	19	4	26	11
		Heat discomfort	53	32	69	98
		Comfort	758	884	825	801
TR04	Living room	Cold discomfort	0	0	0	0
		Heat discomfort	325	600	591	345
		Comfort	339	136	145	383
	Bedroom 2	Cold discomfort	0	0	2	0
		Heat discomfort	67	30	107	151
		Comfort	763	890	811	759
	Bedroom 1	Cold discomfort	7	0	5	4
		Heat discomfort	29	28	78	82
		Comfort	794	892	837	824
CR00	Living room	Cold discomfort	0	0	0	0
		Heat discomfort	233	388	320	297
		Comfort	431	348	416	431
	Bedroom 2	Cold discomfort	4	2	18	1
		Heat discomfort	34	5	34	84
		Comfort	792	913	868	825
	Bedroom 1	Cold discomfort	21	8	49	15
		Heat discomfort	16	8	35	52
		Comfort	793	904	836	843
CR04	Living room	Cold discomfort	0	0	0	0
		Heat discomfort	248	540	515	312
		Comfort	416	196	221	416
	Bedroom 2	Cold discomfort	0	0	2	0
		Heat discomfort	43	14	77	113
		Comfort	787	906	841	797
	Bedroom 1	Cold discomfort	9	0	9	5
		Heat discomfort	18	19	58	62
		Comfort	803	901	853	843
GR00	Living room	Cold discomfort	0	0	0	0
		Heat discomfort	187	420	346	269
		Comfort	477	316	390	459
	Bedroom 2	Cold discomfort	0	0	3	0
		Heat discomfort	29	5	33	68
		Comfort	801	915	884	842
	Bedroom 1	Cold discomfort	11	2	17	8
		Heat discomfort	13	10	31	41
		Comfort	806	908	872	861
GR04	Living room	Cold discomfort	0	0	0	0
		Heat discomfort	232	550	532	299
		Comfort	432	186	204	429
	Bedroom 2	Cold discomfort	0	0	2	0
		Heat discomfort	40	17	73	106
		Comfort	790	903	845	804
	Bedroom 1	Cold discomfort	3	0	5	3
		Heat discomfort	16	21	55	58
		Comfort	811	899	860	849

Note: The living room is occupied for 2,864 hours of the year, and the bedrooms for 3,580 hours. Abbreviations: traditional roof without insulation (TR00), traditional roof with insulation (TR04), cool roof without insulation (CR00), cool roof with insulation (CR04), green roof without insulation (GR00) and green roof with insulation (GR04).

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